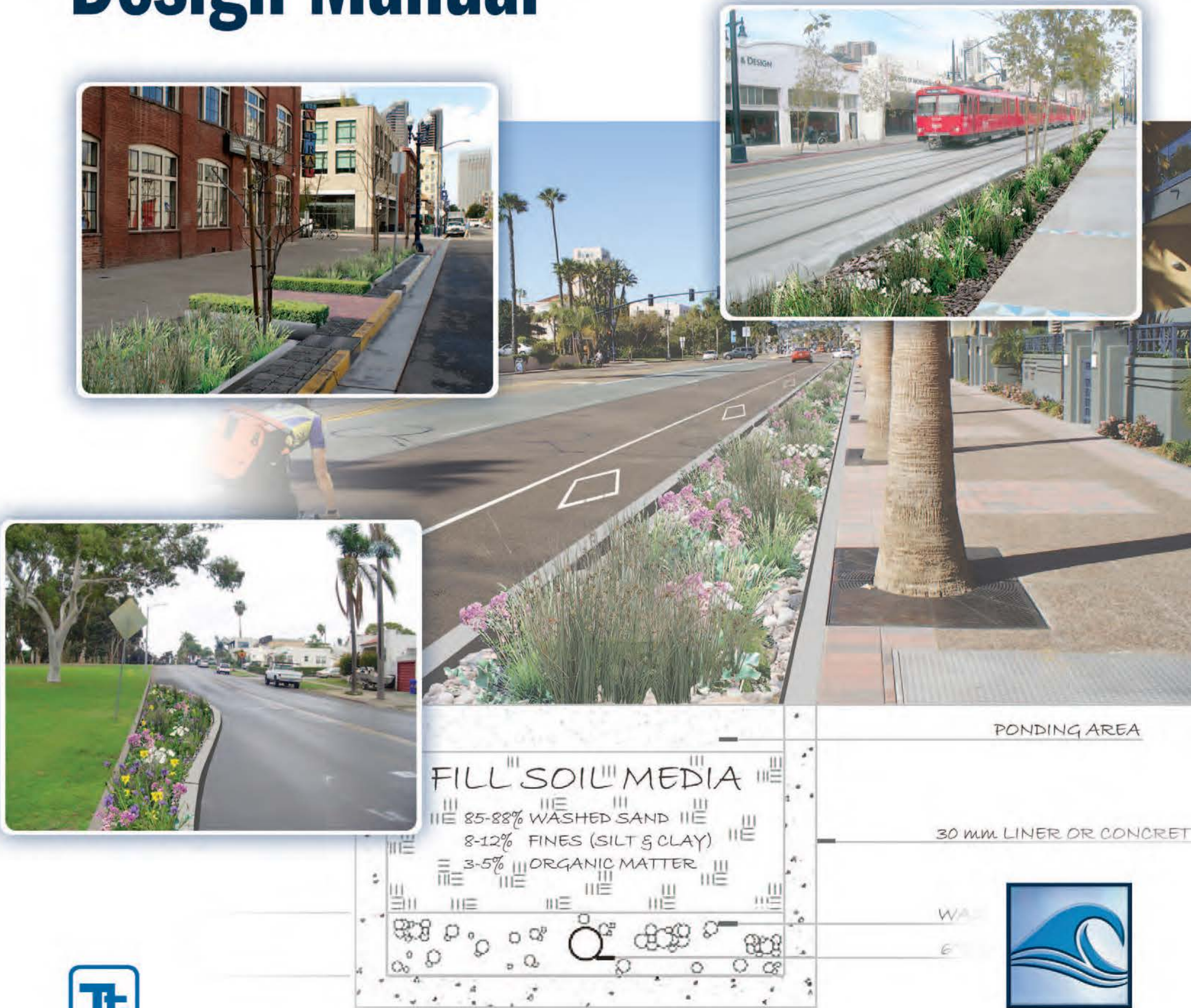
CITY OF SAN DIEGO STORM WATER

San Diego Low Impact Development Design Manual



TETRA TECH

think BLUE SAN DIEGO

Document No. PITS070111-01

July 2011

Preface

This Low Impact Development Design Manual was created to ensure that project designs are effective at carrying out the goals of the storm water regulations and to ensure that these facilities are designed to be reliable and cost effective to maintain. The guidance provided herein is not intended to supplant any requirements found within the Land Development Code or the Land Development Manual, but rather is intended to provide additional guidance in support of those requirements.

Should you find any part of the manual that does not meet this intended purpose, or have any comments, we encourage you to provide feedback in writing to swpp@sandiego.gov with the subject line "Attn: LID Design Manual Comments".

Versions

The first edition of this manual, Document No. PITS070177-01, was issued July 2011. Any subsequent updates will be lead by the Storm Water Division and posted on the "Engineering Documents and References" webpage of the Engineering & Capital Projects Department website.

Acknowledgements

This document was prepared by Tetra Tech, Inc. under the direction of the City of San Diego Storm Water Division, Construction and Development Standards Section, and in coordination with the City Engineer.

Representatives from departments throughout the City that have a role in designing, approving, accepting and maintaining storm water facilities have contributed to the development of this document by participating in interactive workshops and providing written comments.

Page intentionally left blank

Contents

Figures

Tables

List of Acronyms and Abbreviations

BMP	Best Management Practice
CEQA	California Environmental Quality Act
CESA	California Endangered Species Act
CIP	Capital Improvement Project
CWA	Clean Water Act
DSD	Development Service Department
EPA	U.S. Environmental Protection Agency
ESL	Endangered Sensitive Lands
HMP	Hydromodification Management Plan
IWSZ	Internal Water Storage Zone
LID	Low Impact Development or Low Impact Design
MEP	Maximum Extent Practicable
MHPA	Multi-Habitat Planning Area
MSCP	Multiple Species Conservation Program
MS4	Municipal Separate Storm Sewer System
NPDES	National Pollutant Discharge Elimination System
NPS	Non-point Source
SUSMP	Standard Urban Storm Water Mitigation Plan
SWRCB	State Water Resources Control Board
TMDL	Total Maximum Daily Load

1 Introduction

1.1 Purpose of the Manual

Urbanization and development alter and inhibit the natural hydrologic process of surface water infiltration, percolation to groundwater, evapotranspiration, and transpiration. Past traditional engineering approaches tended to route storm water runoff rapidly from developed surfaces into drainage systems, discharging storm flows and pollutants to downstream surface waters. As a result, storm water runoff from developed land is a significant source of many water quality impairments, including beach closing. One of the greatest sources of urban imperviousness is transportation infrastructure including roadways, driveways, sidewalks, and parking facilities. To maintain and improve the main hydrologic functions after development, reducing the overall imperviousness of a site is one of the most important design strategies. That can be achieved in multiple ways including applying low impact development (LID) storm water management practices, alternative layouts of street design, and other methodologies for reducing development footprints and disconnecting directly connected impervious areas from the storm water collection systems.

LID, which works to replicate natural hydrologic processes and reduce the disruptive effects of urban development and runoff, has emerged as an alternative approach that is complimentary to conventional storm water management measures including storm water best management practices (BMPs) used to manage runoff. LID is based on many of the functional unit processes found in the natural environment to treat storm water runoff, balancing the need for engineered systems during urban development with natural features and treatment processes. By using the functional unit processes of the natural environment to provide storm water treatment and control, and employing distributed controls to maximize water storage and re-use opportunities, LID techniques can enhance infiltration, percolation, and evapotranspiration to reduce adverse effects on surface waters, encourage groundwater recharge, and enhance water quality. LID methods offer great versatility in design, and can be incorporated into new urban development, redevelopment designs, and alternative transportation design with relative ease.

Alternative transportation options enhance safer street environments while reducing storm water runoff volume, peak discharges, and water quality problems. Landscaping, street trees, street lighting, and street furniture offer methods to promote additional benefits while creating distinctive, pleasing streetscape that encourage multiple use activity. That is the goal of *Complete Streets* in which our transportation corridors include multiple benefits including transportation opportunities for all users (public, private, pedestrians, bicyclists, motorists) recreation opportunities (e.g., walking and running trails, bicycle paths), and storm water management opportunities (LID storm water management facilities). Such streets often feature safer, more livable, visually aesthetic, and welcoming experience for users.

The City of San Diego has developed this *Low Impact Development Design Manual* as part of its ongoing efforts to balance the city's development goals, especially streets and right-of-way improvements, with the need to protect and enhance the quality of its water resources. This manual outlines the general concepts of LID practices and provides detailed design specifications intended to help designers, planners, and engineers who are involved with development projects, to manage and design projects that incorporate LID and follow the city's *Storm Water Standards: A Manual for Construction & Permanent Storm Water Best Management Practices Requirements* (shortened throughout as the Storm Water

Standards or Storm Water Standards manual) (City of San Diego 2008c). This *Low Impact Development Design Manual* is intended to assist the city's municipal employees in the design of Capital Improvement Projects (CIPs). Local architects, builders, and interested public groups might also find it valuable in planning and designing site-appropriate storm water management BMPs.

1.2 Applicability of the Manual

This manual is intended to assist project proponents to be in compliance with the *Storm Water Standards* manual. Specifically, the manual will assist with design and guidance for implementing LID BMPs on public lands including transportation corridors and other publicly owned property. The manual complements the existing *Storm Water Standards* manual emphasizing specific design components and the importance of site planning in the design of an effective storm water management system. The guidelines are applicable to newly developing areas and to older developments that are undergoing revitalization or redevelopment.

The manual establishes design guidelines to carry out the city's storm water and water quality protection goals. It does not establish a legal standard for such functions, and is not intended to do so. Moreover, the guidelines do not supersede requirements and policies established through adopted community plans, regional and city standard drawings, or other city council adopted policy or regulatory documents or both; instead, the manual is intended to work in concert with those policies and regulations.

The manual is intended to be used by project engineers, planners, and project managers from multiple departments including: the Engineering and Capital Project Department, Planning Department, the Development Services Department, the Storm Water Department and its Pollution Prevention Division, Environmental Services, and the Parks and Recreation Department, to design and implement LID storm water management BMPs in conjunction with city plans and projects.

This document is intended to provide sufficient instruction and technical resources to help city staff properly plan, select, design, and maintain LID BMPs. That is accomplished by providing a balance of detailed technical information with clearly described, step-by-step site assessment, planning, layout, selection, and BMP design instructions. Users of this manual should first become familiar with the fundamental principles and regulatory drivers for LID in the opening chapter. Most importantly, users must first review the current stormwater standards to determine the applicable storm water requirements, then to use this manual for guidance.

1.3 How to Use This Manual

This *Low Impact Development Design Manual* is divided into four chapters: Introduction; Site Assessment, Planning, and Site Design; Structural BMP Properties; and Implementation Considerations. Chapter 1 provides background for understanding the regulatory requirements necessary when developing and implementing LID BMPs. Chapter 2 includes a step-wise process for site planning, development, BMP siting, and sizing. Chapter 3 (and Appendix B) provides understanding of unit-process-based design for selection and placement of LID BMPs. Finally, construction considerations that can affect BMP design and implementation are included in Chapter 4. Six supporting appendices: BMP Sizing and Example Calculations; BMP-Specific Details for Design; Design Examples and Templates; BMP Design Fact Sheets; Local Plant List; and Facility Inspection and Maintenance Checklists are also integral to the steps, processes, construction, and operation and maintenance of LID BMPs. The appendices provide a sizing tool and supporting use document; detailed descriptions, specifications, and drawings for design; engineering drawing templates and examples; plant lists; fact sheets; and facility inspection and maintenance checklists. Those are all tools to assist in effective storm water system development.

Organization of the Manual

Chapter 1: **Introduction** provides the general background and regulatory justification for implementation of LID practices. It includes a discussion of federal, state, regional, and local regulation applicable to storm water management and LID implementation.

Chapter 2: **Site Assessment, Planning, and Site Design** provides step-by-step instructions for site assessment, planning, and preliminary layout of LID BMPs.

Chapter 3: **Structural BMP Properties** includes a summary description of all recommended LID BMPs and instructions for selecting site-appropriate BMPs.

Chapter 4: **Implementation Considerations** summarizes implementation considerations, including operation and maintenance needs and cost-reduction principles.

Appendix A: **BMP Sizing Tool** that is based on site conditions and local rainfall information, the section describes the development and instructions for using a tool that assists with sizing LID BMPs.

Appendix B: **BMP Design Guidance** provides design specifications, considerations, and helpful renderings of what a system might look like once built. Also provided are real-world renderings of design adaptations.

Appendix C: **BMP Design Templates** includes one-page examples of design details for individual BMP applications. Electronic files are also available for download, in MicroStation V8 format, for incorporation into construction drawings.

Appendix D: **Fact Sheets** contains design fact sheets for all LID BMPs included in the manual. The fact sheets are intended to be a one-page summary of key BMP design, construction, and maintenance considerations.

Appendix E: **Plant List** includes a detailed plant list, specific to the San Diego region, to help with LID BMP design.

Appendix F: **Inspection and Maintenance Checklist** provides a facility inspection and maintenance checklist for LID BMPs with checklists combined, in the case of multiple BMPs used together as a treatment train.

Once an understanding of these concepts is realized, the user is ready to apply information from the manual to assist in the design process. By following the step-by-step site assessment, planning, and layout instructions in Chapter 2, the engineer will have successfully selected, sited, and preliminarily sized a set of BMPs well-suited for the conditions, constraints, and water quality needs of the site. Review and assurance of geotechnical requirements for the site design will also have been completed. The final step described in Chapter 2 then directs the engineer to Appendix B to follow detailed design instructions specific to each BMP type summarized in Chapter 3. It is during that detailed design process in which the engineer will rely on many of the other appendices, such as the BMP design drawing templates in Appendix C, and the recommended plant list in Appendix E.

As the engineer develops a greater understanding of LID principles and becomes more experienced in designing BMPs, use of this manual can be further simplified by relying on the fact sheets in Appendix D. Engineers familiar with the design process could choose to reference the one-page fact sheets during the design process to remind themselves of key assumptions and design recommendations.

1.4 Background

In natural, undeveloped landscapes, the hydrologic processes of infiltration of surface water into the ground (both near surface and deep percolation), evapotranspiration, and transpiration work to recycle rainwater through plants and soil, and minimize the transfer of pollutants to surface and ground waters (Figure 1-1). As land development and urbanization occurs, natural or vegetated areas are replaced with streets, parking lots, buildings and compacted soils. Such impervious surfaces modify the natural hydrology, decrease the permeability of the landscape, and dramatically affect natural hydrologic cycles (Figure 1-1). In these impervious areas, where rainwater cannot infiltrate or percolate into the ground or be intercepted or taken up through vegetation and trees, traditional storm water conveyance systems have been designed to efficiently capture and direct runoff away from developed areas and into surface waters such as streams, rivers, and oceans. That process carries pollutants from dispersed or non-point sources (NPS) directly into the receiving surface waters.

The adverse effects associated with urban runoff consist of flow velocity, flow duration, timing, and pollutants generated in an urbanized setting with traditional storm water management. Volume of runoff from directly connected impervious areas is also a concern that can contribute to the above adverse effects. The first concern is the conveyance of pollutants from developed land into receiving surface waters. When rainwater cannot infiltrate into the ground, the water washes off pollutants that have accumulated on the surfaces of buildings and paved areas (Figure 1-2). Because most traditional conveyance systems do not provide treatment to improve the quality of storm runoff, the pollutants picked up by the storm water ultimately are conveyed into nearby surface waters. Pollutants commonly associated with urban runoff include sediment, trash, nutrients (particularly phosphorous and nitrogen), hydrocarbons such as gasoline and oil, pesticides/herbicides, fertilizers, metals, and bacteria or viruses associated with animal waste.

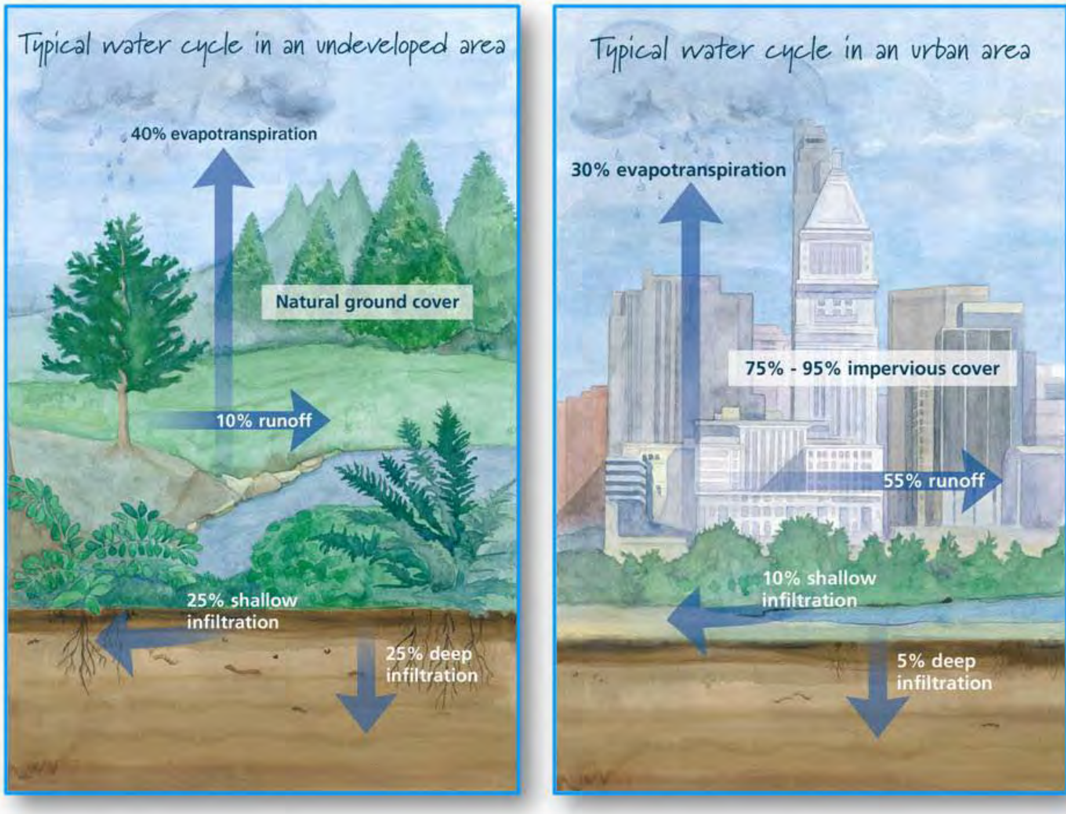


Figure 1-1. Typical water cycle in an undeveloped area versus an urban setting.

A second concern relates to the decrease in absorption, infiltration (and percolation), and interception as a natural site is developed. Decreased interception (the capture of water by vegetation before reaching the ground allowing for evaporation), absorption or infiltration (leading to percolation) prevent water from infiltrating into the ground and create increased overland runoff which can have cascading effects throughout the watershed. The amount of impervious cover in a watershed has been identified as a common factor in watersheds with stream degradation (USEPA 1999), and significant declines in the biological integrity or physical habitat of a stream have been found in watersheds that have as little as a 10 percent increase in the amount of impervious surfaces (SDRWQCB 2007a). With decreased percolation of infiltrated runoff, shallow groundwater recharge rates to streams and surface waters (interflow) are reduced. In turn, this reduces the amount of base flow in the surface waters, which can noticeably alter the physical habitat conditions of streams or shoreline areas. Both reduced infiltration rates and high-velocity surface flows

Figure 1-2. Storm water washes pollutants from impervious surfaces into traditional conveyance systems.

can lead to increased surface erosion or create gullies or both. The processes ultimately are destabilizing to banks and often wash sediment into surface waters. Finally, decreased infiltration leads to greater volumes and longer durations associated with peak storm flushes. Energy generated by the increased peak volumes are further compounded as flows are directed into conveyance systems that slope toward surface waters. Once discharged to surface waters, the energized flow can wash away or erode shorelines or banks. Ultimately, the increased sediment loads to surface waters can dramatically degrade water quality and significantly affect aquatic ecosystems.

In San Diego, the discharge from an NPS can negatively affect surface waters and beach quality. Runoff and NPS pollution are considered the most significant threat affecting the nation's waterways (USEPA 2004). Coastal resources are especially affected; in 2000 the U.S. Environmental Protection Agency (EPA) published the *National Water Quality Inventory Report*, finding that approximately 33 percent of the estuarine square miles assessed were impaired by pollution from urban runoff and storm sewers (USEPA 2000).

San Diego's stunning coastlines (Figure 1-3) offer both habitat for diverse wildlife and spectacular recreational opportunities. Such aquatic resources serve as the centerpiece to San Diego's tourist industry. However, urban runoff has the potential to harm water quality and aquatic resources in the region (City of San Diego 2008a). For example, the California 2006 303(d) list contains eight impairments to San Diego Bay with potential sources specified as *urban runoff/storm sewers* or *unknown nonpoint source* (SDRWQCB 2006). Such impairments can result in beach closings and a decline in revenue generated by tourism. And, while not valued in monetary terms, decline in aquatic resource quality also reduces the appreciation and enjoyment of such resources by the public. With proper storm water management, many of the ill effects of unmanaged urban runoff can be prevented.

Source: City of San Diego

Figure 1-3. Mouth of the San Diego River.

1.5 Storm Water Management and LID Concepts

Traditional storm water management has consisted of flow conveyance away from urbanized areas. Such conveyance systems are engineered to direct flows from impervious surfaces (such as streets, parking lots, sidewalks, and buildings) to curbs and gutters and, ultimately, to surface waters such as streams and oceans. Few people are aware of what happens to storm water once it enters the gutters and storm drain system—particularly that traditional storm water conveyances often do not include water quality treatment before storm flows wash into surface waters (unless in a combined sewer system).

Federal and state regulations require the development of municipal storm water management programs (see Section 1.8). The primary objectives of such programs include identifying bodies of water that fail to meet water quality standards or goals, and those that will continue to fail unless additional action is focused on reducing NPS pollution. For that reason, an integral part of storm water management planning includes incorporating BMPs to enhance water quality and reduce both flow velocities and flow volumes. In support of those goals, the San Diego Storm Water Municipal Permit (SDRWQCB 2007b) (see Section 1.8.1) states that pollutants can be effectively reduced in urban runoff by applying a combination of pollution prevention, source controls, and treatment control BMPs. Pollution prevention is the reduction or elimination of pollutant generation at its source and is considered the best *first line of defense* in treating storm water. LID offers a reliable pollution prevention technique to reduce or eliminate pollutants in storm water.

Functioning as a *first line of defense*, LID is a fundamentally different approach from traditional storm water management. Where traditional storm water management is designed to quickly convey runoff away from urban areas to nearby surface waters and does not focus on water quality treatment, LID aims to manage storm water at the site, often including some form of treatment and volume control for smaller storm events. Treating storm water at the site minimizes the volume that is washed overland and into traditional conveyance systems. Minimizing such volumes, reduces pollutants washed into surface waters and can result in significant water quality improvement. That is of great interest in areas with high recreation or aquatic life habitats such as San Diego.

Figure 1-4. LID incorporated into traditional parking lot design minimizes alterations to natural hydrology.

LID practices offer an innovative way to integrate storm water management into natural landscapes, minimizing alterations to the natural hydrologic regime and reducing the volume of site runoff (Figure 1-4). Implementing LID practices enhances water quality treatment, encourages groundwater recharge, and decreases surface erosion and pollutant transport. Additional benefits of LID implementation include the potential to use LID practices to enhance improved greenways and park lands, and to enrich natural environmental aesthetics in urban settings.

Figure 1-5. Vegetated filter strips reduces pollutants washed into storm water.

Offering considerable versatility with design and implementation, LID concepts can be incorporated into new and existing developments and can, in some cases, be less cost intensive than traditional, structural storm water management systems (USEPA 2007). LID uses the inherent properties of a natural system by minimizing alterations to or mimicking the natural setting; encouraging the natural hydrologic regime; reducing the extent of impervious surfaces and compacted soils on a site to increase opportunities for infiltration; increasing the amount of vegetation on a site to increase filtration as well as bioretention and evapotranspiration; enabling soil amendments to augment biological processes (denitrification) and adsorb pollutants (metals and nutrients); and encouraging sedimentation through flow detention or ponding areas.

1.6 Benefits of Storm Water Management and LID

Proper storm water management achieves a number of important purposes for municipalities and developers. First, water quality is of prime importance, particularly, effects on surface water can degrade essential marine and aquatic life habitats. Degraded water quality will also negatively affect or limit recreational opportunities through beach closings and declines in recreational fishing opportunities. The tourist industry in the San Diego region depends on healthy aquatic resources; therefore, degrading such resources would negatively affect the local economy. For that reason, protecting beaches and surface water quality is the primary purpose for managing storm water and implementing LID practices.

In addition to protecting and enhancing water quality, storm water management systems or programs should be designed to comply with federal and state regulatory requirements. Relevant regulations are discussed in Section 1.8 below. Furthermore, using properly designed and implemented LID techniques also provides a variety of expanded benefits and applications, including complete streets (as described below), increased wildlife, increased property values, improved recreational opportunities, and increased supplemental uses (USEPA 1999).

To meet those goals, it is essential that the design of a storm water management program begin, and be coordinated with, the initial site design. That is discussed in detail in Chapter 2 of the manual. In addition, the other two major phases of development after planning, construction, and final use, must also be considered in designing an effective system. Inadequate consideration of any of those three development phases could result in unnecessary pollutant discharges and flow alterations that adversely affect receiving waters (SDRWQCB 2007b).

Considerable cost savings over traditional approaches often can be achieved through proper storm water management and LID implementation. For example, LID practices typically involve less structural construction material, replacing structures with natural materials (plants, soils, and the like). Additionally, as open units instead of closed, subsurface storage units or conveyance pipes, LID BMPs tend to be easier to access. That can, in turn, reduce maintenance costs. Finally, reducing pollutants in surfaces waters decreases the costs associated with compliance actions, or additional treatment needed to use water resources for other purposes—including irrigation and vehicle washing.

1.7 Incorporating LID in Capital Improvement Projects

Although this manual can guide engineers, architects, and project managers in a wide variety of projects, its focus is on supporting opportunities to incorporate LID practices into municipal capital improvement projects (CIPs). CIPs typically include infrastructure improvements such as developing roads and bridges, renovating municipal buildings, and enhancing parks and open space. An increasing number of CIPs are required to incorporate LID BMPs to comply with the Municipal Permit requirements. As an example, Figure 1-6 shows a conceptual rendering of the University Avenue Mobility Plan, a CIP project in San Diego.

Source: http://www.sandiego.gov/engineering-cip/projectsprograms/uamp/

Figure 1-6. Conceptual rendering of the University Avenue Mobility Plan.

With proper planning, LID design alternatives can be incorporated into such CIPs to minimize site disturbance, protect the hydrology of native, natural areas such as vernal pools, and use key hydrologic features such as flow path directions. Ultimately, incorporating LID into CIPs can minimize site runoff, enhance water quality, and assist in regulatory compliance. In the city of San Diego, planning and designing CIP projects tend to be a collaboration of multiple departments such as Engineering and Capital Projects Department, Streets Division, Environmental Services, Planning Division and the Storm Water Department. To maintain adequate focus on meeting the required storm water management needs, such collaboration requires strong inter-departmental communication, well-established goals and objectives, and clear technical guidance to all involved; this *Low Impact Development Design Manual* is meant to provide such guidance. Specifically, the site assessment process described in Chapter 2 is a crucial process to carry out for proper CIP site design. Additionally, technical details, renderings of example LID applications, and specific design steps are offered in Appendix B to provide guidance with incorporating LID into CIPs.

1.8 Relevant Regulations and Guidelines

Development/redevelopment projects must comply with a number of local, regional, state, and federal regulations regardless of implementing LID practices. Below are select regulations that are specific to the San Diego region. The regulations presented are not meant to be all-inclusive; project managers must consult with the proper regulatory agencies.

1.8.1 Storm Water Regulations

The city's requirement for development projects to implement storm water BMP is based on section 402 (p) of the Clean Water Act. The Clean Water Act amendments of 1987 established a framework for regulating storm water discharges from municipal, industrial, and construction activities under the National Pollutant Discharge Elimination System (NPDES) program. Under the Clean Water Act, municipalities of sufficient size throughout the nation are issued a Municipal NPDES Permit. The primary goal of the permit is to stop polluted discharges from entering the municipally owned storm water conveyance system (the Municipal Separate Storm Sewer System, or MS4), and thus local receiving and coastal waters.

In California, the State Water Resources Control Board (SWRCB) administers the NPDES storm water municipal permitting program through its nine Regional Boards. In the San Diego Municipal Permit issued by the San Diego Regional Board, the city is required to develop and implement construction and permanent storm water BMPs that address reducing pollution from new development and redevelopment projects.

The Municipal Permit provisions include a requirement for all development projects to implement "LID BMPs where feasible which maximize infiltration, provide retention, slow runoff, minimize impervious footprint, direct runoff from impervious areas into landscaping, and construct impervious surfaces to minimum widths necessary" (SDRWQCB 2007b). The permit outlines specific LID requirements for Priority Development Projects (as defined in the Municipal Permit Section D.1.d.1) that will, "collectively minimize directly connected impervious areas and promote infiltration." Priority Development Projects are required to implement the following set of LID BMPs, including site design features, to meet the goal of Municipal Permit Section D.1.d.4:

> (a) The following LID site design BMPs shall be implemented at all Priority Development Projects as required below:
>
>> i. For Priority Development Projects with landscaped or other pervious areas, drain a portion of impervious areas (rooftops, parking lots, sidewalks, walkways, patios, etc) into pervious areas prior to discharge to the MS4. The amount of runoff from impervious areas that is to drain to pervious areas shall correspond with the total capacity of the project's pervious areas to infiltrate or treat runoff, taking into consideration the pervious areas' soil conditions, slope, and other pertinent factors.
>>
>> ii. For Priority Development Projects with landscaped or other pervious areas, properly design and construct the pervious areas to effectively receive and infiltrate or treat runoff from impervious areas, taking into consideration the pervious areas' soil conditions, slope, and other pertinent factors.

iii. For Priority Development Projects with low traffic areas and appropriate soil conditions, construct a portion of walkways, trails, overflow parking lots, alleys, or other low-traffic areas with permeable surfaces, such as pervious concrete, porous asphalt, unit pavers, and granular materials.

(b) The following LID BMPs listed below shall be implemented at all Priority Development Projects where applicable and feasible.

i. Conserve natural areas, including existing trees, other vegetation, and soils.

ii. Construct streets, sidewalks, or parking lot aisles to the minimum widths necessary, provided that public safety and a walkable environment for pedestrians are not compromised.

iii. Minimize the impervious footprint of the project.

iv. Minimize soil compaction.

v. Minimize disturbances to natural drainages (e.g., natural swales, topographic depressions, etc.)

1.8.2 City Land Development Code—Storm Water Standards

Storm Water Standards (City of San Diego 2008c) were promulgated (in accordance with the MS4 permit) as part of the city's Land Development Code to address urban runoff related to land development. The primary objectives of the *Storm Water Standards* are to effectively prohibit non-storm water discharges; reduce discharge of pollutants from storm water conveyance systems to the Maximum Extent Practicable (MEP) by implementing permanent BMPs for the project's extended post-development phase; provide consistency with the Model Standard Urban Storm Water Mitigation Plan (SUSMP) approved March 24, 2009; provide guidance for proper implementation of LID facilities and design approaches; and provide guidance for conformance with regional hydromodification management requirements.

Under the *Storm Water Standards*, development project proponents must complete the *Storm Water Requirements Applicability Checklist* (see Storm Water Standards Applicability Checklist; DS–560) to determine if construction or permanent BMPs are to be incorporated in the site plan. In addition to proper site planning to mitigate runoff effects, structural BMPs are required to be included both in Priority Development Projects (as determined in the *Storm Water Standards*) and standard development projects (non-Priority Development Projects as determined by the *Storm Water Standards*). To control post-development peak storm water runoff discharge rates and velocities, standard and Priority Development Projects are required to implement LID BMPs in accordance with the *Storm Water Standards*; guidance to properly size BMPs to remove pollutants to the MEP is also included on a flow or volume basis.

1.8.3 City of San Diego Hydromodification Plan

In San Diego, Priority Development Projects are subject to the requirements of the Hydromodification Management Plan (HMP). Users of this manual are directed to the San Diego County Hydromodification Management Plan and City Storm Water Standards Manual to determine applicable HMP requirements. The intent of the HMP is to manage increases of discharge runoff rates and durations from all Priority Development Projects, which are likely to increase erosion of channel beds and banks, increase sediment pollution or otherwise affect beneficial use or stream habitat. Post-development runoff may not exceed estimated predevelopment runoff rate and duration where increased runoff rate and duration would result in increased potential for erosion. Site planning for Priority Development Projects must consider the requirements of the HMP; however, the requirements of the HMP are consistent with the principles of LID planning. For example, LID planning can design an increased time of concentration for runoff, which will reduce the runoff rate and duration.

1.8.4 City of San Diego—Street Design Manual

The city's *Street Design Manual* includes design requirements and specifications specific to geometric designs, street element design, and planned development design. It includes standards specific to grade, pavement composition, drainage, rights-of-way, sidewalks, medians, and such. Specific to storm water design, Appendix VI of the document presents *BMP Practices Available to Address Storm Runoff Water Quality Associated with Street Design*, which includes specifications particular to implementing BMPs in curbs, swales, dual drainage systems, medians and cul-de-sacs.

1.8.5 Standard Urban Storm Water Mitigation Plan

To address storm water pollution effects, applicants for development projects are required to submit Urban Storm Water Mitigation Plans consistent with the region's SUSMP. Details and guidelines pertaining to the SUSMP requirements are in the *Storm Water Standards* (City of San Diego 2008c). The SUSMP requires that meet the following objectives are met:

- Reduce priority development project discharges of pollutants from the MS4 to the MEP
- Prevent priority development project runoff discharges from the MS4 from causing or contributing to a violation of water quality standards
- Manage increases in runoff discharge rates and durations from Priority Development Projects that are likely to cause increased erosion of stream beds and banks, silt pollutant generation, or other impacts to beneficial uses and stream habitat due to increased erosive force

1.8.6 Hydrology, Drainage, and Flood Control Design

The City of San Diego's *Storm Water Standards: A Manual for Construction & Permanent Storm Water Best Management Practices Requirements* (City of San Diego 2008c) establishes a procedure to evaluate and characterize flood and storm water in the City. The document provides guidance for jurisdictions to develop policies for flood and storm water management. In addition, the City of San Diego has also developed its *Drainage Design Manual* (2010), which establishes the design standards for the storm drain conveyance system.

1.8.7 City of San Diego—Consultant's Guide to Park Design and Development

The *Consultant's Guide to Park Design and Development* was prepared by the city's Park and Recreation Department and is meant to serve as a guideline for city staff, design consultants, and the general public in designing and developing city park improvements (City of San Diego Parks and Recreation Department, Administrative Services Division, March 2009). Specific to storm water, the park design standards in the guide include grading and drainage standards as well as surface material specifications.

1.9 Environmental Review

The environmental review process (when applicable) is an important process to ensure that environmental consequences resulting from development projects are minimized. Select environmental regulations are included below to assist with project planning. The regulations presented below are not meant to be all-inclusive; project managers must consult with the proper regulatory agencies.

1.9.1 California Environmental Quality Act

The California Environmental Quality Act (CEQA) establishes a review process similar to the National Environmental Policy Act and evaluates the environmental consequences of a project and identifies mitigation measures to prevent adverse degradation of the environment. In the city, the CEQA review process is assigned to the city's Development Services Department. See the city's *Development Permit and Environmental Review Process* at http://www.sandiego.gov/planning/community/pdf/cow/revprocessfullversion.pdf.

1.9.2 Multiple-Species Conservation Program

On a regional level, the Multiple Species Conservation Program (MSCP) is intended to preserve native habitat for multiple species by identifying areas for directed development and areas to be conserved in perpetuity (referred to as Multi-Habitat Planning Area or MHPA) to achieve a workable balance between smart growth and species protection. Any project area that falls within portions of the city's MHPA or includes areas directly adjacent to the MHPA need to demonstrate compliance with the MHPA land use adjacency guidelines (see the city's MSCP Subarea Plan, March 1997, http://www.sandiego.gov/planning/mscp/pdf/subarea.pdf) to address potential indirect effects on the MHPA through features incorporated into the project and/or permit conditions.

Additionally, certain areas with high-quality vernal pools (Figure 1-7) were selected to be subject to individual section 404 permits administered by the U.S. Army Corps of Engineers under the Clean Water Act. Other areas, especially those with low-priority vernal pools, are included in the Clean Water Act section 404 nationwide permit to reduce barriers to development and encourage *smart growth* consistent with the MSCP's goals. The CEQA review includes mitigation of vernal pool impacts through preservation, restoration, or enhancement of resources on-site.

Figure 1-7. Vernal pools offer critical habitat in the San Diego region.

1.9.3 Endangered Species

The California Endangered Species Act (CESA) expands the federal Endangered Species Act and states that all native species of fishes, amphibians, reptiles, birds, mammals, invertebrates, and plants, and their habitats threatened with extinction, and those experiencing a significant decline which, if not halted, would lead to a threatened or endangered designation, will be protected or preserved. Section 2080 of

CESA prohibits the *take* of any endangered or threatened species, where take is defined as the hunt, pursue, catch, capture, or kill. CESA emphasizes early consultation with stakeholders to avoid affecting endangered and threatened species.

The city oversees development that could affect listed species through the Environmentally Sensitive Lands (ESL) Regulations (San Diego Municipal Code, *Land Development Code, Biology Guidelines*, pending amendment). The biology guidelines list narrow endemic species, the presence of which is included in the definition of ESLs. Projects involving ESLs require a discretionary review of the project permit, including biological surveys and species specific mitigation requirements, as described in the *Biology Guidelines* (http://www.sandiego.gov/development-services/industry/pdf/landdevmanual/ldmbio.pdf).

1.9.4 Geologic Hazards

Unstable slopes, slide-prone geologic formations, faults, and liquefaction-prone soils occur in many parts of the city. The relative risk of such soils has been mapped as part of the City of San Diego Seismic Safety Study. The maps indicate where adverse geological conditions might exist, as defined by Geologic Hazard Category (http://www.sandiego.gov/development-services/hazards/hazardsmaps.shtml). The city's *Guidelines for Geotechnical Reports* (http://www.sandiego.gov/development-services/industry/pdf/geoguidelines.pdf) describes investigations that might be required for project approval.

Source: City of San Diego

Figure 1-8. A typical canyon system in San Diego.

1.10 Local and Regional Planning

In addition to compliance with regulations, LID practices can assist in meeting local and regional planning objectives. Planning objectives can include creating sustainable environments that are aesthetically pleasing. Objectives from the city's General Plan and regional/local transportation planning are discussed below.

1.10.1 General Plan

The City of San Diego General Plan (2008b) provides the foundation for all land-use decisions, outlining a *constitution* for development, in the city. The objective of the general plan is to set a long-range vision and comprehensive policy framework for how the city should plan for projected growth, provide public services, and maintain the qualities that define San Diego. Ten elements are addressed in the 2008 general plan including land use and community planning; mobility; economic prosperity; public facilities; services and safety; urban design; recreation; historic preservation; conservation; noise; and housing.

LID concepts align with many of the fundamental guiding principles of the plan, such as enhancing open space networks; enhancing the transportation network, especially for pedestrians; creating quality, well-maintained public facilities; enhancing aesthetics; and promoting a clean, sustainable environment.

1.11 Regional Considerations

LID practices offer substantial versatility and can be integrated into new or existing site plans. However, as with any location, the setting and environment of the San Diego region presents additional environmental or site constraints that must be considered in the LID design. Particular to implementing LID practices in the San Diego region, the topography, climate, soils, hydrology, and surface waters can present additional challenges and limitations. Each of those regional considerations must be addressed and properly considered in the design stage of planning. The regional considerations are described below. General detail on site selection and local considerations is included in Chapter 2, while design specifications are presented within Appendix B.

1.11.1 Climate

San Diego generally enjoys mild, sunny weather throughout most of the year; however, because of the topography, climate in the region can vary considerably in a short geographic distance. In general, the region is considered a semi-arid climate, with evapotranspiration rates of 45 to 50 inches per year. Annually, San Diego receives a mean rainfall of approximately 10 inches of rain (San Diego County 2007). Because of limited precipitation, the scarcity of water and ever increasing demands on the limited supply, it is ideal to incorporate native vegetation or vegetation that is resilient to water shortages and periodic flooding into LID practices. A list of plants appropriate for the San Diego area is provided in Appendix D.

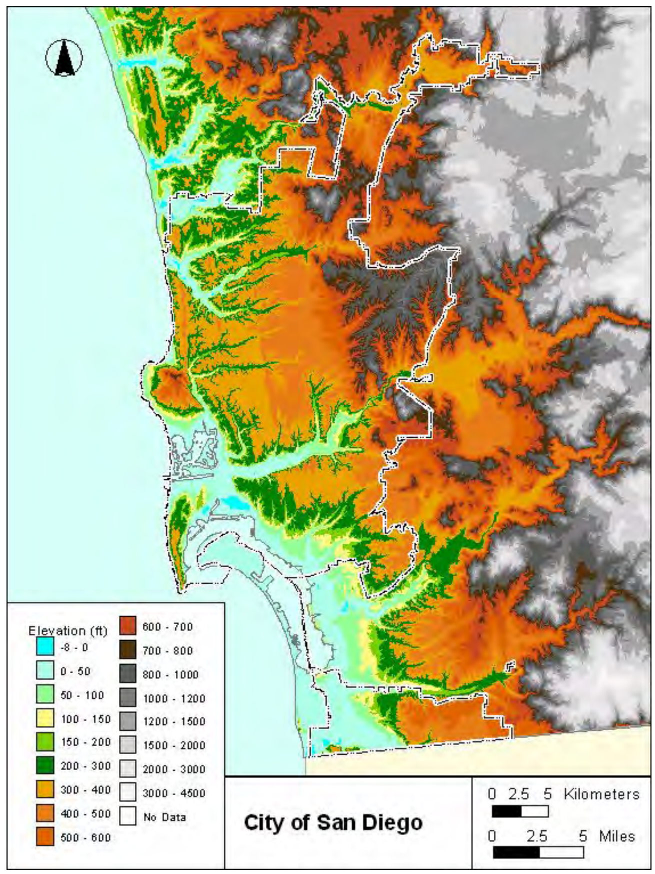


Figure 1-9. Topography of the city.

1.11.2 Topography

San Diego is a city in a region with unique and varied landscapes. The topography of San Diego consists largely of mesas, valleys, and canyons (Figure 1-9). Topography affects hydrologic flows; shallow slopes can cause storm water to pond, while steep slope areas might require additional design measures to prevent erosion. Developers must use caution in the San Diego region to ensure that slopes are adequately stabilized and BMPs are placed appropriately, avoiding steep slopes.

1.11.3 Hydrology

The San Diego region's predevelopment hydrologic conditions consisted primarily of infiltration in many locations, with only larger storms washing from mesas into adjacent canyons. Before development, rainfall from smaller storms likely collected in existing depressions on the mesas and formed vernal pools. Over time, vernal pools would have slowly evaporated with only larger storms leading to significant flow through the canyons. Hydrology controls for developments in San Diego typically have focused on collecting and routing storm water runoff from the mesas into the nearest canyon or the closest surface water.

Because of the physical features of the typical mesa-canyon systems, there is often limited room to implement traditional centralized storm water treatment systems, making the LID approach and multiple distributed storm water systems much more practical for San Diego's unique and varied landscapes.

LID can be implemented to mimic the typical predevelopment hydrology regimes by capturing storm water runoff and allowing it to infiltrate where possible, or by storing runoff in the soils until it can be taken up by plants or evaporated, taking advantage of the high evapotranspiration rates and low annual rainfall in the area.

Figure 1-10. Surface waters in the San Diego region.

1.11.4 Surface Waters

The proximity of so much of San Diego's land area to surface waters (Figure 1-10), from small streams to the Pacific Ocean, offers additional justification to implement LID BMPs to protect water quality. The major receiving waters in the city consist of the Pacific Ocean, San Diego Bay, the San Diego River, Mission Bay, the San Dieguito River, Los Penasquitos Creek, the Otay River, and the Tijuana River. The use of LID techniques to improve water quality, reduce pollutants reaching surface waters, and particularly to increase critical dry-weather base flows in streams and rivers, can have a substantial positive effect on the city's surface waters.

1.11.5 Soils

One of the fundamental concepts of LID techniques is to use infiltration capacity to the extent possible to mimic natural hydraulic conditions. This concept is unique to LID design strategies where a smaller design storm is targeted. The *City of San Diego Drainage Design Manual* currently recommends analyses of sites using a blanket Soil Type D classification. This approach is appropriate for flood control which, in general, targets larger storms. In those conditions, infiltration capacity is relatively insignificant compared to the runoff volume of the target storm. However, infiltration can have a significant impact in runoff volume reduction for the 85th percentile storm water design storm, making actual soil type an integral design parameter. San Diego's soil types present substantial challenges for storm water management, and require careful attention and consideration when choosing and implementing LID measures. Soils are characterized into four hydrologic soil types by the Natural Resources Conservation Service on the basis of the soil's potential for runoff, which is an important concern in the San Diego region. The Natural Resources Conservation Service soil types are as follows:

- Soil Type A: sand, loamy sand, or sandy loam types of soils. It has low runoff potential and high infiltration rates even when thoroughly wetted.
- Soil Type B: silt loam or loam. It has a moderate infiltration rate when thoroughly wetted.
- Soil Type C: sandy clay loam. It has low infiltration rates when thoroughly wetted.
- Soil Type D: clay loam, silty clay loam, sandy clay, silty clay, or clay. They have very low infiltration rates when thoroughly wetted.

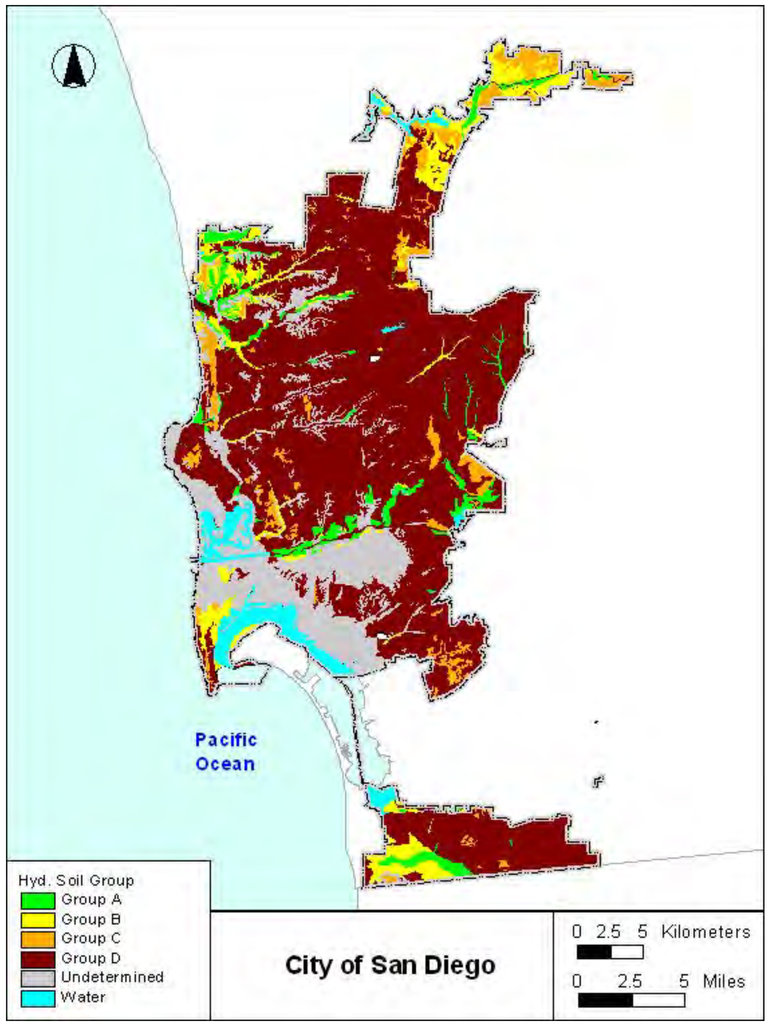


Figure 1-11. Soils in the San Diego region.

The dry soils in the San Diego region consist principally of clays, with low nutrients and low iron content. That creates additional challenges for establishing vegetative cover. The San Diego area has a high concentration of Group C and D soils (Figure 1-11). Group C and D soils are characterized by relatively low percolation rates (San Diego County 2007) and could present additional challenges for infiltration. Areas with C and D soils require careful attention and often some variations to the typical standards for designing and implementing LID BMPs; underdrains or soil amendments, as discussed in Appendix B, could be required to increase infiltration.

1.12 References

City of San Diego. 2008a. *City of San Diego Jurisdictional Urban Runoff Management Program, Annual Report 2008*.

City of San Diego. 2008b. *City of San Diego General Plan*. Resolution No. R-303473. San Diego, CA.

City of San Diego. 2008c. *Storm Water Standards: A Manual for Construction & Permanent Storm Water Best Management Practices Requirements*. San Diego Municipal Code: Land Development Manual. City of San Diego.

City of San Diego. 2010. *San Diego Drainage Design Manual*. Accessed April 6, 2010.

San Diego County. 2003. *Hydrology Manual*.

San Diego County. 2007. *Low Impact Development Handbook, Stormwater Management Strategies*. County of San Diego, Department of Planning and Land Use, San Diego, CA.

SDRWQCB (San Diego Regional Water Quality Control Board). 2006. *Board Approved of Clean Water Act Section 303(d) List of Water Quality Limited Segments*.

SDRWQCB (San Diego Regional Water Quality Control Board), 2007a. *Discussion of Significant Modifications to the Directives of Order No. R9-2007-0001*.

SDRWQCB (San Diego Regional Water Quality Control Board). 2007b. *Waste Discharge Requirements for Discharges of Urban Runoff from the Municipal Separate Storm Sewer Systems (MS4s) Draining the Watersheds of the County of San Diego, the Incorporated Cities of San Diego County, the San Diego Unified Port District, and the San Diego County Regional Airport Authority.* Order No. R9-2007-0001, NPDES No. CAS0108758.

USEPA (U.S. Environmental Protection Agency). 1999. *Preliminary data summary of urban storm water best management practices*. EPA-821-R-99-012. U.S. Environmental Protection Agency, Office of Water.

USEPA (U.S. Environmental Protection Agency). 2000. *Low Impact Development (LID), A Literature Review*. EPA-841-B-00-005. U.S. Environmental Protection Agency, Washington, DC.

USEPA (U.S. Environmental Protection Agency). 2004. *Storm Water Best Management Practice Design Guide: Volume 1, General Considerations*. EPA/600/R-04/121. U.S. Environmental Protection Agency, Washington, DC.

USEPA (U.S. Environmental Protection Agency). 2007. *Reducing Stormwater Costs through LID Strategies and Practices*. EPA-841-F-07-006. U.S. Environmental Protection Agency, Washington, DC.

2 Site Assessment, Planning, and Design

2.1 Site Planning and Design Principles

All projects that are not exempt from the *Storm Water Standards* (i.e., CIPs, Standard Development Projects, and Priority Development Projects) will be subject to LID requirements in the *Storm Water Standards* manual (City of San Diego 2008b). The MS4 permit requires the city to prescribe the necessary requirements during the planning phase and before project approval for all development projects so that discharges of pollutants from the MS4 will be reduced to the MEP (SDRWQCB 2007). Such requirements include implementing LID BMPs, where feasible. Priority Development Projects are subject to the requirement of LID BMPs that minimize directly connected impervious areas and promote infiltration, and additional LID BMPs where applicable and feasible. Standard LID BMP requirements use natural features to slow and filter storm water runoff. Project characteristics will define which LID BMPs are applicable. When determining the appropriate LID requirements, project managers must consider characteristics such as site location, existing topography and soils, and planning elements. These characteristics and their impacts on design are important because LID BMPs are permanent features that may impact other project elements, therefore, it is critical to conduct thorough site assessments to avoid the need for re-design at later stage. The *Storm Water Standards* manual also provide information for considering LID at a site.

The following principles compose the fundamental planning concepts of LID (USEPA 1999):

1. *Using hydrology as the integrating framework*

   Integrating hydrology during site planning begins with identifying sensitive areas, including streams, floodplains, wetlands, steep slopes, highly permeable soils and woodland conservation zones. Through that process, the development envelope—the total site areas that affect the hydrology—is defined.

2. *Thinking micromanagement*

   Distributed control of storm water throughout the site can be accomplished by applying micromanagement techniques, or integrated management practices, on small subcatchments or on residential lots. Micromanagement techniques foster opportunities to maintain the natural hydrology, provide a much greater range of control practices, allow control practices to be integrated into landscape design and natural features of the site, reduce site development and long-term maintenance costs, and provide redundancy if one technique fails.

3. *Controlling storm water at the source*

   Undeveloped sites possess natural storm water mitigation functions such as interception, depression storage, and infiltration. Those hydrologic functions should be restored or designed as close as possible to the source to minimize and then mitigate the hydrologic effects of site development. Biorentention cells, as shown in Figure 2-1, serve this function.

4. *Using simple nonstructural methods*

   Stockpiling and use of existing soils vegetation, and natural drainage features can be integrated into LID designs with systems using such materials appearing more natural than foreign material including concrete troughs and vault systems. Examples include bioretention cells and curb pop-outs as in Figures 2-1 and 2-2.

Figure 2-1. Bioretention cell.

5. *Creating a multifunctional landscape*

   Urban landscape features such as streets, and green spaces, can be designed to be multifunctional by incorporating detention, retention, and filtration functions, such as curb pop-outs, as shown in Figure 2-2.

Figure 2-2. Example of curb pop-outs.

LID methods are intended to reproduce predevelopment hydrologic conditions, through infiltration, evaporation, and storage of storm water runoff, while allowing for full development (Prince George's County 1999). A successful development balance that minimizes site alterations as the first step of LID site planning must include a thorough site assessment. The primary objective of the site assessment process is to identify limitations and development opportunities specific to LID. For example, development opportunities include available space, use of right-of-way as appropriate, and maximizing opportunities where properly infiltrating soils exist. Constraints or limitations that need to be factored into site planning when implementing LID practices include slow-infiltrating soils (typically clays), soil contamination, steep slopes, adjacent foundations of structures, wells, and water table characteristics that could affect the degree of infiltration that is possible (San Diego County 1999).

Siting and selecting appropriate LID BMPs is an iterative process that requires comprehensive site planning with careful consideration of all nine steps detailed in this chapter. A site planner or engineer can follow these steps in developing final site plans, as described in Figure 2-3. The steps are arranged on the basis of the anticipated design phases of site assessment, preliminary design, and final design (Phases I, II, and III, respectively). The decisions made under each step should be documented and submitted with the Water Quality Technical Report required by the *Storm Water Standards*.

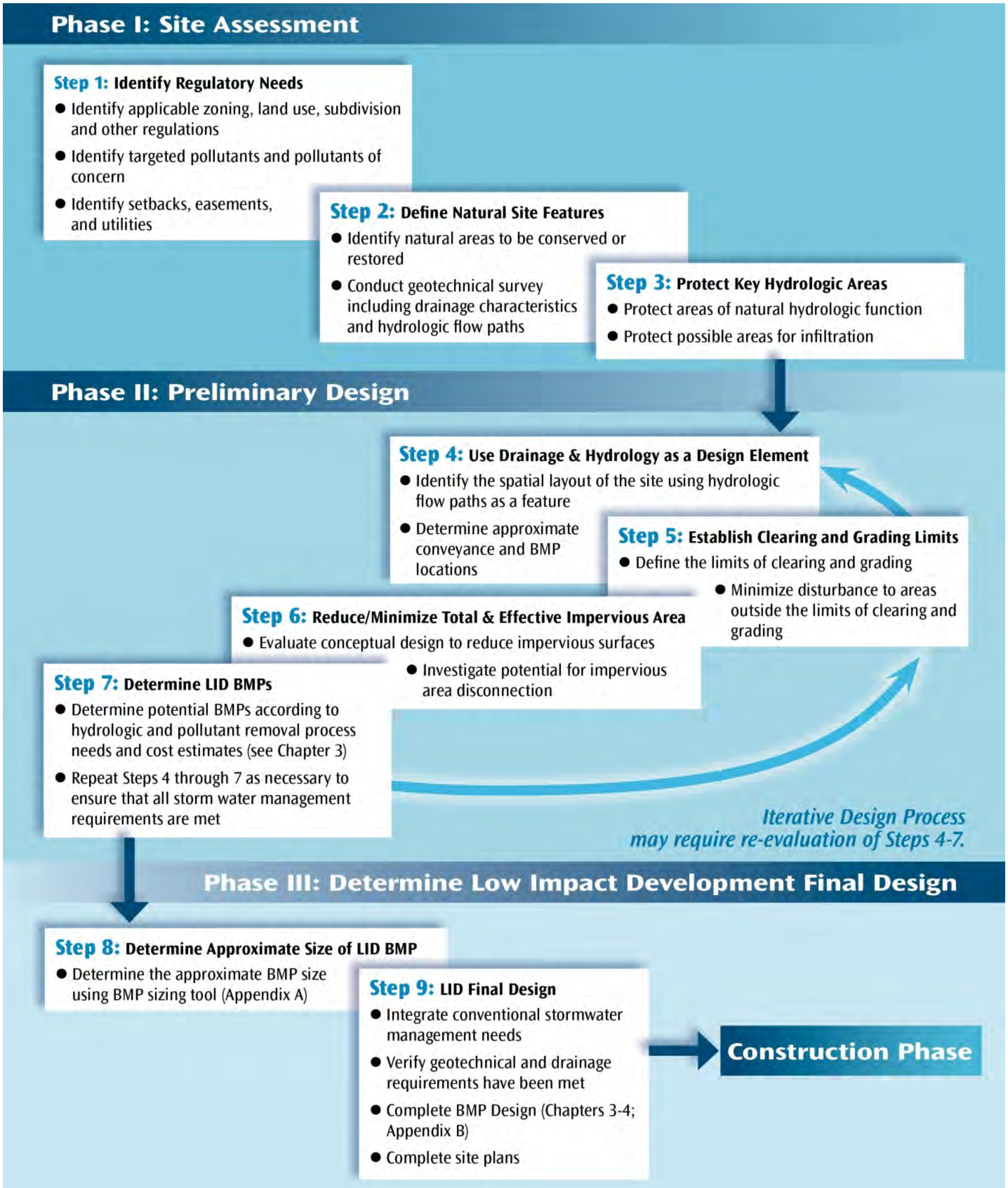


Figure 2-3. Flow Diagram of steps involved with developing an LID-based site plan.

In the preliminary site plan, the development envelope (site boundary) is delineated. Applicable zoning, land use, subdivision, local road design regulations, and other local requirements such as San Diego's *Storm Water Standards* and the MSCP all should be identified to the extent applicable at this stage (Step 1). To make the best and most optimal use of LID techniques on a site, a comprehensive site assessment must be completed that includes an evaluation of existing site topography, soils, vegetation, and hydrology including surface water and groundwater features. With such considerations, the site assessment phase provides the foundation for consideration of and proper planning around existing natural features and to retain or mimic the site's natural hydrologic functions (Steps 2 and 3). Phase II, site planning, covers steps 4–7. Defining preexisting and site specific drainage patterns is useful for determining potential locations of storm water BMPs (Step 4). With natural and hydrologic features identified, protected and used for determining design elements, clearing, grading, and other construction site planning needs can balance storm water management requirements to determine areas most suitable for development, drainage, and treatment (Step 5). After the preliminary site configuration has been determined in light of the existing features, impervious area site plans (buildings, roadways, parking lots, sidewalks) can be evaluated for opportunities to minimize total impervious area in the site planning phase (Step 6). The specific types of LID BMPs are determined next (Step 7; e.g., a bioretention cell versus porous pavement for storm water storage and infiltration). In Phase III, final LID BMP footprints and sizes are estimated (Step 8; and for sizing, see Appendix A). An iterative process working between Steps 4 and 7 can help determine the final site layout for completing the design process (Step 9). These steps are presented in more detail in the following sections. When Step 6 is completed, detailed determination of storm water management practice selection and design that considers BMP construction, and operation and maintenance (Chapters 3 and 4) should be consulted to complete Phase III and the final site design process. Steps 8 and 9 assist in determining BMP sizing and final design.

An example conceptual site was created to demonstrate the phases of site assessment, preliminary design and planning through the final designs, and show how the site changes with each step. Figure 2-4 demonstrates a site for a CIP, which includes the construction of a new library, an adjoining parking lot, and a surrounding park, that has the setbacks identified as a part of the site-planning process. This example site will be used to illustrate the steps described in the following sections.

Figure 2-4. Flow diagram of steps involved with developing an LID-based site plan.

2.1.1 Phase I—Site Assessment

The first phase of site planning is composed of the site assessment. Steps 1 through 3 below delineate the site assessment process.

Step 1: Identify Regulatory Needs

LID implementation must be consistent with the applicable federal, state, and local regulations presented in Chapter 1. A general discussion of how the LID standards work with local regulations is included in this chapter. All development projects are required to comply with the City's Storm Water Standards manual requirements.

In brief, the multijurisdictional MS4 permit requires the city (and co-permittees) to prescribe and administer necessary requirements for all development projects (both during the planning phase and before project approval) that ensure that discharges of pollutants from the MS4 will be reduced to the MEP (San Diego Regional Water Quality Control Board 2007). Such requirements include implementing LID BMPs where feasible. For example, the MS4 permit contains specific LID requirements for all Priority Development Projects. The permit requires that for all Priority Development Projects with landscaped or pervious areas, a portion of impervious area drainage must drain through a pervious area before discharge to the MS4. For such projects, the permit also requires that the pervious areas be designed effectively to receive and infiltrate or treat runoff from impervious areas. Finally, the MS4 permit requires that a portion of any low traffic areas having appropriate soil conditions be constructed with permeable surfaces, such as pervious concrete, porous asphalt, or granular materials.

To Complete Step 1:

- **Identify applicable zoning, land use, subdivision, and other regulations**
- **Identify setbacks, easements, and utilities**
- **Identify targeted pollutants and pollutants of concern**

All projects that are not exempt from the *Storm Water Standards* are subject to the LID BMP requirements in the *Storm Water Standards* manual. Priority Development Projects are subject to required LID BMPs that minimize directly connected impervious areas and that promote infiltration and additional LID BMPs where applicable and feasible. Standard LID BMP requirements use natural features to slow and filter storm water runoff. Project characteristics will define which LID BMPs are applicable. Characteristics such as site location and planning elements need to be considered when determining the appropriate LID requirements.

Identify applicable zoning land use, subdivision, and other local regulations

Zoning ordinances and comprehensive planning by any local government entity (county, city, and such) provide a framework to establish a functional and visual relationship between growth and urbanization (USEPA 1999). For the city, the Land Development Code is in Chapters 11–14 of the Municipal Code. The city has also produced a *Land Development Manual* (http://www.sandiego.gov/development-services/industry/landdevmanual.shtml), which provides information to assist property owners and developers who are applying for permits to use or develop land in the city. All private property is in a designated base zoning district, and some property might also be in an overlay zone, which modifies the regulations of the base zone to address specific issues such as development of property surrounding an airport, special height limits, or additional parking requirements.

CIPs can occur in the public right-of-way; open space, parks, and such. Zoning requirements for open space land uses are in Chapter 13 Article 1 Division 2 of the San Diego Municipal Code. Chapter 6 Article 2 of the city's Municipal Code establishes rules and regulations regarding public rights-of-way and land development. Additional applicable regulations are described in Section 1.7. It is recommended that identification of land uses also be shown in a visual format similar to Figure 2-5.

Identify setbacks, easements, and utilities

Defining the boundaries of the site (yellow-dashed line indicating parcel boundaries) also includes identifying the required setbacks and any easements or utilities present on the site. Chapter 13, Article 1, Divisions 2–6 of the San Diego Municipal Code provide the basic regulations regarding the size and scale of development, such as permitted density, setbacks and structure height on the basis of the applicable zoning code. Setbacks will restrict the buildable area.

Planning and assessment must also include identifying easements on the site. Easements that could be present include a road or sidewalk (right-of-way) easement, a public utility easement, which allows a utility to run gas, water, sewer or power lines through a private property, or a railway easement. One should consult with local utilities departments (e.g., electric, wastewater) to determine whether utilities are on-site or below ground, and for the required distance that site disturbance should be maintained from any utilities present. Easements on a site can be determined by consulting as-built drawings and records research. Easement setbacks may include vernal pool, canyon, or foundation setbacks as illustrated in Figure 2-5.

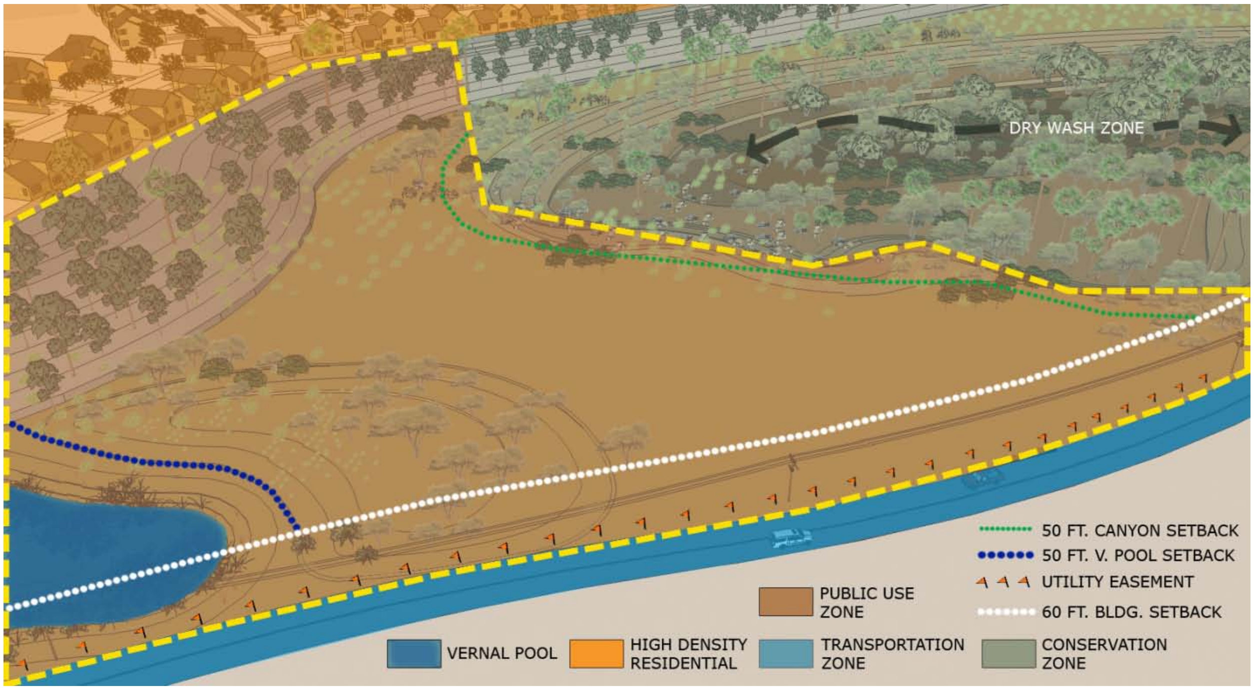


Figure 2-5. Identify applicable zoning requirements, utility easements and site setbacks.

Identify targeted pollutant needs

All Priority Development Projects are subject to the requirements of the HMP of the SUSMP. The intent of the HMP is to manage increases of discharge runoff rates and durations from all Priority Development Projects that are likely to increase erosion of channel beds and banks, increase sediment pollution or otherwise affect beneficial use or stream habitat. Post-development runoff on such sites might not exceed the estimated predevelopment runoff rate and duration where increased runoff rate and duration would result in increased potential for erosion. Site planners for Priority Development Projects must determine whether the requirements of the HMP apply, and then consider the requirements of the HMP in site design, which are consistent with the principles of LID planning. For example, LID planning can design an increased time of concentration for runoff, which will reduce the runoff rate and duration.

The California SWRCB identifies impaired waterbodies that warrant attention and additional resources. Impaired bodies of water fail to meet water quality objectives and require development of implementation plans targeted at both point source and NPS of pollution. Implementation plans for total maximum daily loads (or TMDLs) often target NPS of pollutants by requiring the incorporation of BMPs; implementing LID offers an effective tool used to enhance water quality to the maximum extent practical. For that reason, site planning should include identifying any impaired water or waters in the region and assessing pollutants of concern to allow planners and designers to consider target pollutant reduction needs in the design phase. The *Storm Water Standards* provide a procedure for identifying the pollutants of concern on the basis of a receiving waters 303(d) listing.

Priority Development Projects are also required to identify anticipated and potential project pollutants generated by land use type to be submitted with the required Water Quality Technical Report. For guidance in identifying the project's anticipated pollutants and for pollutants of concern see Chapter 3 and the *Storm Water Standards*.

Step 2: Define Natural Site Features

Site planning and design should consider how CIPs such as road design can use existing natural features of the site in effort to retain natural hydrologic functions. Identifying natural or sensitive areas is an integral factor in defining the site area for development as well as placing site needs and features in the context of the overall watershed.

Natural/sensitive areas

To enhance a site's ability to support source control and reduce runoff, the conservation and restoration of natural areas must be considered in the site design process. By conserving or restoring the natural drainage features, natural processes are able to intercept storm water, thereby reducing the amount of runoff.

To Complete Step 2:

- **Identify natural areas to be conserved or restored**
- **Conduct a geotechnical survey including drainage characteristics and hydrologic flow paths**

Fundamental principles encouraging conservation and restoration of natural areas consist of the following:

- Minimize site grading and the area of disturbance by isolating areas where construction will occur. Doing so will reduce soil compaction from construction activities. Additionally, reduced disturbance can be accomplished by increased building density or height, if possible.

- When possible, the site should be planned to conform to natural landforms and to replicate the site's natural drainage pattern. Building roads and sidewalks on the existing contour ensures that the natural flow paths and hydrology continue to function.
- An essential factor in optimizing a site layout includes conserving natural soils and vegetation, particularly in sensitive areas such as habitats of sensitive species, wetlands, existing important trees, hillsides, woodland conservation zones, and existing streams. Such areas can be used as natural features in site planning to avoid or reduce potential effects of development. Vernal pools, for example, form as a function of the underlying soil type and provide habitat for a number of sensitive species. Once affected through development, mitigating such sites is not always successful, and sensitive habitat might not be recovered.
- In areas of disturbance, topsoil can be removed before construction and replaced after the project is completed. When handled carefully, such an approach limits the disturbance to native soils and reduces the need for additional (purchased) topsoil during later phases.
- Impervious areas (i.e., square footage of parking lots, sidewalks, and roofs) should be minimized by designing compact, taller structures; narrower streets; and using underground or under-building parking.

The San Diego *Storm Water Standards* manual describes methods for determining the least sensitive areas of the site. The least sensitive areas of the site should be determined, as follows, in order of increasing sensitive areas: areas devoid of vegetation, including previously graded areas and agricultural fields; areas of nonnative vegetation, disturbed habitats, and eucalyptus woodlands where receiving waters are not present; areas of mixed chaparral and nonnative grasslands; areas containing coastal scrub communities; all other upland communities; and occupied habitat of sensitive species and all wetlands. Hillsides should be considered more sensitive than flatter areas, and, where possible, the site layout should conform to natural landforms, avoid excessive grading and disturbance, and replicate the site's natural drainage. Mapping such locations is essential for understanding the natural site features along with the planned development.

Vernal pools are a habitat in the San Diego region that requires special consideration. Vernal pool habitats are protected under the MSCP for San Diego. An inventory of vernal pools is at the San Diego's Vernal Pool Inventory Web site (http://www.sandiego.gov/planning/mscp/vpi/index.shtml).

In the example shown in Figure 2-6, the natural and sensitive areas that should be considered for protection during development are identified on the site map, including vernal pools, native tree groves, steep slopes (hillside), and the adjacent canyon.

Understand soils through geotechnical surveys

Priority Development Projects are required to conduct a geotechnical investigation. The *Storm Water Standards* provides the preparation guidelines and the requirements for the final report submittal, and requires the Geologic Investigation Report to be prepared in conformance with the City of San Diego *Guidelines for Geotechnical Reports* (2008a), Appendix D to its *Land Development Manual*, at http://www.sandiego.gov/development-services/industry/pdf/geoguidelines.pdf. A geotechnical engineer licensed in California should perform a detailed geotechnical evaluation of surrounding soils. The intent of a soil survey is to minimize disturbance to existing soils and to identify and protect (and use areas with) soils that provide greater infiltration as potential locations for storm water BMPs (Figure 2-6). In addition, natural drainage characteristics and hydrologic flow paths should be identified. These features can be used in design and protected in future steps to maintain the sites natural drainage characteristics.

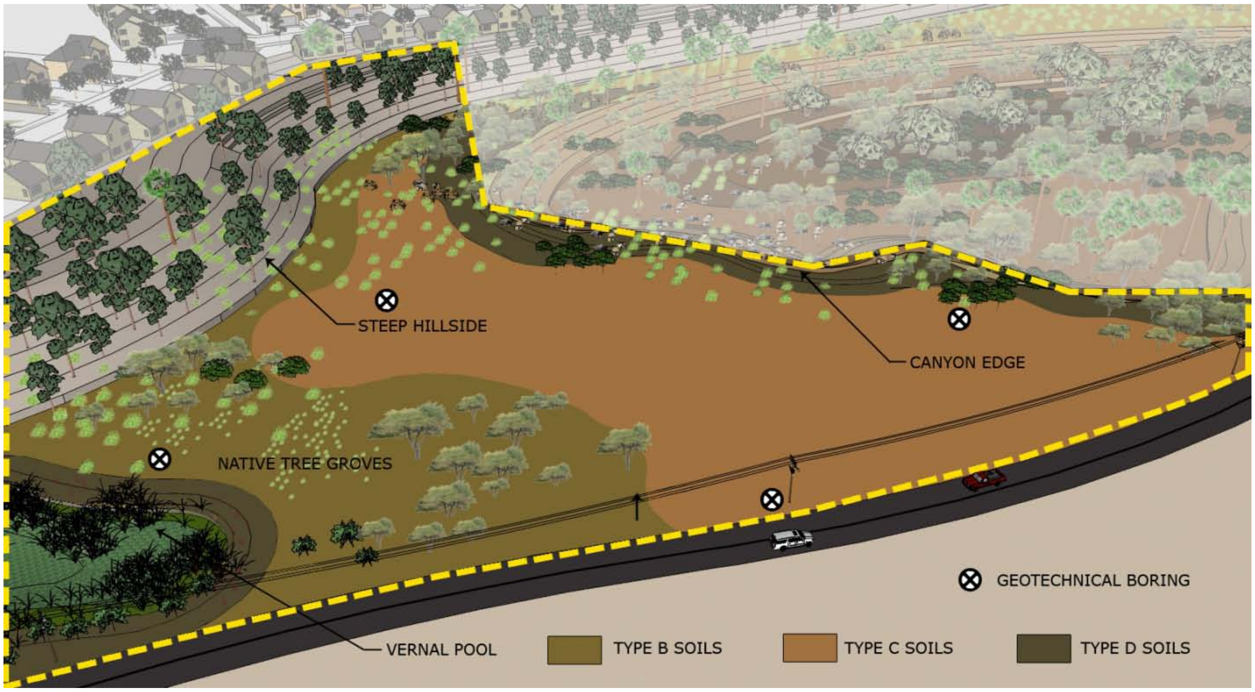


Figure 2-6. Protect natural and sensitive areas (vernal pool, native tree groves, steep hillside, canyon edge) and conduct geotechnical survey to characterize infiltration capacity of soils.

Step 3: Protect Key Hydrologic Areas

Following the concept of LID site planning of using hydrology as the integrating framework, the key hydrologic areas such as hydrologic flow paths and infiltrating soils are protected. To the extent possible, natural hydrologic functions of the site should be preserved. Application of LID techniques results in a hydrologically functional landscape that can function to slow runoff rates protecting receiving waters and reducing the total volume of runoff.

Second only to flow regimes in ensuring proper hydrology, healthy soils, or media often serve as essential elements for achieving LID functions and providing source control for storm water treatment. For example, upper soil layers are conducive to slowly filtering and storing storm water, allowing unit processes such as infiltration, sorption, evapotranspiration, and surface retention to occur.

> ***To Complete Step 3***
>
> - **Protect areas of natural hydrologic function**
> - **Protect possible areas for infiltration**

Site features that should be protected include riparian areas, floodplains, stream buffers, wetlands, and soils with infiltration potential. Using the information collected during the Step 2 soil surveys, more specific locations of soils with greater infiltration rates that are near or on hydrologic flow paths should be protected to avoid or limit net hydrologic impacts. As an example, Figure 2-7 indicates the key hydrologic areas that should be considered for protection. The blue area of possible infiltration should be separated from other site features by placing a construction fence to avoid compaction and promote protection of this site feature. In addition, the areas having a natural hydrologic function either through storage or conveyance should be protected (also see Figure 2-8 in setting site clearing and grading limits).

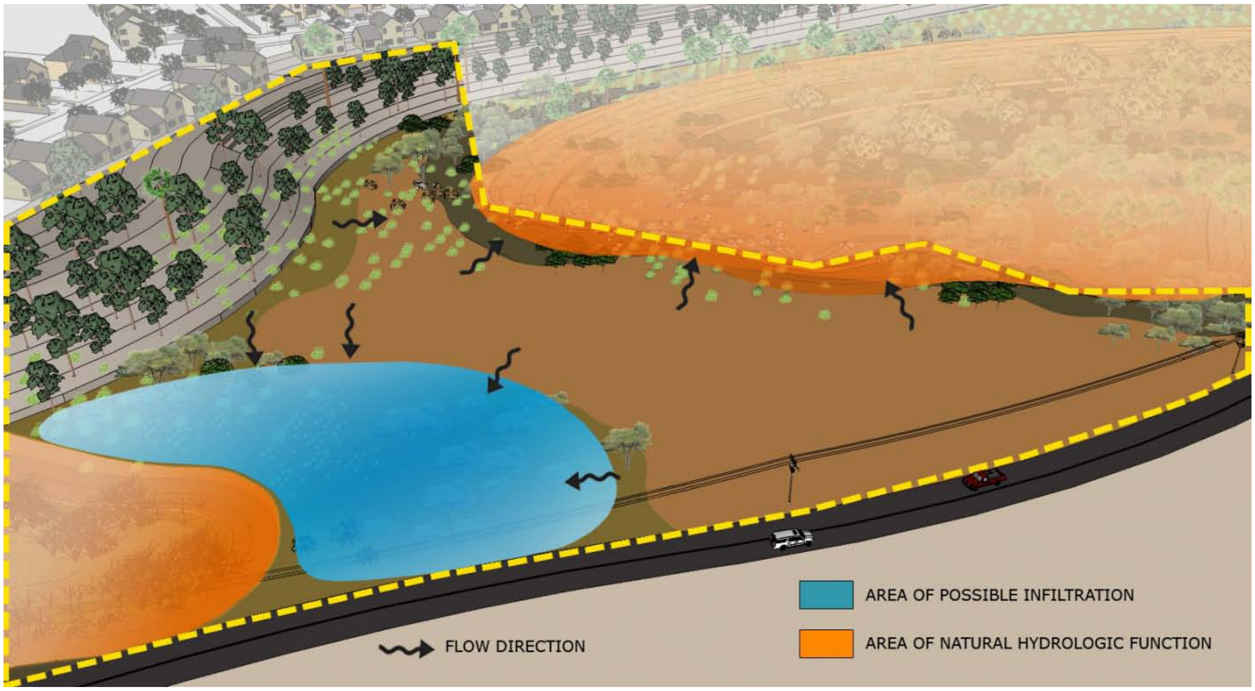


Figure 2-7. Identify and protect key hydrologic areas, such as infiltrating soils (blue area) and vernal pools (orange areas.)

With the conclusion of Phase I, the initial site assessment has been completed. The decisions made regarding LID practices during the site assessment process should be documented to ensure that if changes are required during future Phase II and Phase III, the original design ideas are available for reference. That helps ensure that LID planning is considered during every component of project site planning. For CIP projects, it is recommended to conduct Phase I steps upon receipt of the project from the Preliminary Section. Phase II of site planning, described below, results in a preliminary design plan.

2.1.2 Phase II—Preliminary Design

The result of the second phase of site planning is a completed preliminary design done by conducting steps 4 through 7, below. Working through those steps is an iterative process for designing a preliminary plan that implements LID concepts as fully as possible.

Step 4: Use Drainage and Hydrology as a Design Element

Natural hydrologic functions (i.e., a flow path) should be included as a fundamental component of the preliminary design. Naturally present functions should be retained, or when that is not an available option, natural functions should be replicated with appropriate BMP placement.

Spatial site layout options

Natural hydrologic functions, including interception, depression storage, and infiltration, should be distributed throughout site to the extent possible. In conserving predevelopment and retrofit hydrology, runoff volume, peak runoff rate, flow frequency and duration, and water quality control must be considered. Rainfall abstractions are the physical processes of interception, evaporation, transpiration, infiltration, and storage of precipitation.

To Complete Step 4:

- **Identify the spatial layout of the site using hydrologic flow paths and natural drainage as a feature**
- **Determine approximate infiltration and conveyance and BMP locations**

Runoff flow frequency and duration should try to mimic predevelopment conditions by implementing practices to minimize runoff volume and rate. LID practices also provide pollutant removal processes that enhance water quality treatment for the designed treatment volume.

By setting the development envelope back from natural drainage features, the drainage can retain its hydrologic functions and its water quality benefit to the watershed as shown in the example in Figure 2-8.

Spatial layout should use the natural landforms and hydrologic flow paths identified previously as a major design element of the site. Common elements using that premise include designing open drainage systems to function as both treatment and conveyance devices. Impervious elements such as parking lots, roadways, and sidewalks can be designed on the existing contour to minimize impacts to the natural hydrologic flow path.

Determine potential BMP locations

Storm water management practices can be designed to achieve water quality goals by applying four basic elements, alone or in combination: infiltration, retention/detention, filtration, and evapotranspiration.

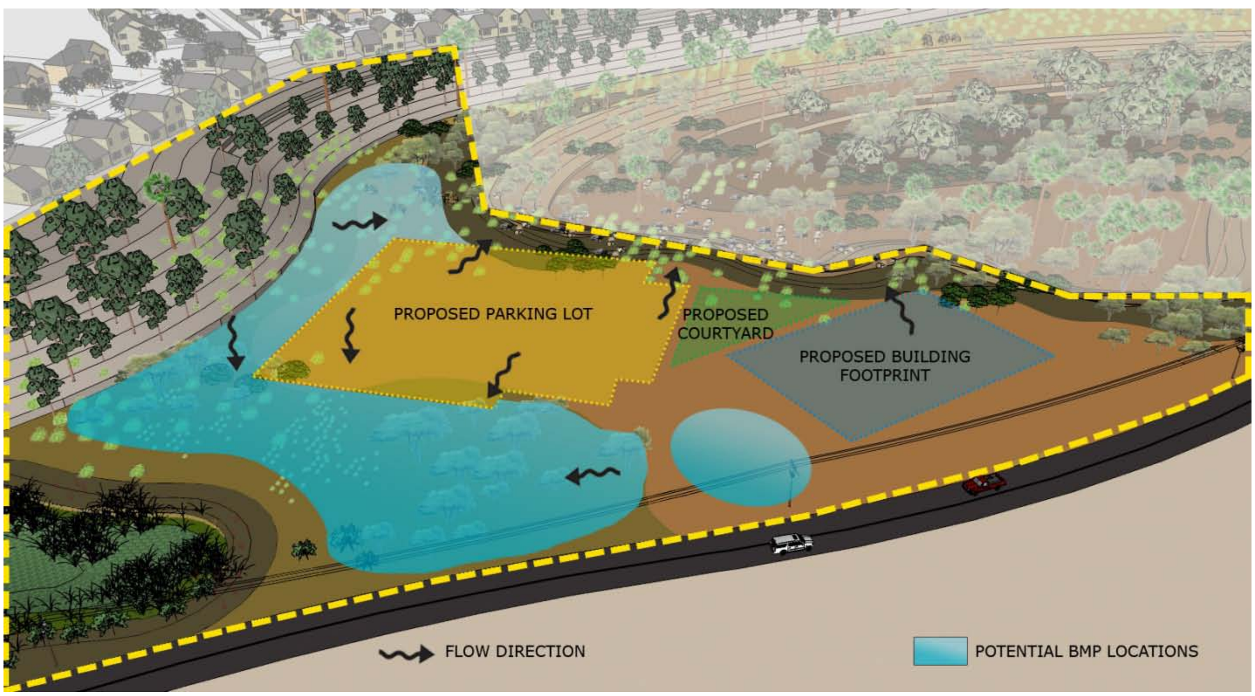


Figure 2-8. Identify ideal locations for LID implementation based on site conditions.

Infiltration systems should be designed to match predevelopment infiltration rates and to infiltrate the majority of runoff. Existing site soil conditions generally determine whether infiltration is feasible without soil amendments. Other site conditions that preclude infiltration are high groundwater tables, steep slopes, or shallow bedrock.

Retention/detention systems are intended to store runoff for gradual release or reuse. Retention/detention basins also allow for evaporation of runoff, and evapotranspiration by plants. They are most appropriate where soil percolation rates are low or where longer retention times are designed into the system.

Biofiltration devices are designed using vegetation to achieve low-velocity flows, to allow settling of particulates and straining of pollutants by vegetation, rock, or media. Pollutant degradation can also occur through biological activity and sunlight exposure. Biofilters are especially useful in treating runoff from parking lots and along highways.

Selecting the appropriate structural BMPs for a project area should be based on site-specific conditions (e.g., land availability, slope, soil characteristics, climate condition, and utilities) and storm water control targets (e.g., peak discharge, runoff volume, or water quality targets).

In the example shown in Figure 2-8, areas are identified that will be developed for parking and building footprints. The figure also indicates ideal locations where LID BMPs can be placed (such as a biofiltration swale and bioretention) and can be incorporated into the natural drainage paths to function as conveyance and treatment LID BMPs. The infiltration opportunities identified previously in Figure 2-7 suggest that the blue oval near the road (Figure 2-8), which is on hydrologic soil group C would be more suitable for a filtration LID BMP, while much of the rest of the potential BMP area is on hydrologic soil group B indicating that this area would be better for infiltration LID BMPs. Note that both filtration and infiltration LID BMPs can also meet landscaping requirements and create features that enhance and beautify the site.

Step 5: Establish Clearing and Grading Limits

Limits of clearing and grading refer to the total site area that is to be developed, including all impervious and pervious areas. The area of development ideally should be in less sensitive locations with respect to hydrologic function and should be outside protected areas and areas containing setback regulations, easements, and utilities.

To Complete Step 5:

- **Define the limits of clearing and grading**
- **Minimize disturbance to areas outside the limits of clearing and grading**

Site fingerprinting refers to site clearing and development with minimal disturbance of existing vegetation and soils. Such techniques include reducing paving and compaction of highly permeable soils; minimizing the size of construction easements and material storage areas; site clearing and grading to avoid removal of existing trees; delineating and flagging the smallest site disturbance area possible; and maintaining existing topography. Figure 2-9 illustrates the use of orange construction fencing to limit clearing and grading areas of more sensitive areas to preserve the natural features, drainage pathways, and maintain infiltration on suitable soils at the example site as identified in previous steps.

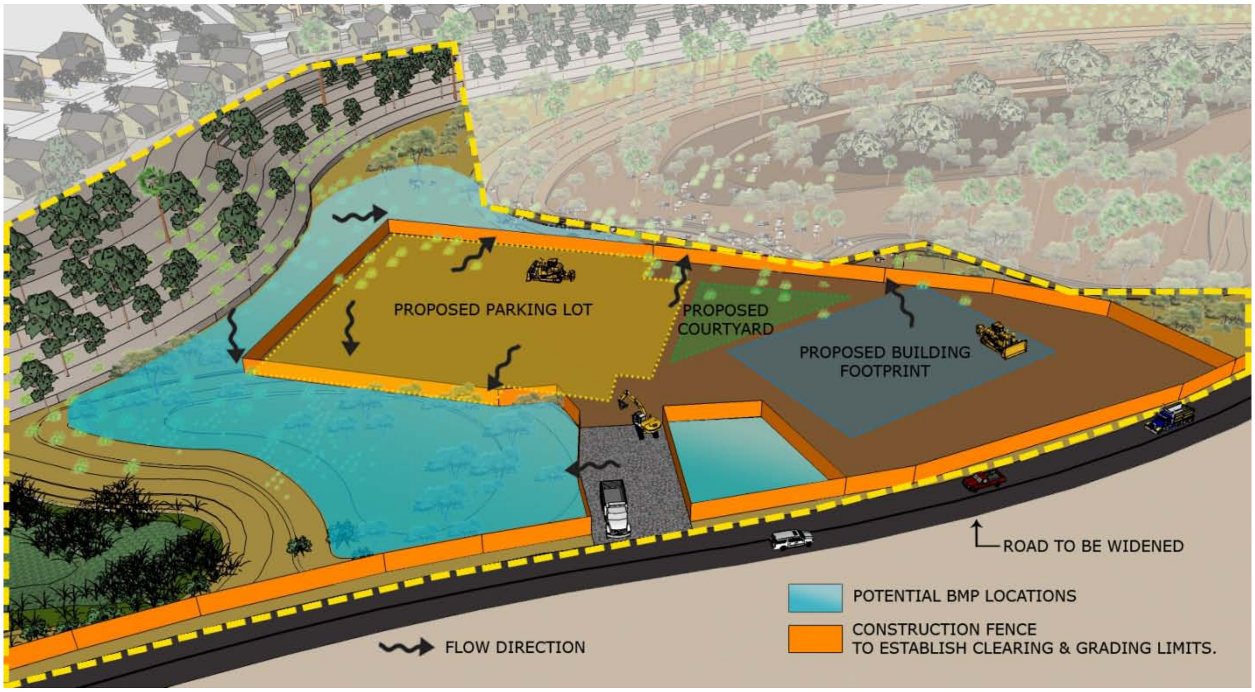


Figure 2-9. Establish grading envelope to protect natural areas and infiltrating soils.

Step 6: Reduce/Minimize Total and Effective Impervious Area

Rainfall that does not infiltrate or pool where it falls results in rainfall runoff. As the imperviousness of the site increases, runoff also increases. Predevelopment runoff, measured as a runoff coefficient, or the ratio of runoff volume to the total amount of rainfall, can be maintained by compensating for the loss of abstraction through planning and design. Such tools can be used to also manage the peak runoff rate.

Impervious area disconnect

Diverting storm water runoff from impervious areas such as rooftops and pavement to adjacent pervious areas can be used to infiltrate storm water runoff and to reduce flow rates (shown in Figure 2-9). Proper design can align pervious surfaces in line with building drainage. Such a technique is also referred to as impervious area disconnect. To reduce the storage and conveyance requirements, the directly connected impervious area of the site should be minimized to the extent practicable. That can be accomplished by increasing the building density by increasing the vertical extent and minimizing the horizontal extent. It can also include using permeable features instead of impermeable including permeable pavement for walkways, trails, patios, parking lots, and alleys; constructing streets, sidewalks, and parking lot aisles to the minimum width necessary. Possible locations for placing impervious area disconnect techniques are shown in the figure below in orange. As shown in the example in Figure 2-10, the medians along either side and in the middle of the roadway provide vegetated pervious areas for minimizing the total impervious area and for infiltration and filtration processes to take place. The figure also demonstrates the use of pervious pavement in the parking lot and alongside the roadway (in red).

> ***To Complete Step 6:***
> - **Investigate the potential for impervious area disconnection**
> - **Evaluate the conceptual design to reduce impervious surfaces**

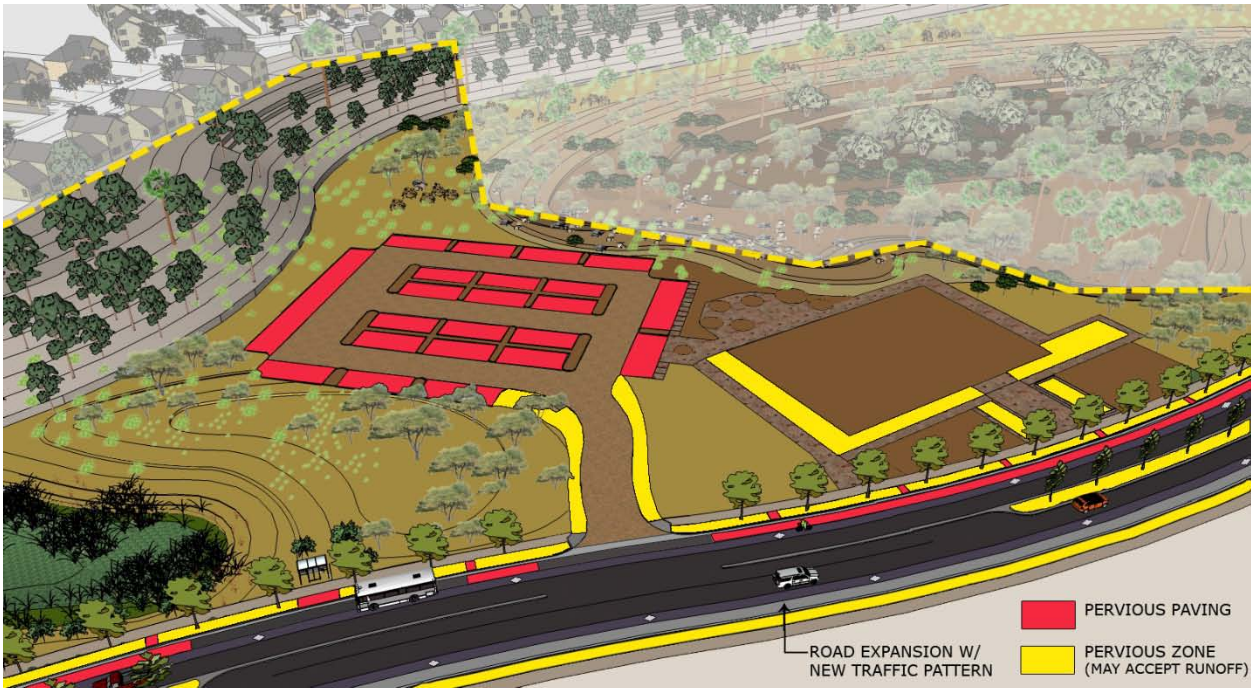


Figure 2-10. Site example demonstrating placement of pervious material (red) and opportunities to minimize connected impervious area (yellow).

Minimize impervious area

Street layouts often can be designed to reduce the extent of paved areas, and street widths can be narrowed and shortened to decrease the total impervious area as long as applicable street design criteria are satisfied. Eliminating curbs and gutters along streets and including curb cuts around parking areas, where consistent with city standards and where appropriate, can promote drainage to on-site pervious areas and decrease directly connected area considerably. Other options include replacing curbs and gutters with roadside vegetated swales and directing runoff from the paved street or parking areas to adjacent LID facilities. Such an approach for alternative design can reduce the overall capital cost of the site development while improving the storm water quantity and quality issues and the site's aesthetic values. Figure 2-10 illustrates the inclusion of pervious paving and bioretention systems with curb cuts along the street right-of-way to demonstrate locations where that can be achieved.

Specific examples of alternative transportation options include narrow paved travel lanes; consolidated travel lanes; increased green parking areas; and horizontal deflectors (chicanes) or intersection pop-outs. Such options can be included for other multi-beneficial purposes such as traffic calming, increased parking spaces, pedestrian safety, and improved aesthetics. Four examples of transportation alternatives are described below.

Narrowed travel lanes: Narrow travel lanes can help reduce impervious area and infrastructure costs, calm traffic in pedestrian-oriented areas, and create room for storm water facilities. Existing roadways can be narrowed but maintained in accordance with established minimum roadway standards. Residential street crossings are often combined with traffic-calming measures that are designed to maintain low vehicle speeds, such as raised crosswalks, chicanes, and gateway narrowing (City of San Diego 2002).

Consolidated travel lanes: Consolidating travel lanes or incorporating on-street parking can increase landscape areas along a street. The increased landscape space could be used for storm water facilities and create space for bike lanes, wider sidewalks, and a more balanced and vibrant streetscape. Convert unused asphalt space next to travel lanes into landscape areas or permeable pavingthat can be used for storm water management.

Increased green parking: Techniques used to reduce the total impervious coverage and consequential runoff from parking lots are broadly referred to as *green parking*. Green parking techniques include minimizing the number and dimension of parking stalls, using alternative pervious pavers where ever suitable, incorporating storm water BMPs such as depressed bioretention islands into parking lot designs, encouraging shared parking and incentivizing structured parking (Figure 2-9). When implemented together as a train of storm water facilities, green parking alternatives reduce volume and the mass of pollutants generated from parking lots, reduce the urban heat island effect, and enhance a site's aesthetics.

Intersection deflectors (chicane): A chicane is a traffic channelization that causes a series of tight turns in opposite directions in an otherwise straight stretch of road (City of San Diego 2002). The combination of narrowed street width and the serpentine path of travel slow traffic (Figures 2-11 and 2-12). On new streets, chicanes narrow the street by widening the sidewalk or landscaped parkway. On streets considered for retrofit, raised islands are installed to narrow the street. Advantages of chicanes include reduced traffic speeds, opportunities for landscaping, and created spaces for storm water management facilities. Chicanes are inappropriate for use on streets classified as collector or higher, bus routes, emergency response routes, where there is a grade that exceeds 5 percent, or where stopping sight distance is limited such as at the crest of a hill.

Figure 2-11. Bioretention incorporated into a horizontal deflector.

Figure 2-12. Bioretention incorporated into a horizontal deflector at an intersection crosswalk.

Intersection pop-outs: Intersection pop-outs are curb extensions that narrow the street at intersections by widening the sidewalks at the point of crossing (City of San Diego 2008a). They are used to make pedestrian crossings shorter and reduce the visual width of long, straight streets (Figure 2-13). Where intersection pop-outs are constructed by widening the landscaped planting strip, they can have positive effects on the visual appearance of the neighborhood and provide more opportunities for storm water controls at the site by facilitating interception, storage, and infiltration. Intersection pop-outs should be designed to properly accommodate bicyclists, transit vehicles, and emergency response vehicles. Intersection pop-outs can be installed on local streets; however, pop-outs are inappropriate on major streets and primary arterials.

Figure 2-13. Example of an intersection pop-out.

In addition to the storm water benefits, inclusion of many of the LID street design features can have multiple benefits. The California Complete Streets Act, passed in 2007 (AB 1385), is intended to enhance roadways to encourage healthy physical activity such as walking or cycling and reduce traffic and greenhouse gas emissions. Complete Streets offer opportunities to incorporate storm water BMPs that are consistent with the act's directive to incorporate additional features that enhance safety and convenience for pedestrians, bicyclists, individuals with disabilities, seniors, and users of public transportation.

Reduced width of road sections can also reduce total site imperviousness. Streets, sidewalks, and parking lot aisles should be constructed to the minimum width possible without compromising public safety and access. Additionally, sidewalks and parking lanes can be limited to one side of the road.

Traffic or road layout can significantly influence the total imperviousness of a site plan. Selecting an alternative road layout can result in a sizeable reduction in total site imperviousness. Alternative road layout options that can reduce imperviousness from the traditional layout pattern use fragmented parallel; warped parallel; loops and cul-de-sac patterns. Guidance on opportunities for alternate street layouts is provided in the city's *Street Design Manual* (2002).

Other transportation opportunities for reducing impervious area include using shared driveways, limiting driveway widths to 9 feet and using driveway and parking area materials that reduce runoff and increase the time of concentration (e.g., grid systems and paver stones).

Several iterations of manipulating site imperviousness can be done to consider natural features, areas of infiltration, and hydrologic pathways to best achieve a balance between necessary imperviousness with disconnected and pervious site features. Once the total area of imperviousness has been minimized, the impervious areas can be incorporated into the site plan.

In Figure 2-9, opportunities for imperviousness reduction and runoff disconnection were identified for both the building site and for alternative transportation options. The sidewalk surrounding the building was disconnected by routing runoff to the pervious landscaped areas surrounding the building (shown in orange) and pervious paving was identified in the low-traffic areas of the parking lot to reduce site imperviousness. Pervious paving was also identified as an opportunity for reduction in impervious area for on-street parking (shown in red) and a median bioswale along with right-of-way bioretention were identified as methods for runoff disconnection (shown in orange).

Step 7: Determine LID BMPs

A BMP is a facility with unit operations that can be made up of one or more unit processes for providing treatment. LID BMPs employ a number of unit processes: settling/sedimentation, filtration, sorption, photolysis, biological processes (bioaccumulation and biotransformation/phytoremediation), and chemical processes (for complete unit processes, see Chapter 3) for pollutant removal. It is important to consider a BMPs unit operations when selecting a BMP to ensure that the management practice will provide the necessary benefits and avoid potential complications.

To Complete Step 7:

- **Determine potential BMPs according to hydrologic and pollutant removal process needs and cost estimates (see Chapter 3)**
- **Repeat Steps 4 through 7 as necessary to ensure that all storm water**

Settling and sedimentation is the physical process of particle separation as a result of a difference in density between the solids and water. Most BMPs use settling to some degree, especially through detention or retention practices such as bioretention.

Filtration is the physical process of separating solids from a liquid media; particles are strained out of passing water by the smaller interstitial space the water flows through in the porous medium. *Sorption* refers to the processes of absorption, an incorporation of a pollutant into a substance of a different state. *Adsorption* is the adherence of a pollutant to the surface of another molecule. Filtration and sorption are common unit processes in a number of BMPs such as swales and planter boxes. Sorption is also referred to under chemical treatment processes.

Floatation is a treatment unit process where the mechanism for pollutant removal is opposite to that in settling and sedimentation. In floatation, the density of pollutants, such as trash and petroleum, is less than that of water. Oil/water separators are the primary BMP practices that use floatation.

Biological treatment processes (bioaccumulation, biotransformation, phytoremediation) are often processes that occur in practices that incorporate soils and plants for pollutant removal via biological transformation or mineralization, pollutant uptake and storage, or microbial transformation. It can also include organisms that consume bacteria. BMPs that can be designed to use such unit processes are bioretention, bioswales, and planter boxes (See Section 3.3).

Chemical treatment processes include sorption, coagulation/flocculation, and disinfection. Chemical characteristics of storm water such as pH, alkalinity, and reduction-oxidation (redox) potential, determine which chemical process is appropriate. Sorptive BMPs generally include engineered media for removing pollutants of concern. Precipitation and disinfection processes require actively adding chemicals to encourage coagulation/flocculation and precipitation or chemicals such as chlorine to mitigate pathogenic microbes in storm water.

Using multiple treatment processes either in individual or multiple practices is called a *treatment train*. Meeting targeted treatment objectives can usually be achieved using a series of LID BMPs in a treatment train. Treatment trains can often be designed along rights-of-way, in parking lots, underground, or incorporated into landscaped areas. LID site planning should result in a treatment train of LID strategies and BMPs to meet treatment and water quality goals. For further details on treatment train BMP implementation, see Section 3.3.

In addition to pollutant removal, LID BMPs provide hydrologic controls by reducing peak flows and volume through processes of infiltration, evaporation, and storage, reproducing predevelopment hydrologic functions.

A number of factors should be considered for choosing appropriate BMPs for a site. For example, the presence of group C or D soils on a site might preclude the use of an infiltration BMP or require the use of an underdrain into the design of infiltration BMPs. Additionally, the low level of precipitation and high evapotranspiration rates usually present in San Diego would likely exclude the use of a BMP requiring a permanent pool, such as a storm water wetland, because precipitation is not great enough to maintain a continual or permanent pool of water. Native vegetation, which is adapted to the local climate and soils, should be used for vegetated BMPs, as much as possible, when soils allow. If native soils are replaced with imported soils to improve infiltration, non-native but drought tolerant plants might be a desired choice. For a table of appropriate vegetation, see Appendix E. Other geotechnical, site-specific considerations include the level of the underlying water table, any existing infrastructure in retrofit designs, and the presence of areas of concern that exhibit soil and groundwater contamination.

The information gathered and organized during Steps 1–6 provide the foundation for selecting BMP types that are most appropriate to meet the stormwater management needs of the site. Chapter 3 of this document summarizes information about specific LID BMPs and provides thorough guidance on selecting appropriate LID BMPs for a site. Table 3-3 succinctly summarizes the selection criteria and should be consulted to assist in the process. Additionally, Appendix B provides substantial detail about BMP applicability and design requirements and can be referenced during the process.

The example shown in Figure 2-14 indicates the approximate type and locations of potential storm water management practices. It is possible that type, size, or location could change according to site construction or other site design changes and requirements.

At the completion of Phase II, the site planning for the project is complete. At that point in the site planning process, the development area should be delineated and the approximate type and potential locations for appropriate BMPs should be identified. The preliminary plan should be documented in addition to the decisions that were made in developing the preliminary plan for future reference and to ensure that the LID planning concepts are carried through to project construction. After the preliminary design is completed, the final design is achieved through identifying the appropriate LID facility type and size for meeting storm water management needs and requirements.

Figure 2-14. Site plan indicating all possible BMP locations (blue areas) and types (annotated).

2.1.3 Phase III—Determine Low Impact Development Final Design

Step 8: Determine Approximate Size of LID BMPs

The level of control that is required for a site to achieve storm water management goals can be determined through a site-specific hydrologic evaluation. The hydrologic evaluation is performed using hydrologic modeling and analysis techniques. A stepwise process is followed to conduct a hydrologic evaluation. The first step is to delineate the watershed and subwatershed areas. The second step is to define the design storm. Next, the type of model to be used should be determined, followed by data collection for predevelopment conditions. Step 5 includes evaluating predevelopment, baseline conditions. Step 6 is to evaluate the site planning benefits, such as decreased impervious coverage, and compare that to baseline conditions. The next step is to evaluate the hydrologic control from implementation of one or more LID BMPs.

To Complete Step 8:

- **Determine the approximate BMP size using the BMP sizing tool (Appendix A)**

For Priority Development Projects, the water quality design storm event is defined in the *Storm Water Standards* manual LID BMPs are also required for Priority Development Projects that infiltrate, reuse, or remove via evapotranspiration the feasible portion of the post project 85^{th} percentile water quality design storm. If infiltration of the design storm is proven to be infeasible, the project should include alternate LID BMPs that filter the portion of design storm that is not infiltrated, reused, or removed via evapotranspiration. If infiltration, reuse, removal through evapotranspiration, and filtration of the entire 85^{th} percentile water quality design storm is proven infeasible, the project must provide treatment control BMPs to treat the portion not treated via LID BMPs.

For specific technical guidance on appropriate BMP sizing, see Appendix A of this document.

Step 9: LID Final Design

Following iterations of Steps 4–7 and BMP sizing in Step 8, additional conventional storm water control techniques can be added to the site as necessary to meet site drainage and other requirements (Figure 2-15). Review of the earlier documentation of decisions made during planning phases should also be conducted to ensure that the intent of the LID planning principles were carried through to the final design. The iterative review process can result in more or less area required for storm water management. Notice that in Figure 2-15, the iterative process resulted in the elimination of planter boxes at the base of the building as the other LID BMPs provided the required volume of capture.

To Complete Step 9:

- **Integrate conventional stormwater management needs**
- **Verify geotechnical and drainage requirements have been met**
- **Complete BMP designs such as finish details and notes**
- **Complete the site plans**

The key to finalizing the BMP design process is to consult the design instructions for the selected BMP types in Appendix B of this document. By following those instructions and using the example engineering drawing templates in Appendix C, the designer can develop final details, plan views, cross sections, profiles, and notes. The example shown in Figure 2-14 illustrates the final site layout, including the properly sited and sized BMP locations.

Figure 2-15. Completed site plan including iterations of Steps 4–7 and BMP sizing completed.

Completing Step 9 concludes Phase III of the design process. Chapter 4 provides considerations for implementing the chosen BMPs that should be reviewed as part of the final design process and final construction. BMP construction, inspection, and operation and maintenance are discussed there.

2.2 References

City of San Diego. 2002. *Street Design Manual*.

City of San Diego. 2008a. *City of San Diego General Plan*.

Prince George's County. 1999. *Low Impact Development Design Strategies, An Integrated Approach*. EPA-841-B-00-003. Prepared for the U.S. Environmental Protection Agency, Washington, DC, by Prince George's County, MD, Department of Environmental Resources, Programs and Planning Division.

San Diego County. 2007. *Low Impact Development Handbook, Stormwater Management Strategies*. County of San Diego, Department of Planning and Land Use, San Diego, CA.

SDRWQCB. 2007. *Waste Discharge Requirements for Discharges of Urban Runoff from the Municipal Separate Storm Sewer Systems (MS4) Draining the Watersheds of the County of San Diego, the Incorporated Cities of San Diego County, the San Diego Unified Port District, and the San Diego County Regional Airport Authority*. Order No. R9-2007-0001. San Diego Regional Water Quality Control Board, San Diego, CA.

USEPA (U.S. Environmental Protection Agency). 2000. *Low Impact Development (LID), A Literature Review*. EPA-841-B-00-005. U.S. Environmental Protection Agency, Washington, DC.

3 LID Selection—Structural BMPs

Structural BMPs are implemented to capture, infiltrate, filter, and treat storm water runoff from a project area to meet the required level of controls in terms of water quantity and quality. Selecting the appropriate structural BMPs for a project area should be based on site-specific conditions (e.g., land availability, slope, soil characteristics, climate condition, and utilities) and storm water control targets (e.g., peak discharge, runoff volume, or water quality controls). Selected BMPs should be sized according to the numeric sizing requirements for treatment control BMPs that are presented in the city's *Storm Water Standards: A Manual for Construction & Permanent Storm Water Best Management Practices Requirements* (shortened throughout as Storm Water Standards)(City of San Diego 2008b) and Appendix B. A general description for each BMP is presented in this chapter. For a more detailed description and design specifications for each BMP, see Appendix B.

3.1 Selecting Structural BMPs

Selecting the proper BMP and BMP location depends on site-specific precipitation patterns, soil characteristics, slopes, existing utilities, and any appropriate setbacks from buildings or other infrastructures as determined in Step 1 of Chapter 2. Further, selecting applicable and feasible LID BMPs will depend on the type of project, its characteristics, and the planning elements associated with the location of the project.

A general checklist for characterizing drainage areas and BMPs is below.

Drainage Area Characterization

- Total area
- Percent imperviousness: total and directly connected
- Soil characteristics
- Depth to water table
- Topography, slope
- Land cover and land use (existing and future)
- Utilities
- Development history and existing buildings
- Storm drainage systems, location of outfalls
- Projected roadway alignment modifications, roadway expansion
- Rainfall records and statistical analysis of storm characteristics and frequency

BMP Characterization

- Type of BMP
- BMP surface area
- Surrounding soil characteristics
- Depth to water table
- Design target(s) according to any combination of volume, flow, or water quality control criteria
- Inlet and outlet features
- Primary storm water treatment unit process

A BMP selection matrix is presented at the end of this chapter and is based on the characterization information for each BMP, mainly tributary area, area slope, depth to seasonal high water table, soil characteristics and infiltration rate, and setbacks.

3.2 Storm Water Runoff Requirements for BMP Sizing

The target capacity of a structural BMP should be established using the characterization of the drainage area and local hydrology. Structural BMPs should be designed by applying either volume- or flow-based design criteria. Numeric sizing requirements for treatment BMPs based on storm water volume and flow controls are presented in section the city's *Storm Water Standards* (City of San Diego 2008b).

Further details regarding BMP sizing and example calculations are in Appendix A.

3.3 General Description of BMP Practices

Objectives of storm water LID BMPs are to first slow and filter runoff using natural features. Infiltration and evapotranspiration, along with retention for reuse, offer additional benefits of the LID BMPs. LID BMPs are designed to remove or significantly reduce pollutants in storm water runoff. Pollutants of concern include sand, silt, and other suspended solids; trash; metals such as copper, lead, zinc; nutrients such as nitrogen and phosphorus; certain bacteria and viruses; and organics such as petroleum hydrocarbons and pesticides. Methods of pollutant removal include sedimentation settling, filtration, plant uptake, ion exchange, adsorption/absorption, and bacterial decomposition. Floatable pollutants such as oil, debris, and scum can be removed with separator structures. Table 3-1 indicates the major or dominant unit processes used for pollutant removal and secondary and optional processes based on designs of BMPS that incorporate those unit processes.

LID BMPs often provide multiple unit processes, depending on design. Table 3-2 shows the removal processes for each LID BMP type including the major functions, followed by secondary and possible optional unit operations, depending on design. Structural treatment control BMPs can be used singularly or in series as integrated management practices to achieve the desired level of pollutant removal. Using a combination of multiple structural LID BMPs with multiple treatment processes in one system is called a treatment train. Meeting targeted treatment objectives can usually be achieved using a series of storm water treatment systems in a treatment train. That approach can apply to new designs and in retrofitting existing storm water treatment facilities. Such systems can often be designed along rights-of-way, in parking lots, or incorporated into landscaped areas to fit in relatively small or long, linear areas. An

Table 3-1. Water quality unit processes for pollutant removal

Pollutants	Removal processes					
	Settling	Filtration/straining	Sorption	Bioaccumulation	Biotransformation/ phytoremediation	Other (e.g., photolysis; volatilization)
Sediment	+	+	–	–	–	–
Nutrients	+	o	+	+	+	–
Trash	+	+	–	–	–	o
Metals	+	–	+	+	+	–
Bacteria	+	(+)	–	+	+ &	+ *
Oil and grease	–	+	+	o	+	+
Organics	+	o	o	+	+	+

Note: ( ) optional function; + major function; o secondary function; – insignificant function; & consumed by other organisms; * photolysis

Table 3-2. Hydrologic and water quality unit processes for LID BMPs

Structural BMPs	Hydrologic controls			Removal processes					
	Storage/detention or flow attenuation	Infiltration	Evapotranspiration	Settling	Filtration	Sorption	Bioaccumulation	Biotransformation/ phytoremediation	Other (e.g., photolysis; volatilization)
Bioretention	+	(+)	o	o	+	o	+	+	(o)
Bioswale	(+)	(+)	o	o	o	o	o	o	(o)
Permeable pavement	+	(+)	–	–	+	–	–	–	–
Infiltration trench	+	+	(o)	o	+	o	–	–	–
Planter boxes	+	(+)	o	o	+	o	(+)	(+)	(o)
Sand filter	o	(o)	–	–	+	(o)	–	–	(o)
Vegetated filter strip	–	+	+	o	o	o	–	–	–
Vegetated swale	(o)	(o)	o	+	+	–	–	–	–
Cisterns/rain barrels	+	–	–	–	–	–	–	–	–

Note: ( ) optional function; + major function; o secondary function; – insignificant function existing storm water treatment facilities. Such systems can often be designed along rights-of-way, in parking lots, or incorporated into landscaped areas to fit in relatively small or long, linear areas. An example of a four-stage design is to have filter strips drain to swales that convey the storm water to a bioretention area that uses a forebay primarily for settling. A treatment train can achieve most, if not all, removal processes in the designed treatment system. Effectiveness of individual or multiple integrated practices can be assessed in terms of removal of substances or groups of pollutants.

Structural treatment control BMPs can be online or offline from the storm drainage systems, used singularly or in combination, or shared by multiple drainage areas, pursuant to the following criteria (City of San Diego 2008b):

- All structural treatment control BMPs must infiltrate, filter, or treat the required runoff volume or flow before discharging to any receiving waterbody supporting beneficial uses.
- Post-construction structural treatment control BMPs for a single priority development project must collectively be designed to comply with the numeric sizing treatment standards.
- Shared BMPs must be operational before the use of any dependent development or phase of development. Shared BMPs will be required to treat only the dependent developments or phases of development that are in use.
- Interim storm water BMPs that provide equivalent or greater treatment than is required can be implemented by a dependent development until each shared BMP is operational. If interim BMPs are selected, the BMPs will remain in use until permanent BMPs are operational.

From the city's *Storm Water Standards* (City of San Diego 2008b), the Priority Development Projects' managers will select a single or combination (treatment train) of structural BMPs to maximize pollutant removal for the pollutant(s) of concern using the following criteria:

- The project has the potential to discharge to an impaired waterbody, as listed by the Clean Water Act section 303(d).
- If the project is anticipated to discharge a pollutant for which the receiving water is listed as impaired, select one or more BMPs to target the removal of the specific pollutants. Downstream receiving waters of the project will also be given consideration when selecting treatment BMPs.
- If the project's receiving waters are not listed as impaired, select one or more BMPs that maximize the removal of the pollutants the project is anticipated to generate.

Identifying and selecting BMPs on the basis of the pollutant(s) of concern is a function of site constraints, properties of the pollutant(s) of concern, BMP performance, stringency of permit requirements, and watershed-specific requirements such as TMDLs. Pollutants of concern are especially important in water-limited stream segments and must be carefully reviewed in relationship to unit processes and potential BMP performance. When no specific pollutant has been targeted for removal, regulators can address pollutant removal through flow- or volume-based requirements or both. Under such circumstances, cost can become an important deciding factor in BMP selection.

3.4 Infiltration BMPs

Infiltration BMPs are storm water treatment and control BMPs that are designed to encourage percolation and groundwater recharge. Infiltration BMPs mainly use the interaction of the chemical, physical, and biological processes between soils and water to filter out sediments and sorb constituents from storm water (FHWA 2002). As storm water percolates into the ground, fine material suspended in storm water is captured in the soil.

Infiltration BMPs have a number of important limitations and cannot be used in all locations. Native soils must be tested to determine if the infiltration rates of the soils are acceptable for infiltration BMPs. Infiltration BMPs are not applicable at locations where groundwater flow would prevent storm water infiltration from draining between storm events or where groundwater pollution potential is high because of high pollution loads (*hotspots*), sensitive groundwater areas (*areas of concern*), or a high groundwater table. Pollution prevention should be carefully implemented to protect groundwater quality at sites where infiltration practices are used. It is important that infiltration BMPs have sufficient clearance from the bottom of the BMPs to the seasonal high groundwater level or any impermeable soil layers. An internal water storage zone (IWSZ) can be incorporated into any BMP with an underdrain to improve nitrogen removal and allow infiltration in hydrologic type C and D soils. An IWSZ can be designed as either a permanent zone or a variable zone with the upturned elbow at the outlet of the underdrain. Such a created sump area can store storm water and release it slowly through infiltration/exfiltration and evapotranspiration. When the BMP is constructed, care must be taken to place the underdrain (i.e., height from the bottom) so as to maintain the desired IWSZ. Details on designing an IWSZ are in Appendix C.

3.4.1 Bioretention

Bioretention BMPs are small-scale, shallow, vegetated, depressed areas with a soil (often engineered soil media) and plant-based filtration device that removes pollutants through a variety of physical, biological, and chemical treatment processes. Such BMPs usually consist of a grass buffer strip, media bed, ponding area, mulch layer, and planting soil media. The depressed area is planted with small- to medium-sized vegetation including trees, shrubs, and groundcover that can withstand urban environments and tolerate periodic inundation and dry periods. Pretreatment of storm water flowing into bioretention BMPs is recommended to remove large debris, trash, and larger particulates and ponding areas can be designed to increase flow retention and flood control capacity.

Bioretention

- Area Typically Served (acres): < 5
- Area Required for BMP: 4%–8%
- Major Maintenance: Mowing/plant replacement
- Effective Life Time: 5–20 years
- Pollutant Removal

Sediments: High	Nutrients: Medium
Trash: High	Metals: High
Bacteria: High	Oil & Grease: High
Organics: High	

Bioretention is well suited for removing storm water pollutants from runoff, particularly for smaller storm events. Bioretention units are generally used to treat storm water runoff from impervious surfaces in urbanized areas. Bioretention BMPs can be used to partially or completely meet storm water management requirements on smaller sites. Bioretention will typically need to be used in conjunction with other structural controls, however, to ensure flood protection.

It might be preferable to include bioretention units for storm water management in median strips, parking lot islands, and rights-of-way along paved roadways. Figure 3-1 shows an example of implementing bioretention BMPs in the right-of-way with a horizontal restriction layer. Actual examples of bioretention applications are shown in Figure 3-2 and Figure 3-3.

Figure 3-1. Bioretention in the right-of-way with a horizontal restriction layer.

Generally, bioretention BMPs should have the following design features:

- Preferably located upland from inlets that receive sheet flow from impervious areas.
- On sites with soils of sufficient percolation capacity or a suitable outlet for an underdrain system to fully drain the BMP in 24 to 48 hours. Bioretention can also be effective in areas with low infiltration capacity soils with the use of an underdrain system.
- Native and noninvasive plant species that have tolerance for urban environments, frequent inundation, and San Diego's arid climate, which maximizes overall effectiveness of bioretention BMPs.
- An overflow structure with non-erosive overflow channel must be incorporated to safely pass flows that exceed the capacity of the BMP.
- Incorporating pretreatment such as a grass filter strip, sediment forebay, or grass channel upstream of the practice will enhance the treatment capacity of the bioretention unit.

Figure 3-2. Bioretention incorporated into a common area.

Figure 3-3. Bioretention incorporated into traditional parking lot design.

3.4.2 Bioswales

Bioswales are shallow, open channels that are designed to treat runoff primarily through infiltration and remove larger pollutants by filtering water through vegetation in the channel. Bioswales can serve as conveyance for storm water and can be used in place of traditional curbs and gutters; however, when compared to traditional conveyance systems, the primary objective of bioswales is infiltration and water quality enhancement rather than conveyance (except for excessive flow).

Bioswales can have ranges of design variations with or without check dams, subsurface storage media, and underdrains. Bioretention media can be added to a bioswale to improve water quality, reduce the runoff volume, and modulate the peak runoff rate, while also providing conveyance of excess runoff.

Bioswale

- Area Typically Served (acres): 2–4
- Area Required for BMP: 10%–20%
- Major Maintenance: Mowing
- Effective Life Time: 5–20 years
- Pollutant Removal

Sediments: High	Nutrients: Medium
Trash: High	Metals: High
Bacteria: High	Oil & Grease: High
Organics: High	

Bioswales are well suited for use in the right-of-way of linear transportation corridors and provide a conveyance system with the added benefits of filtration and infiltration of runoff, depending on design (Figure 3-4). Bioswales with subsurface bioretention media provide enhanced infiltration, water retention, and pollutant-removal capabilities.

Figure 3-4. Bioswale along a parking lot.

Runoff reduction is achieved by interception, infiltration to the soils, and evapotranspiration by the vegetation. Pollutants are removed through filtration, bio-uptake, sedimentation, and sorption. As a design option, higher storm water quantity and quality controls can be achieved in larger bioswales by using check dams to pond the water for temporary storage and added infiltration in the system. To prevent sediments from accumulating, vegetated swales can be used with pretreatment BMPs such as filter strips, vegetated filters, or other sediment-capturing devices, especially in areas of high sediment loads or where the site is not entirely stabilized.

General guidelines for applying bioswales are below:

- Bioswales are applicable to sites with either soils of sufficient percolation capacity or a suitable outlet for an underdrain system to fully drain the water in 24 to 48 hours.
- Native and noninvasive plant species that tolerate urban environments and frequent inundation are the best for the overall effectiveness of bioswales.
- As conventional swales, bioswales should be designed with sufficient sidewall depth to safely convey runoff from major storms without out-of-bank flow.
- Incorporating pretreatment such as a grass filter strip, sediment forebay, or grass channel upstream of the swales may be required to ensure effective treatment.

3.4.3 Permeable Pavement

Conventional pavement results in increased surface runoff rates and volumes. However, permeable pavements work by allowing streets, parking lots, sidewalks, and other impervious covers to retain their natural infiltration capacity while maintaining the structural and functional features of the materials they replace (Figure 3-5). Permeable pavements contain small voids that allow water to drain through the pavement to an aggregate reservoir and then infiltrate into the soil. If the native soils below the permeable pavements do not have enough percolation capacity, underdrains can be included to direct the storm water to other downstream storm water control systems. Permeable pavement BMPs can be developed using modular paving systems (e.g., concrete pavers, grass-pave, or gravel-pave) or poured in place solutions (e.g., porous concrete or permeable asphalt).

Permeable Pavement

- Area Typically Served (acres): 2–4
- Area Required for BMP: N/A
- Major Maintenance: Semiannual vacuum cleaning/sweeping
- Effective Life Time: 15–20 years
- Pollutant Removal

Sediments: High	Nutrients: Low
Trash: High	Metals: Medium
Bacteria: Medium	Oil & Grease: High
Organics: Low	

Permeable pavement is used to reduce the volume of storm water runoff by converting an impervious area to a treatment unit. The aggregate sub-base can provide water quality improvements through filtering and enhance additional chemical and biological processes. The volume reduction and water treatment capabilities of permeable pavements are effective at reducing storm water pollutant loads.

Figure 3-5. Permeable pavers in an angled parking area

Permeable pavement is typically used to replace traditional impervious pavement for most pedestrian and vehicular applications. However, permeable pavement is generally not suited for areas with high traffic volumes or loads. Composite designs that use conventional asphalt or concrete in high-traffic areas adjacent to permeable pavements along shoulders or in parking areas can be implemented to ensure appropriate functions in both transportation systems and storm water management requirements. Generally, permeable pavements are most often used in constructing pedestrian walkways, sidewalks, driveways, low-volume roadways, and parking areas of office buildings, recreational facilities, and shopping centers.

General guidelines for applying permeable pavement BMPs are below:

- Permeable pavements can be substituted for conventional pavements in parking areas, low-volume/low-speed roadways, pedestrian areas, and driveways if the grades, native soils, drainage characteristics, and groundwater conditions of the paved areas are suitable.
- Permeable pavement is not appropriate for storm water hotspots where hazardous materials are loaded, unloaded, or stored.
- The granular capping and subbase layers should provide adequate construction platform and base for the overlying pavement layers.

- If permeable pavement is installed over low-permeability soils, an underdrain should be installed to ensure water removal from the subbase reservoir and pavement.
- The infiltration rate of the soils or an installed underdrain should drain the subbase in 24 to 48 hours.
- An impermeable liner can be installed between the subbase and the native soil to prevent water infiltration when clay soils have a high shrink-swell potential or if a high water table or bedrock layer exists.
- Measures should be taken to protect permeable pavements from high sediment loads, particularly fine sediment.
- Appropriate pretreatment BMPs for run-on to pavement include filter strips and vegetated swales and bioswales.

3.4.4 Infiltration Trench

Infiltration trenches are narrow, linear BMPs that have similar functions as bioretention areas with variable surface materials, including rock or decorative stone, designed to allow storm water to infiltrate into subsurface soils. Runoff infiltrates into the soils and is stored in the void space between the stones. Infiltration trenches can reduce runoff volume and remove fine sediment and associated pollutants. Pretreatment using vegetated buffer strips or vegetated swales and bioswales is important for limiting the amount of coarse sediment entering the trench that can clog and render the trench ineffective. Figure 3-6 shows an example of infiltration trench between curb and trail/sidewalk.

Infiltration Trench

- Area Typically Served (acres): 2–4
- Area Required for BMP: 2%–4%
- Major Maintenance: Sediment/debris removal
- Effective Life Time: 10–15 years
- Pollutant Removal

Sediments: High	Nutrients: MediumHigh
Trash: High	Metals: High
Bacteria: High	Oil & Grease: High
Organics: High	

Infiltration trenches are designed to reduce the volume of runoff while enhancing water quality through pollutant-removal mechanisms such as filtration and sorption. They also allow for groundwater recharge. Infiltration trenches must be used with pretreatment systems such as vegetated filter strips or other sediment-capturing devices to prevent sediments from clogging the trench.

Figure 3-6. Infiltration trench between the curb and trail/sidewalk.

Infiltration trenches are well suited for roadway medians or shoulders and for locations with limited available space.

General guidelines for applying infiltration trenches are below:

- Infiltration trenches require more than 0.5 inch per hour infiltration.

- For sites with clay-based or compacted soils, the infiltration trench can be designed with subsurface storage sized to store the water quality volume from its contributing drainage area. In combination with subsurface storage, or as an alternative, an underdrain could be used as an outlet.
- Infiltration units are applicable to sites with soils of sufficient hydraulic conductivity or suitable outlet for an underdrain system to fully drain the water in 24 to 48 hours.
- Pretreatment is suggested for infiltration trenches to remove sediments, prevent clogging, and allow for expected performance. Vegetated filter strips and bioswales are commonly used for pretreatment. A pea gravel apron can also be used for pretreatment before the infiltration trench.

3.5 Filtration BMPs

Filtration BMPs have been used widely because of their relatively small footprint and moderate physical requirements (FHWA 2002). Filtration BMPs are primarily used to physically strain runoff and effectively trap debris and particulates from washing off-site or downstream. Filtration BMPs also enhance the absorption of pollutants in the filter media (soil or plant media), providing further water quality improvements. For example, surface or underground filters that use sand, peat/sand, or composite filter media are classified as a filtration practice because the water quality is improved as water flows through the media.

Filtration BMPs are designed to provide storm water quality management because they provide physically based straining and filtration through smaller pore spaces. Such BMPs provide areas for sediment retention to remove larger particles and debris; further downstream, the filter media can remove or reduce fine and some soluble constituents through sorptive processes. Most filtration BMPs are designed to treat only a portion of a storm event, usually based on volume- or flow-based designs; however, because of their versatility, filtration BMPs can be incorporated into a wide range of landscapes including roadway corridors, rights-of-way, sidewalks, and areas with limited space, certain filtration BMPs (i.e., sand filters) can be implemented underground. Filtration BMPs can also be improved with the inclusion of vegetation, a process referred to as *biofiltration*.

3.5.1 Planter Boxes

A planter box is a precast concrete box containing soil media and vegetation that functions similarly to a small biofiltration BMP but is completely lined with an incorporated underdrain as shown in Figure 3-7. Planter boxes have been implemented around paved streets, parking lots, and buildings to provide initial storm water treatment to runoff from the impervious areas (Figure 3-8). Roof downspouts are directed to planter boxes, which then attenuate and filter the runoff. Planter boxes provide on-site storm water treatment options, green space, and natural aesthetics in tightly confined urban environments.

Planter Box

- Area Typically Served (acres): < 1
- Area Required for BMP: 0.5%–3%
- Major Maintenance: Debris/sediments removal
- Effective Life Time: 5–20 years
- Pollutant Removal

Sediments: High	Nutrients: Medium
Trash: High	Metals: High
Bacteria: High	Oil & Grease: High
Organics: High	

Planter boxes are usually implemented around buildings and along sidewalks. Planter boxes intercept and filter runoff from adjacent impervious areas before it enters the storm water conveyance system. Such an application offers an ideal opportunity to minimize directly connected impervious areas in highly urbanized areas. The vegetation and soil media in the planter box provide similar functionalities of bioretention BMPs.

Figure 3-7. Completely lined planter box in right-of-way.

Planter boxes can fully control runoff from small storms. Runoff from large storms, however, should bypass the planter box to the storm water conveyance system. Small trees and shrubs that are tolerant to frequent inundation conditions are suitable for planter boxes (Figure 3-8).

General guidelines for applying planter boxes are below:

- Planter boxes are installed immediately upstream of standard storm water inlets or very close to roof downspouts.
- Planter boxes can be used for retrofits to provide storm water quality improvements. The practices can be also used in new construction in areas where space is a premium or where infiltration is not feasible.

Figure 3-8. Planter boxes in the right-of-way.

- Elevations of the inlet and underdrain must ensure gravity flows to the main storm water conveyance system.
- Planter boxes are intended for controlling small storms but not larger events. Runoff from larger events should be bypassed to the adjacent storm water conveyance system.
- As upstream storm water control devices, pretreatment is typically not incorporated into the design of planter boxes.

3.5.2 Sand Filter

A sand filter is a treatment system that is used to remove particulates and solids from storm water runoff by facilitating physical filtration (Figure 3-9). It is a flow-through system designed to improve water quality from impervious drainage areas by slowly filtering runoff through sedimentation and filtration chambers. With increased detention time, the sedimentation chamber allows larger particles to settle to the bottom of the chamber. The filtration chamber removes pollutants and enhances water quality as the storm water is strained through a layer of sand. The treated effluent is collected by underdrain piping and discharged to the existing storm water collection system or another BMP.

Sand Filter

- Area Typically Served (acres): 2–5
- Area Required for BMP: 2%–3%
- Major Maintenance: Biannual media cleanout
- Effective Life Time: 5–20 years
- Pollutant Removal

Sediments: High	Nutrients: Low
Trash: High	Metals: High
Bacteria: Medium	Oil & Grease: High
Organics: High	

Sand filters are suitable for placement in densely developed, highly impervious areas, especially those in which the construction of vegetated BMPs is not practical. Sand filters should not receive direct runoff from pollutant hotspots (e.g., industrial sites, service stations) without pretreatment. Additionally, sand filters are not appropriate in areas with potentially high sediment loadings unless significant pretreatment is provided. The maximum flow rate through the sand filter is greatly reduced by sediment deposition on the surface.

General guidelines for applying sand filters are below:

- Sand filters are designed to treat runoff from small, impervious drainage areas and are ideal for sites with limited open space.
- A sand filter should have sufficient hydraulic head to allow storm water to flow through the filter by gravity.
- Filtered storm water from sand filters is usually allowed to infiltrate into the underlying soils, although an underdrain or adequate subsurface storage might be needed if soils are not suitably permeable.

Source: NCSU-BAE

Figure 3-9. A sand filter.

- Incorporate bypass flow for extreme events in which the storm water flow rate to the system exceeds the capacity of the sand filter by diverting through an overflow structure.
- Pretreatment for sand filters consists of a filter strip and plunge pool or sedimentation basin to remove sediments and particulates before the storm water enters the filter.

3.5.3 Vegetated Filter Strip

Vegetated filter strips are bands of dense, permanent vegetation with a uniform slope, designed to provide pretreatment of runoff generated from impervious areas before flowing into to another BMP as part of a treatment train. When on soils with high percolation rates, vegetated filter strips can also provide infiltration, improving volume reduction. Increased infiltration can decrease the necessary horizontal length. Such characteristics make it ideal to use vegetated filter strips as storm water BMPs around roadside shoulders or safety zones. An example of vegetated filter strip along paved area is shown in Figure 3-10.

> **Vegetated Filter Strip**
> - Area Typically Served (acres): < 5
> - Area Required for BMP: 25%
> - Major Maintenance: Mowing
> - Effective Life Time: 20–50 years
> - Pollutant Removal
>
> | | |
> |---|---|
> | Sediments: High | Nutrients: Low |
> | Trash: Medium | Metals: High |
> | Bacteria: Low | Oil & Grease: High |
> | Organics: Medium | |

Vegetated filter strips are implemented for improving storm water quality and reducing runoff flow velocity. As water flows in a sheet across the vegetated filter strip, the vegetation filters out and settles the particulates and constituents, especially in the initial flow of storm water. Plants in vegetated filter strips then infiltrate storm water into the soils or take up pollutants. Removal efficiency is often dependent on the slope, length, gradient, and biophysical condition of the vegetation in the system.

Vegetated filter strips are well suited for treating runoff from roads, parking lots, and disconnected building downspouts. The BMPs are intended to treat sheet flow from adjacent impervious areas and can be effective at removing sediments and other pollutants. In a storm water treatment train, vegetated filter strips often serve as pretreatment for other BMPs such as bioretention units, bioswales, or infiltration trenches by decreasing arriving sediment loads and reducing flow velocity.

Source: CASQA

Figure 3-10. Vegetated filter strip

Reductions in runoff volume from small storms can be achieved if the soils have sufficient percolation capacity. As water sheet flows across a vegetated strip, the contact time needs to be sufficient enough for infiltration to occur. Vegetated filter strips can provide reliable water quality benefits for relatively low costs and low to moderate maintenance, but they function best as part of a treatment train. The BMP can have an appreciable aesthetic appeal if it is properly designed, constructed, and maintained.

General guidelines for applying vegetated filter strips are below:

- Vegetated filter strips are typically used to treat drainage from a relatively small, impervious area.
- The toe and top of the slope should have only a minor slope (as flat as possible) to encourage sheet flow and prevent erosion. If necessary, vegetated filter strips can include energy dissipaters or level spreaders to generate diffuse flow and to reduce the velocity of the storm water from impervious areas before it enters the filter strip.
- Analysis of the existing soils is highly recommended at the start of the design phase to determine infiltration rates. If the soil is high in clay content, infiltration rates can be improved with soil amendments such as compost (for additional information on soil amendments, see Chollak and Rosenfeld 1998). Soils unsuitable for sustaining healthy, dense, vegetative cover should be avoided.

- If necessary, vegetated filter strips can include berms at the downstream end to temporarily detain the runoff and improve performance.
- Selected turf should be able to withstand storm water flows and sustain vitality through moderate wet and dry periods.

3.5.4 Vegetated Swales

Vegetated swales are shallow, open channels that are designed to remove pollutants by physically straining/filtering water through vegetation in the channel. Swales can also serve as conveyance for storm water and can be used in place of traditional curbs and gutters. When compared to traditional conveyance systems the primary objective of vegetated swales is filtration and water quality enhancement rather than conveyance. An effective vegetated swale achieves uniform sheet flow through densely vegetated areas. When soil conditions allow, infiltration and volume reduction are enhanced by adding a gravel drainage layer underneath the swale.

Vegetated Swale

- Area Typically Served (acres): < 2
- Area Required for BMP: 10%–20%
- Major Maintenance: Mowing
- Effective Life Time: 5–20 years
- Pollutant Removal

Sediments: Medium	Nutrients: Low
Trash: Low	Metals: Medium
Bacteria: Low	Oil & Grease: Medium
Organics: Medium	

Vegetated swales are well suited for use in the right-of-way of linear transportation corridors and provide a conveyance system with the added benefits of filtration and infiltration of runoff, depending on the design (Figure 3-11). Vegetated swales with subsurface bioretention media provide enhanced infiltration, water retention, and pollutant-removal capabilities.

Figure 3-11. Vegetated swale.

Pollutants are removed primarily through filtration and sedimentation. As a design option, higher storm water quantity and quality controls can be achieved in larger swales by using check dams to pond the water for temporary storage and enhance infiltration. To prevent sediments from accumulating, vegetated swales can be used with pretreatment BMPs such as filter strips, vegetated filters, or other sediment capturing devices, especially in areas of high sediment loads or where the site is not entirely stabilized.

General guidelines for applying vegetated swales are below:

- If organic content is less than 5 percent, soil in the vegetated swales should be amended with 2 inches of well-rotted compost, mixed with native soils.
- Native and noninvasive plant species that tolerate urban environments and frequent inundation are the best for the overall effectiveness of vegetated swales. Vegetated cover should be at least 4 inches tall.

- As conventional swales, vegetated swales should be designed with sufficient sidewall depth to safely convey runoff from major storms without out-of-bank flow.
- Incorporating pretreatment such as a grass filter strip, sediment forebay, or grass channel upstream of the swales might be required to ensure effective treatment.
- Swales should not be used in areas that receive runoff from areas of concerns or hotspots.

3.6 Volume-Storage and Reuse BMPs

Buildings are the second major contributor of urban storm water problems following transportation surfaces and infrastructure. The use of structural BMPs around buildings is intended to maximize rainfall interception and minimize pollutants introduction into storm water. As an additional structural BMP successful in reducing runoff washed from buildings, cisterns and rain barrels are examples of volume-storage and reuse BMPs. With the goal of reducing the total runoff volume washed into the traditional storm water conveyance system (MS4), cisterns and rain barrels are especially effective in capturing volumes from smaller storm events. Once captured, the storm water is slowly released between storm events and used for irrigation. The controlled release reduces peak storm volumes and, therefore, reduces runoff and erosion potential.

3.6.1 Cisterns and Rain Barrels

Cisterns and rain barrels are containers that can capture rooftop runoff and store it for future use. With control of the timing and the volume released, the captured rainwater can be more effectively released for irrigation or alternative grey water uses between storm events. Rain barrels tend to be smaller systems, less than 100 gallons. Cisterns are larger systems that can be self-contained above-ground or below-ground systems generally larger than 100 gallons. Below-ground systems frequently require a pump for water removal. For San Diego and surrounding areas, cisterns and rain barrels primarily provide control of storm water runoff. Treatment can be successful when cisterns and rain barrels are used in a treatment train along with BMPs such as bioretention. Rain water in cisterns or rain barrels can be controlled by permanently open outlets or operable valves depending on project specifications.

Cisterns/Rain Barrels

- Typical sizes
  - Cisterns: > 100 gallons
  - Rain barrels: < 100 gallons
- Major Maintenance: Prevent clogging
- Effective Life Time: 20–30 years
- Pollutant Removal: Provided by downstream BMP.

Cisterns and rain barrels can be a useful method of reducing storm water runoff volumes in urban areas where site constraints limit the use of other BMPs.

A cistern typically holds several hundred to several thousand gallons of rainwater that can be used in a variety of settings in residential, commercial, governmental, and industrial applications. Cisterns provide non-potable water for irrigation, toilet flushing, cooling system makeup, and equipment and vehicle washing. A rain barrel functions similarly to a cistern but tends to be smaller, simpler, and is primarily used on applications for single-family homes such as gardening. Rain barrels are usually installed at the discharge point of roof downspouts (Figure 3-12). Homes and buildings can have more than one cistern or rain barrel.

It is ideal to limit the rainwater collection area to rooftops because roof areas have lower concentrations of pollutants than runoff from other impervious areas.

Figure 3-12. Rain barrels

General guidelines for applying cisterns/rain barrels are below:

- Cisterns and rain barrels can be installed above or below grade, indoors or outdoors.
- Positive outlet for overflow should be provided a few inches from the top of the tank and should be sized to safely discharge excess volume when the tank is full.
- Outdoor cisterns or rain barrels should be protected from algal or insect growth.
- Overflows from the cistern or rain barrel should be directed to pervious areas to allow maximum infiltration potential.
- A pump might be required to deliver the captured rainwater from the cistern. The pump should be capable of delivering the needed capacity at the necessary pressure.
- To collect less contaminated rainwater, first flush diverters can be designed to bypass cisterns or rain barrels. Filters can be added to remove debris and particulate pollutants from the storm water before it enters cisterns or rain barrels.

3.7 BMP Selection Matrix

Table 3-3 is a tool to help select practices according to site characteristics and constraints when considering LID storm water management practices. Existing or expected site characteristics can be used to determine individual practices or a suite of practices that might be appropriate in site design. In addition, relative cost considerations can assist in specific BMP selection particularly between two or more BMPs that achieve the project's goal and meet permit compliance. As such, the table lists dollar signs as qualitative costs for a relative comparison between types of LID BMPs rather than actual values.

Costs are based on local information and recommendations compiled from local vendors and actual costs from current and previous projects for each individual type of BMP. Estimated costs in this table and in Appendix B cover all components of construction and operation and maintenance for various sized projects but do not cover other conveyance needs that may be applicable. Cost estimates are based on the design standards recommended in Appendix B and can vary widely depending on the necessary configuration of the BMP and specific site constraints. These cost numbers are estimates and intended for planning purposes only. The project manager must refine these numbers throughout the phases of design to prepare a more accurate project construction estimate for bidding purposes. Cost estimates, particularly the maintenance costs, do not account for cost savings accompanied with integrated practices, such as integrating bioretention areas into landscaping where the routine maintenance could be included in the budget for typical landscape maintenance. The inclusion of various sizes of projects in the maintenance costs attempts to include those costs in which an economy of scale has been observed. The sizes selected for this analysis were:

- Large LID BMP systems = 4000 ft^2,
- Medium LID BMP system = 2000 ft^2, and
- Small LID BMP system = 500 ft^2.

These categories are based on typically sized LID BMPs. As the LID BMP area represent systems, the area can include the application of multiple LID BMPs. Appendix B also provides more detailed information on costs based on the frequency and type of maintenance required, such as routine maintenance (costs associated with maintenance required monthly up to every 2 years), intermediate maintenance (costs associated with maintenance required every 6 to 10 years) and replacement maintenance (costs associated with replacement of the system; estimated as a service life of 20 years). Table 3-3 does not include the more detailed frequency costs.

Once individual or groups of BMPs have been selected using this matrix, consult Appendix B to develop detailed designs. Through this process these storm water management components can be integrated into the city's storm water management system.

Table 3-3. LID management practice selection matrix according to site characteristics

Attribute		LID practice type												
		Bioretention[a]		Bioswale		Permeable pavement[b]		Infiltration trench	Planter boxes	Sand filter		Vegetated filter strip	Vegetated swale	Cisterns/rain barrels
		(no UD)	(UD)	(no UD)	(UD)	(no UD)	(UD)			(no UD)	(UD)			
Contribute drainage area (acres)		< 5		< 2		N/A		< 2	< 0.35	< 5		< 1	< 2	Rooftop
Soil infiltration rate (inches/hour)		> 0.5	< 0.5	> 0.5	< 0.5	> 0.5	< 0.5	> 0.5	N/A	> 0.5	< 0.5	Any soil except fill	> 0.5	N/A
Water table separation (feet)		> 10 ft	≥ 2 ft	> 10 ft	≥ 2 ft	> 10 ft	≥ 2 ft	> 10 ft	N/A	> 10 ft	≥ 2 ft	> 10 ft	> 10 ft	Below-grade tanks must be above the water table and bedrock[c]
Depth to bedrock (feet)		> 10 ft	≥ 2 ft	> 10 ft	≥ 2 ft	> 10 ft	≥ 2 ft	> 10 ft	N/A	> 10 ft	≥ 2 ft	> 10 ft	> 2 ft	
Unit slope		< 2%		< 2%		< 6%		<2%	N/A	< 6%		< 6%	< 4%	<5%
Pollutant removal	Sediments	High		High		High		High	High	High		High	Medium	Pollutant removal provided by downstream BMP, refer to specific BMP for removal efficiency
	Nutrients	Medium		Medium		Low		Medium	Medium	Low		Low	Low	
	Trash	High		High		High		High	High	High		Medium	Low	
	Metals	High		High		Medium		High	High	Low		High	Medium	
	Bacteria	High		High		Medium		High	High	Medium		Low	Low	
	Oil & grease	High		High		Medium		High	High	Medium		High	Medium	
	Organics	High		High		Low		High	High	Medium		Medium	Medium	
Runoff volume reduction		High	Medium	High	Medium	High	Medium	High	Low	Medium	Low	Low	Low	Medium
Peak flow control		Medium		Medium		Medium		Medium	Low	Medium		Low	Low	Medium
Groundwater recharge		High	Low	High	Low	Medium	Low	High	N/A	Medium	Low	Low	Low	Low
Setbacks (ft)	Structures	> 10 ft		> 10 ft		> 10 ft		> 10 ft					> 10 ft	> 5 ft
	Steep slopes	> 50 ft		> 50 ft		> 50 ft		> 50 ft					> 50 ft	> 50 ft
Costs[d]	Construction	$ - $$		$ - $$		$$ - $$$		$ - $$	$$	$ - $$		$	$	$ - $$
	O & M (small)	$$-$$$		$$-$$$		$$-$$$		$$	$$	$$-$$$		$$	$$	$$
	O & M (medium)	$ - $$[e]		$ - $$[e]		$$		$ - $$	$ - $$	$$		$	$ - $$	$ - $$
	O & M (large)	$ - $$[e]		$ - $$[e]		$ - $$		$ - $$	$ - $$	$$		$	$ - $$	$ - $$

Notes: UD = Underdrain; [a] If lined, see Planter box column; [b] If lined, see Sand filter with underdrain column; [c] For tank outlet and overflow; [d] Costs are relative, can be variable project to project, and are generalized. Please see Appendix B for more specific cost information; [e] Based on necessary regular landscape maintenance already required.

3.8 Meeting the Storm Water Runoff Requirements Simultaneously

The targets for treatment of storm water runoff in San Diego are expressed as either volume- or flow-based criteria as described in the *Storm Water Standards* manual. The volume-based requirement for an LID facility is to capture and treat the entire runoff volume from the volume-based design storm event. The flow-based requirement for an LID BMP facility is to treat the design runoff rate by applying the rainfall intensity-based water quality design storm.

An LID BMP facility can consist of a single, structural BMP or a series of structural BMPs (i.e., a treatment train), and storm water runoff drains from the designated drainage area to each LID BMP facility. To meet the volume- and flow-based storm water runoff requirements at the same time, an LID BMP facility should capture the entire runoff volume from the volume-based water quality design storm and the runoff treatment rate of the facility through infiltration, or filtration should be greater than or equal to the maximum runoff rate from the rainfall intensity-based water quality design storm. If an LID BMP facility meets only the volume-based requirement, the system should be redesigned to have a greater runoff treatment rate by increasing infiltration capacity or reducing outlet flow rate to meet both requirements. If an LID BMP facility meets only the flow-based requirement, the system should have larger runoff capture volume by adjusting storm water storage areas including internal water storage zones (IWSZs) to meet both requirements simultaneously.

3.9 References

Chollak, T., and P. Rosenfeld. 1998. *Guidelines for Landscaping with Compost-Amended Soils*. University of Washington College of Forest Resources, Seattle, WA.

City of San Diego. 2008a. *City of San Diego General Plan*. Resolution Number R-303473.

City of San Diego. 2008b. *Storm Water Standards: A Manual for Construction & Permanent Storm Water Best Management Practices Requirements*. San Diego Municipal Code: Land Development Manual. City of San Diego.

FHWA (Federal Highway Administration). 2002. *Storm Water Best Management Practices in an Ultra-urban Setting: Selection and Monitoring*. Federal Highway Administration, Washington, DC.

4 Implementation Considerations

Implementing storm water control structural BMPs can be complicated and a challenging task when planning and site characterization are given little consideration, design needs are not understood, inexperienced contractors perform the construction, or operation and maintenance are inadequate. The construction phase is often where many mistakes occur. They could stem from design problems or because of the contractors' inexperience. Consider the potential construction problems in this section as they relate to improved designs to avoid future issues. Also, during the design phase, it is important to think about whether the project will undergo monitoring and evaluation. Finally, because operation and maintenance are important to facility function, access and methods to complete maintenance tasks during the operation phase are also important to consider. It is recommended that the project manager include the considerations presented in this section in the project specifications.

4.1 BMP Construction

Major functions of structural BMPs can be damaged by common construction practices, such as compacting soils by using heavy equipment, erosion and sediment build-up, or working in saturated conditions. Construction oversight and inspections recommended by a qualified inspector familiar with the functions of structural BMPs for quality control and assurance. In addition, construction oversight should ensure that the proper erosion control practices are implemented in accordance with federal, state, and local regulations. Construction specifications may include the following measures intended at protecting the BMP while construction operations are underway:

- Establish a protective zone around valued natural areas.
- Minimize the use of heavy equipment, especially in areas for infiltration BMPs.
- Minimize soil disturbance and unprotected exposure.
- Expose only as much area as needed for immediate construction.
- As areas are disturbed and graded, apply appropriate treatment to minimize erosion risks.
- Keep infiltrating storm water BMPs protected from unwanted sediment contribution during the construction phase.
- Provide a temporary outlet to convey runoff down slope with sediment traps at outlets/inlets.
- Minimize the movement of soil into the drainage system.
- Use sediment and erosion protection practices early in the site clearing and grading process to reduce the sediment-laden runoff reaching soils intended for future infiltration.
- Protect the facility from outparcel sediment erosion.

Areas to be protected should be delineated before grading and clearing starts. It is best to indicate such restrictions on the site plan. Areas of existing vegetation that are planned for preservation should be clearly marked with a temporary fence. If trees have been designated for preservation, keep equipment away from them to prevent root and trunk damage. Trenching should be as far away from tree trunks as possible (outside the tree drip line), and the trenches should be filled in quickly to avoid root drying.

Soil-disturbing activities at the construction site can increase erosion and sediment risks. Apply an effective combination of temporary soil erosion and sediment controls to minimize the discharge of sediments from the site or from entering a storm water drainage system or natural receiving water. Properly applying the temporary controls (both on-site and for out parcels with the potential to contribute sediment) is essential and can help preserve the long-term capacity and function of the permanent storm water BMPs. Inspection and maintenance is required to ensure the control effectiveness.

Many urban sites, especially retrofit conditions, have little or no organic material in the soil structure because they have been paved over for many years. Appendix B provides information on specific media requirements to prepare for planting.

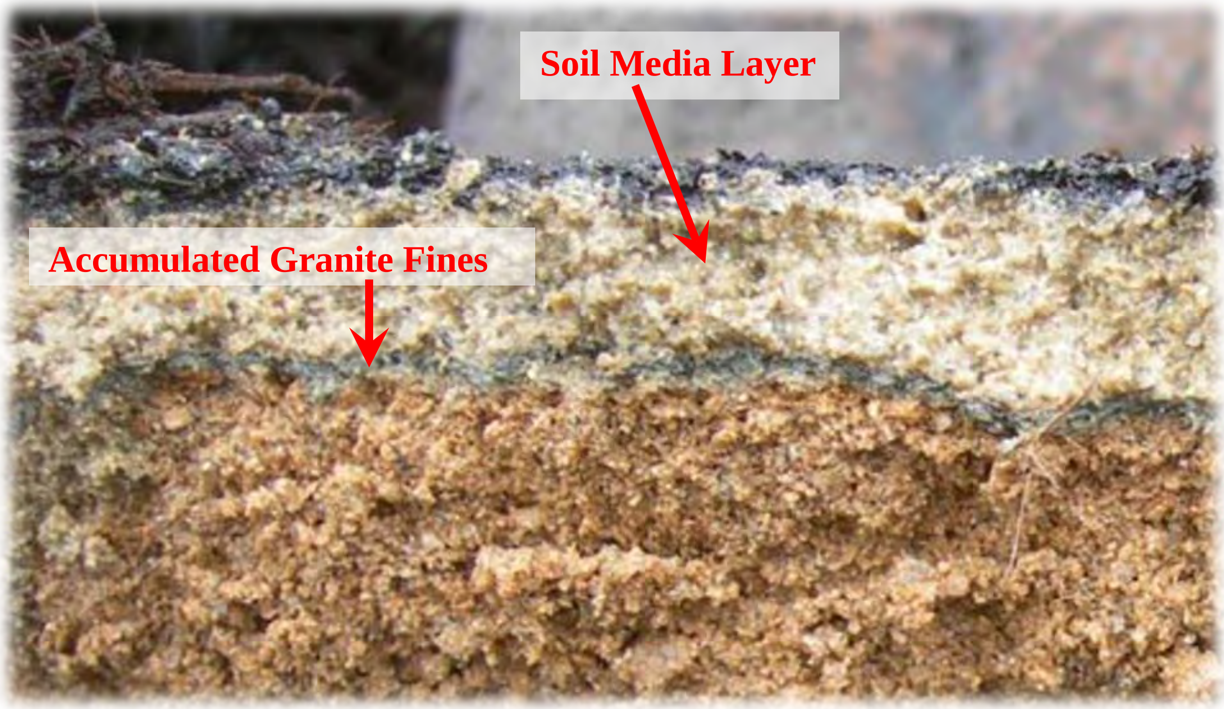
Accurate grading of stormwater infrastructures, including structural BMPs and hardscape areas, is critical for assuring the natural gravity flows and the designated BMP functions. The designer and contractor should work together to ensure that the project is correctly built to plan. If necessary, arrange for appropriate training to occur before starting a BMP construction project and on-demand during construction.

Proper construction sequencing can reduce the risk of clogging by excessive fines accumulation in the soil media layers. Imported soil media should not be incorporated into BMPs until all areas of the construction site are stabilized. Soil media should not be installed until at least the first course of asphalt (minimum 1 inch) has been set for roads and parking lots; that minimizes the amount of fines washed from the bedding layers into the BMP. A geotextile liner might not be sufficient to prevent fines from migrating into and clogging the soil media layer, and for that reason, proper construction sequencing is crucial. Figure 4-1 is an example of the fines that can accumulate and clog the soil media if proper construction sequencing is not followed.

Inspection of all construction phases to ensure that BMPs are properly installed as anticipated are essential, especially when critical elements of a structural BMP are being installed, such as inverts, inlets, outlets, overflow, and underdrains. In the design notes, designers should stipulate whether the type of materials specified cannot be substituted because of potential lack of function (e.g., engineered media). If an element of a structural BMP system was not properly constructed or the wrong materials were used, the entire system might not function and could result in system failure.

4.2 Routine Operational BMP Inspection and Maintenance

To maintain the effectiveness of structural BMPs, regular inspection is essential. Generally, BMP inspection and maintenance can be categorized as routine and as-needed. As-needed inspection/maintenance should be conducted after events such as major storms. Routine activities, performed regularly (e.g., monthly) ensure that the BMP is in good working order and continues to be aesthetically pleasing. Routine inspection is an efficient way to prevent potential nuisance situations from developing and reduce the need for repair or maintenance. Routine inspection also reduces the chance of polluting storm water runoff by identifying and correcting problems regularly.



Source: NCSU-BAE

Figure 4-1. Accumulated fines layer as a result of improper construction sequencing.

In addition to the scheduled regular inspections, all BMPs should be checked if any potential changes could happen to the BMP, especially after every large storm event. Inspecting a structural BMP after a storm event should occur after the expected drawdown period for the BMP. The inspector can then determine if BMPs are draining correctly.

Inspecting structural BMPs consists of technical and nontechnical activities as summarized below:

- Inspect the general conditions of the BMP area and the adjacent areas directly around the BMP.
- Maintain access to the site including the inlets, side slopes (if applicable), forebay (if one exists), BMP area, outlets, emergency spillway, and so on.
- Examine the overall condition of vegetation.
- Eliminate any possibility of public hazards.
- Check the conditions of inflow points, pretreatment areas (if they exist), and all outlet structures.
- Inspect and maintain the inlet and outlet regularly and after big rainfall events.
- Ensure that the pretreatment areas meet the original design criteria.
- Check the encroachment of invasive plants in vegetated areas. This task could require more frequent inspections during the growing season.
- Inspect water quality improvement components. Specifically, check the storm water inflow, conveyance, and outlet conditions.

- Inspect hydrologic functions for proper operations such as maintaining sheet flow where designed, pretreatment is functioning, maintenance of design storage capacity, and proper operation of outlet structures.
- Check conditions downstream of the BMP to ensure that the flow is not causing hydromodification issues below the facility.

Checklists with maintenance specifications and requirements are provided in Appendix F. In general, individual BMPs can be described with minimum performance expectations, design criteria, structural specifications, date of implementation, and expected life span as provided in Chapter 3 and detailed in Appendix C. Recording such information will help the inspector determine whether a BMP's maintenance schedule is adequate or requires revision. Checklists also provide a useful way for recording and reporting whether major or minor renovation or routine repair is needed. The effectiveness of a BMP might be a function of the BMP's location, design specifications, maintenance procedures, and performance expectations. Familiarity with the characteristics is important for inspectors to recognize and understand.

In every inspection, whether routine or as-needed, the inspector should document whether the BMP is performing correctly and whether any damage has occurred to the BMP since the last inspection. Ideally, the inspector will also identify what should be done to repair the BMP if damage has occurred. Documentation is very important in maintaining an efficient inspection and maintenance schedule, providing evidence of ongoing inspection and maintenance, and detecting and reporting any necessary changes in overall management strategies.

4.3 BMP Operation and Maintenance

The major goal of BMP operation and maintenance is to ensure that the BMP is meeting the specified design criteria for storm water flow rate, volume, and water quality control functions. If structural LID systems are not properly maintained, BMP effectiveness can be reduced resulting in deterioration in water quality. Training should be included in program development to ensure that maintenance staff has the proper knowledge skills and abilities. It is important that regular maintenance and any need-based repairs for a structural BMP be completed according to schedule or as soon as practical after the problem is discovered for effective storm water control. If a BMP is improperly managed, detrimental effects on the landscape and increased potential for water pollution and local flooding could occur.

From the city's *Storm Water Standards* (City of San Diego 2008), the following operation and maintenance activities are required for each storm water management facility:

- Determine the responsible party for maintaining treatment facilities. Identify the means by which ongoing maintenance will be assured (for example, a maintenance agreement that runs with the land).
- Identify typical maintenance requirements and allow for the requirements in the project planning and preliminary design phases.
- Prepare a maintenance plan for the site incorporating detailed requirements for each treatment and flow-control facility.
- Maintain the facilities from the time they are constructed until ownership and maintenance responsibility are formally transferred.

- Formally transfer operation and maintenance responsibility to the site owner or occupant. A warranty, secured by a bond, or other financial instrument, could be required to secure against lack of performance because of flaws in design or construction.
- Maintain the facilities in perpetuity and comply with the city's self-inspection, reporting, and verification requirements.

Most structural BMP maintenance work is not technically complicated, such as mowing, removing trash and debris, removing sediment, and the like. More specialized maintenance training might be needed, however, to sustain BMP effectiveness for more sophisticated systems. General maintenance activities on structural BMPs for the two major categories (filtration and infiltration) of LID facilities are as follows:

Infiltration BMPs

- Mowing and maintaining upland vegetated areas if applicable
- Cleaning and removing debris after major storm events
- Cleaning out accumulated sediment
- Repairing or replacing stone aggregate
- Maintaining inlets and outlets
- Removing accumulated sediment from forebays or sediment storage areas when 50 percent of the original volume has been lost

Biofiltration and filtration BMPs

- Removing trash and debris from control openings
- Watering and mowing vegetated areas
- Removing and replacing all dead and diseased vegetation
- Stabilizing eroded side slopes and bottom
- Repairing erosion areas
- Mulching void areas if needed
- Maintaining inlets and outlets
- Repairing leaks from the sedimentation chamber or from deteriorating structural components
- Removing the top few inches of media, and cultivating the surface, when filter bed is clogged
- Cleaning out accumulated sediment from filter bed once depth exceeds approximately one-half inch or when the filter layer no longer draws down within 24 hours

In regions where dry and wet seasons are clearly distinguished, as is the case in Southern California, conducting special maintenance activities before a wet season can be very helpful. Conducting routine BMP inspection and maintenance before the wet season helps to prevent increased erosion from storm events. If a BMP does not meet the specified design criteria, it must be repaired, improved, or replaced before a wet season starts. In particular, any accumulated sediment and trash should be removed to maximize the performance of the facility throughout the following wet season. Any disturbed area that is not actively being graded must be fully protected from erosion.

Detailed descriptions on operation and maintenance for individual systems are in Appendix B. General maintenance issues for individual BMPs are presented in the following sections.

4.3.1 Bioretention

Maintenance activities for bioretention units should be focused on the major system components, especially landscaped areas. Bioretention landscape components should blend over time through plant and root growth, organic decomposition, and develop a natural soil horizon. Those biologic and physical processes over time will lengthen the facility's life span and reduce the need for extensive maintenance.

Irrigation might be needed, especially during plant establishment periods. In periods of extended drought, temporary supplemental irrigation could be used to maintain plant vitality. Irrigation frequency will depend on the season and type of vegetation. Native plants might require less irrigation than nonnative plants.

Routine maintenance should include a twice-yearly evaluation of the trees and shrubs and subsequent removal of any dead or diseased vegetation (CASQA 2003). Routine inspections for areas of standing water in the BMP and corrective measures to restore proper infiltration rates are necessary to prevent mosquito and other vector habitat formation. To maintain the treatment area's appearance, it might be necessary to prune and weed. Replace mulch when erosion is evident or when the site begins to look unattractive. Depending on pollutant loads, soil media might need to be replaced within 5 to 10 years of construction (CASQA 2003).

4.3.2 Bioswale

The maintenance objectives for bioswale systems consist of optimizing storm water conveyance capacity, runoff volume control, and pollutant removal efficiency. To meet those objectives, it is important to maintain a consistent ground cover in the channel. Maintenance activities involve replacing or redistributing mulch, mowing (where appropriate), weed control, irrigating during drought conditions, reseeding bare areas, and clearing debris and blockages. Manage vegetation on a regular schedule during the growth season to maintain adequate coverage. Accumulated sediment should also be removed manually to avoid concentrated flow. Minimize fertilizer and pesticide application, possibly to periods of plant establishment only. Irrigation might be needed to maintain plant vitality, especially during plant establishment or in periods of extended drought. Irrigation frequency will depend on the season and type of vegetation. Native plants require less irrigation than nonnative plants and should be incorporated into site designs where feasible.

4.3.3 Permeable Pavement

The primary maintenance requirement for permeable pavement consists of regular inspection for clogging. The main goal of the maintenance program is to prevent clogging by fine sediment particles. To maintain the infiltrative capacity of permeable pavements, vacuum sweeping should be performed a minimum of twice a year. Frequency of vacuum sweeping should be adjusted according to the intensity of use and deposition rate on the permeable pavement surface. Settled paver block systems might require resetting. When modular pavements incorporate turf into their void area, normal turf maintenance practices, including watering, fertilization, and mowing might be required (FHWA 2002).

For proper performance, maintenance staff must ensure that storm water is infiltrating properly and is not standing or pooling on the surface of the permeable pavement. Standing water can indicate clogging of the void space. In such cases, vacuuming is necessary. If ponding still occurs, it might be necessary to inspect the media sublayer and possibly the underdrain.

4.3.4 Infiltration Trench

The primary maintenance requirement for infiltration trenches involves inspecting and removing sediment and debris accumulation to prevent clogging. In addition to reduced water quality performance, clogged infiltration trenches with standing water can become a nuisance and harbor mosquito breeding. It is also necessary to inspect the pretreatment device and conduct repairs and maintenance as needed. If a vegetated pretreatment is used, periodically mow the areas to maintain the grass height at an equal or greater height of the design flow depth. Accumulated debris must be removed monthly from the infiltration trench surface and the pretreatment areas.

4.3.5 Planter Box

General maintenance requirements for planter boxes are the same as the routine periodic maintenance of any landscaped areas or bioretention BMPs. The primary maintenance requirement for planter boxes is to inspect the vegetation and soil media. Regularly remove any accumulated trash and sediment in the device, especially after large storms, and inspect soils to evaluate root growth and channel formation in the soil media.

4.3.6 Sand Filter

The primary maintenance requirement for sand filters is to remove trash, accumulated sediment, and hydrocarbons. If the filter does not drain in the design drawdown time because of sediment accumulation, the top layer (1–3 inches) of sand (media) must be replaced.

4.3.7 Vegetated Filter Strip

Vegetated filter strips require minimal maintenance, with the majority of maintenance satisfied through mowing. Mowing, for safety and aesthetics or to suppress weeds and woody vegetation, might be necessary once or twice a year. Primary maintenance activities are similar to other vegetated areas. However, gravel diaphragms or verges could require the removal of encroaching grass and sediment.

Irrigation might be needed to maintain plant vitality, especially during plant establishment and extended periods of drought. Irrigation frequency can be determined as with other turf management on the basis of the season and type of vegetation. Native plants often require less irrigation than nonnative plants and are recommended when feasible.

Trash tends to accumulate in strip areas, especially along roadways. The need for litter removal should be determined through periodic inspections, but litter should always be removed before mowing.

4.3.8 Vegetated Swale

The maintenance objectives for vegetated systems include optimizing filtration and storm water conveyance capacity. To meet those objectives, it is important to maintain a dense, healthy vegetative cover in the channel. Maintenance activities involve mowing, weed control, irrigating during drought conditions, reseeding bare areas, and clearing debris and blockages. Manage vegetation on a regular schedule during the growth season to maintain adequate coverage. Accumulated sediment should also be removed manually to avoid concentrated flow. Minimize fertilizer and pesticide application, possibly to periods of plant establishment only. Irrigation might be needed to maintain plant vitality, especially during plant establishment or in periods of extended drought. Irrigation frequency will depend on the season and type of vegetation. Native plants require less irrigation than nonnative plants and should be incorporated into site designs where feasible.

4.3.9 Cisterns/Rain Barrels

General maintenance activities for cisterns and rain barrels are similar to the routine periodic maintenance for on-site drinking water wells. The primary maintenance requirement is to inspect the tank and distribution system and test any backflow-prevention devices. Rain barrels require minimal maintenance to prevent any clogging several times a year and after major storms. Cisterns also require inspections for clogging and structural soundness twice a year. Accumulated sediment must be removed at least once a year.

4.4 Reducing Project Costs

Implementing more natural storm water management practices with less reliance on conventional, impervious designs can reduce overall project costs. In addition, such facilities can help provide social, environmental, and economic benefits. Using an LID approach can be one of the more effective ways to reduce construction costs to minimize the effects on the existing storm water collection systems. Long-term operation and maintenance costs reduction goals can be achieved when more naturalized approaches are used because the native vegetation is adapted to the local weather conditions requiring less irrigation and other maintenance attention resulting in effective treatment with minimal maintenance.

Installing storm water BMPs at upstream areas can provide considerable cost saving opportunities for the downstream areas. Increased costs to implement storm water BMPs might be offset by reduced costs associated with flood controls, pollution mitigation, and public health issues in the watershed-scale evaluation.

Implementing green parking techniques like applying permeable pavement and other alternative transportation options can reduce stormwater management costs as well. Maximizing parking spaces, minimizing stall dimensions, and encouraging shared parking can result in considerable construction cost savings.

Relative cost-effectiveness of a structural BMP can be established on the basis of planning, design, and construction costs. Annual operation and maintenance expenses for the expected life of the management practice should also be included in cost-effective assessments. Such cost information and the use of specified removal efficiencies for a structural BMP can be a useful tool when implementing pilot projects to determine costs and benefits for storm water controls at a larger, citywide scale.

4.5 Demonstration Projects

Demonstration or pilot projects provide value to the planning, design, and maintenance communities providing valuable information. Features that were done correctly and those that were done incorrectly can serve as learning opportunities and provide essential information on successful components and components that must be improved through all phases of design construction and post-construction. Information gathered can also provide further understanding and acceptance for nonmunicipal entities through the application of LID BMPs. That understanding can reduce concerns about risk as experience and technical knowledge is gained from implementing demonstration projects.

Demonstration projects provide concrete examples of how LID BMPs can be implemented in an environment. That can reduce uncertainty about whether the LID BMPs will actually work in a particular setting. Demonstration projects can offer overall guidelines and examples for the designs, materials, and implementation of structural BMPs as well as the general ideas concerning site planning, design, and development strategies associated with integrating LID management practices and strategies. Those projects can be used as guidelines for performance evaluations, long-term operation and maintenance needs, and cost estimations for individual or integrated treatment trains of LID facilities. The projects also allow engineers and designers to verify proper function and maintenance of the systems.

Demonstration projects can illustrate how storm water LID BMP strategies might be incorporated into other areas of site development strategies. Alternative transportation options to enhance safer street environments, such as traffic safety and control, can improve storm water quantity and quality problems. Demonstration projects can also be useful in forensic engineering into systems that fail or do not meet quality or flow-control expectations. Improvements can then be made on future designs through the iterative, adaptive management approach common at that stage of understanding according to the number of projects completed to date.

Monitoring of demonstration projects is essential. Monitoring is a fundamental component of implementing stormwater management plans and facilities to evaluate how successfully the plan or facility is and whether changes are needed in operation, maintenance (procedures or frequency), or design to meet regulatory goals. The monitoring program is often unique to each BMP or demonstration site and must be designed in the context of the objectives of the program. For example, a monitoring program for municipality seeking to comply with monitoring requirements under its NPDES permit may have relatively straight-forward goals for certain pollutants of concern. However, also important is the more in-depth monitoring information gathered when determining factors affecting LID facility performance.

By monitoring demonstration projects for performance, results can be used to make predictions on the water quality and flow benefits gained by implementation compared to costs. This will help decision makers determine the most cost efficient facility for various conditions that will have the most benefit to water quality and help meet regulatory requirements. In addition, the information gathered on technical performance of BMPs is expected to provide important input for simulation modeling of pollutant impacts associated with specific management scenarios in other locations or at a larger scale. Key principles of monitoring pilot projects include:

- Dedicate the time and resources to develop a sound monitoring plan. Complexities of plans will vary depending on monitoring objectives.
- Be sure to plan and budget for an adequate number of samples to enable proper data interpretation.
- Be aware of the many variables that need to be documented as part of a monitoring program.
- Be sure that the monitoring design properly identifies the relationship between storm characteristics and the design basis of the BMP and answers selected management questions.

- Properly implement and follow the monitoring plan, clearly documenting any adjustments to the program. Particularly important are proper equipment installation and calibration, proper sample collection techniques and analysis, and maintenance of equipment for longer term programs.
- Maintain data in an organized and well-documented manner, including not only monitoring data, but also BMP design and maintenance practices and site characteristics.
- Clearly report study limitations and other caveats on use of the data.

The City of San Diego has developed an Effectiveness Assessment Monitoring Guidance document that provides a framework and guidance for planning, execution, data evaluation, and reporting considerations when evaluating LID facilities. The document also contains guidance that can help City staff plan and execute a study plan/methodology, to ensure that 1) project revisions are accounted for in the final monitoring plan, 2) available resources are efficiently applied, and 3) that project Management Questions can be effectively addressed.

4.6 References

CASQA (California Stormwater Quality Association). 2003. *Stormwater Best Management Practice (BMP) Handbooks: New Development and Redevelopment Handbook*. California Stormwater Quality Association.

City of San Diego. 2008. *Storm Water Standards: A Manual for Construction & Permanent Storm Water Best Management Practices Requirements*. San Diego Municipal Code: Land Development Manual. City of San Diego.

FHWA (Federal Highway Administration). 2002. *Storm Water Best Management Practices in an Ultra-urban Setting: Selection and Monitoring*. Federal Highway Administration, Washington, DC.

USEPA (U.S. Environmental Protection Agency). 2006. *BMP Inspection and Maintenance, Fact Sheet*.

Glossary

Berm. A raised barrier used to control erosion and sedimentation by reducing the rate of surface runoff or directing water to areas not susceptible to erosion.

Best management practices (BMPs). Effective and practical methods with the intent to protect water quality by preventing or reducing the movement of sediment, nutrients, pesticides, and other pollutants from the land to surface and ground water bodies.

Bioretention. A storage and removal process in which contaminants and sediments are removed from storm water runoff by collection into a treatment area generally consisting of natural media such as grass, sand, mulch, or plants.

Biofilter. A pollution-control technique using living material to capture and biologically degrade process pollutants.

Bioswale. A broad, shallow channel with a dense stand of vegetation covering the side slopes and bottom. It is effective in trapping particulate pollutants, promoting infiltration, and reducing the flow velocity of storm water runoff.

Chaparral grasslands. Dense growth of shrubs and trees that commonly grow in climates of hot, dry summers and cool, moist winters. It is a native shubbery to southwestern United States.

Chemical treatment processes. Removal processes that involved chemical reactions to induce sorption, coagulation, flocculation, settling, and precipitation of pollutants of concern.

Chicane. An alternative transportation design—specifically, a type of horizontal deflector that allows for the incorporation of storm water management. Chicanes are artificial feature creating extra turns in a roadway to slow cars.

Cistern. A basin or receptacle built to capture and store rainwater. Cisterns are generally larger than rain barrels and can generally hold more than 100 gallons of water. They can be contained either above or below ground. However, below-ground application often requires mechanical pumps requiring electricity and more maintenance.

Compacted soils. Soil that is compessed to a degree that prevents roots from spreading and water from properly soaking into the soil, making the soil unable to support plant growth.

Conveyance system. A network of several components that can include catch basins, storm sewers, creeks, storm water detention ponds, lift stations, force mains, and ditches designed to accommodate and drain storm water runoff.

Curb bump outs. A storm water management technique that stretches a landscaped corner of a curb into the existing parking lane of a street. Such a landscaped curb is slightly depressed to allow water to pond and soak into the ground before overflowing to the existing curb storm sewer inlet.

Depression. An area completely or mostly surrounded by higher land and ordinarily has interior drainage.

Depression storage. An area of land that is able to retain water in its pits and depressions, thus preventing it from flowing.

Detention basin/area. An area usually installed on or adjacent to developed areas. It is generally a tradtional storm water management technique to manage excess runoff.

Development envelope. The site boundary or total site area that affects the hydrology of interest.

Easement: A right-of-way—generally a road, sidewalk, or public utility—to allow passage through a private property.

Endemic. Native to an area or location.

Environmentally Sensitive Lands (ESL). Land containing steep hillsides, sensitive biological resources, coastal beaches, sensitive bluffs, or Special Flood Hazard Areas (San Diego Municipal Code section 113.0103).

Erosion. The weathering or transport of sediments, soils, rocks due to the adjacent flow of water.

Evapotranspiration. Transpiration by plants that transfers moisture from the earth to the atmosphere by means of evaporation.

Exfiltration. The loss of water from a drainage system due to percolation or absorption into the surrounding soil.

Filtration. A physical process that involves passing water through a porous media or vegetation to separate larger solids from smaller solids and liquids.

Filtration BMPs. Storm water management techniques that strain runoff and effectively trap debris and particulates to prevent them from washing downstream. Soil media and plant stems can be effective in removing trash, coarser particles, and pollutants from storm water runoff.

Floatation. A removal process in which pollutants that are less dense than water are retained from the water surface.

Floodplains. A nearly flat area along the course of a stream or river that is naturally (and often historically) subject to flooding.

Forebay. A small pool near the inlet of a storm water management facility designed to serve as an initial storage area to trap and settle out sediment and heavy pollutants.

Geologic hazards. Types of adverse geologic conditions capable of causing damage or loss of property and life. Such hazards include unstable slopes, slide-prone geologic formations, faults, and liquefaction-prone soils.

Green parking. Techniques applied to reduce impervious cover in a parking lot. Techniques include minimizing the dimensions of parking lot spaces, using alternative pavers in overflow parking areas, using bioretention areas, and providing economic incentives for structured parking.

Greenways. A corridor of undeveloped land, such as along a river or between urban centers, that is reserved for recreational use or environmental preservation.

Gullying. Flowing or running water resulting indeep cutting or erosion of the soil that resemble large ditches and washes.

Horizontal deflectors (bump-out). A transportation alternative for the incorporation of storm water management. Main traffic-calming devices designed to narrow roads as a means to slow traffic. Examples of horizontal deflectors include median slow points, and chicanes.

Hot spots. Areas of concern that have a high potential of, or known, soil or other potential contamination. Examples include gas stations, industrial areas, automotive repair facilities, and dry cleaners.

Hydrograph Modification Plan. A plan designed to manage increases of discharge runoff and durations that are likely to cause erosion of channel beds and banks or sediment pollution. It is not designed to correct existing erosion problems but to prevent further erosion problems from new or redevelopment projects.

Impaired waterbody. A lake, river, or stream whose water quality does not meet water quality standards and is considered *compromised*. Such bodies of water are identified as 303(d)-listed waters and could require the development, adoption, and implementation of plans to reduce specified pollutants to improve the quality of water.

Impervious surfaces. Usually artificial surfaces, such as pavement, sidewalks, or rooftops, that consists of a material impenetrable by water. Because of the lack of possible infilitration, such surfaces contribute to storm water runoff.

Impervious area disconnect. A technique designed to divert storm water runoff by directing runoff from impervious surfaces to pervious surfaces capable of infiltration.

Infiltration trench. A type of BMP that is used to manage storm water runoff and improve water quality. It is a shallow excavation filled with gravel or crushed stone design to store and infiltrate storm water through soils for treatment before reaching groundwater.

Interception. The amount of rainfall that remains on pervious and impervious surfaces (leaves, topsoil, pavement, asphalt, and the like) including puddles and does not infiltrate into the ground or become runoff. Rainfall that is intercepted often evaporates, infiltrates, or is transpired by plants.

Internal Water Storage Zone (IWSZ). A storm water BMP design feature incorporated to provide additional storage, particularly in poorly infiltrated soils and control the release of stored water. It can be incorporated into any BMP with an underdrain. It often uses designs such as an upturned elbow at the outlet impounding water internally so that stored water can be released slowly through infiltration/exfilitration and evapotranspiration.

Land Development Code. Chapters 11-5 of San Diego's Municipal Code are referred to as the Land Development Code. The chapters contain the city's planning, zoning, subdivision, and building regulations.

Low impact development (LID). A land planning and engineering design approach to managing stormwater runoff. LID incorporates conservation design and the use of on-site natural features (evaporation, transpiration, and infiltration) to protect water quality and encourage implementation of engineered hydrologic contols to replicate predevelopment hydrologic regime of natural watersheds.

Median slow point. Raised islands at the centerline of a street that narrow the path of travel and result in reduced traffic to reduce speeds. Additionally, they offer a location to incorporate alternative transportation designs that include storm water management techniques.

Maximum Extent Practicable (MEP). The maximum degree of pollution reduction that is achievable by applying practical, technologically feasible, and economically achievable BMPs.

Multi-Habitat Planning Area (MHPA). The city's planned habitat preserve within the MSCP region. Lands in the MHPA are to be conserved to protect habitat, open space, and biodiversity.

Multiple Species Conservation Program (MSCP). A comprehensive habitat conservation planning program for southwestern San Diego County. It aims to preserve a network of habitat and open space, to protect biodiversity and to enhance a region's quality of life. Its areas of jurisdiction are known as Multi-Habitat Planning Areas, or MHPAs.

Municipal Separate Storm Sewer System (MS4). A conveyance system or collection of conveyance systems that is owned by a state, city, town, or other public entity that discharges to U.S. waters as regulated by the Clean Water Act. The systems are designed to collect and convey only storm water runoff; they do not include combine sewer systems or any part of a sewage treatment plant or publicly owned treatment works.

Municipal storm water management (MS4) programs. Program implemented in accordance to National Pollutant Discharge Elimination System or municipal separate storm sewer system permit requirements. Such programs must develop storm water management plans that include measurable goals, implement storm water management controls and identify bodies of water within the jurisdiction that fail to meet water quality standards or goals, or those that will continue to fail unless action is focused on reducing non-point sources of pollution.

Natural Resources Conservation Service. A federal agency, under the U.S. Department of Agriculture, that works in partnership with landowners to conserve and sustain natural resources on private lands. It provides planning and assistance designed to benefit the soil, water, air, plants, and animals that result in productive lands and healthy ecosystems.

Non-Point Source (NPS) Pollution. Pollution not from a single discharge but from many diffuse sources. It can be caused by rainfall or snowmelt moving over and through the ground.

Overlay Zone. A zone applied in conjunction with other zoning districts that may impose a set of additional requirements or relax a set of requirements imposed by the underlying zoning district.

Permeable pavements. A storm water management alternative to conventional concrete that allows water to infiltrate (through surfaces that would normally be impermeable) by replacing impervious area with a permeable surface that contains media and storage under the surface to reduce pollutant loads and the volume of storm water runoff.

Phytoremediation. The use of plants for in-situ removal of contaminants from contaminated soil, water, sediments, and air. S form of remedial treatment is an energy-efficient and aesthetically pleasing method of remediating sites with low to moderate levels of contamination.

Planter boxes. A storm water treatment option that is a precast concrete box containing soil media and vegetation. Planter boxes typically incorporate an underdrain into their design. They are often used in conjunction with downspout disconnection or rain barrels as initial stormwater treatment before it enters the storm water conveyance system.

Pollution prevention. An approach to reduce or eliminate a pollutant at the source of generation.

Ponding area. An area incorporated into a storm water BMP that provides surface storage of storm water, enhances evapotraspiration, settles larger particles and allows water to infiltrate to the groundwater.

Predevelopment hydrologic conditions/regimes. Hydrological processes that existed before an area was developed. Such processes can include natural infiltration, surface storage, and native vegetation.

Rain barrel. A water storage tank used to collect and store rain water runoff typically from rooftops via rain gutters. Rain barrels are typically less than 100gallons.

Riparian areas. Land on the bank of a river or other body of water.

San Diego Seismic Safety Study. Study report that contains maps indicating where adverse geological conditions might exist, as defined by Geologic Hazard Category.

San Diego County (2003) Hydrology Manual. A document intended to provide a uniform procedure to evaluate flood and storm water in San Diego County. It provides guidance for jurisdictions to develop policies for flood and storm water management.

San Diego Drainage Design Manual. The City of San Diego storm water manual containing established design standards and procedures for storm water drainage and flood management facilities. The design standards and procedures provide guidance in the selection, design, construction, and maintenance of storm water drainage and flood management facilities. The manual is complementary to this manual.

Sand filter. A treatment system that uses physical filtration to remove particles and solids from storm water runoff. Generally suitable for places where vegetated BMPs are not practical.

Sedimentation. The physical process of particle separation as a result of the density differences between solids and water.

Site fingerprinting. An LID approach that considers placement of development in areas less likely to affect environmentally sensitive areas such as wetlands and steep slopes, future restoration areas, and temporary and permanent vegetative forest buffer zones.

Setbacks. The distance required by law between the edge of a structure such as a building or utility and the property line. Generally, setbacks restrict the buildable area.

Standard Urban Storm Water Mitigation Plan (SUSMP). Depending on the type of project, a SUSMP is required by the Municipal Storm Water National Pollutant Discharge Elimination System Permit to reduce the quantity and improve the quality of runoff that leaves a site. Details and guidelines pertaining to the SUSMP requirements are in the *Storm Water Standards* manual.

Storm Water Standards manual. The City of San Diego manual providing guidance and standards for construction and permanent storm water BMP requirements. It prohibits non-storm water discharges and establishes requirements for new development projects, both during and after the construction phase, to reduce pollutants to the *Maximum Extent Practicable*. Also provides guidance for proper implementation of LID facilities and conformance with the regional hydromodification management requirements. This LID manual is complementary to the *Storm Water Standards* manual.

Storm Water Requirements Applicability Checklist. A form required by the City of San Diego Development Services that evaluates the completeness of permanent storm water BMP requirements and the construction storm water BMP requirements. The checklist is in Appendix A of the *Storm Water Standards* manual.

Structural BMPs. Mitigative techniques implemented to remove or significantly reduce pollutants in storm water runoff. They are designed to capture, infiltrate, filter, and treat storm water runoff from a project or drainage. Structural BMPs might be required to achieve a level of controls in terms of water quantity and quality.

Swale. A shallow trough-like depression that conveys storm water mainly during rainstorms or snowmelts. Swales enhance both filtration and can be designed to increase infiltration of storm water.

Topography. The description of the characteristics, features and configurations of the physical terrain or land surfaces such as canyons, streams, and hillsides.

Total maximum daily loads (TMDLs). The maximum amount of a pollutant load per day that a waterbody can receive and still safely meet water quality standards.

Traditional storm water management. A collection system designed to efficiently convey runoff away from urban areas to nearby surface waters generally without focus on water quality treatment.

Transpiration. The loss of water vapor from parts of plants including leaves, stems, flowers, and roots.

Treatment train. A series of treatment practices and/or processes designed to meet a target treatment objective.

Underdrain. A collection system designed to drain infiltrated storm water beneath or within a BMP unit, often using perforated pipe.

Vegetated filter strip. Vegetated surfaces designed to treat sheet flow from adjacent surfaces by slowing runoff velocities, filtering out sediment and other pollutants, and providing potential infiltration into underlying soils.

Vernal pools. Ephemeral pools of water usually devoid of fish to allow for the safe development of natal amphibian and insect species. They are protected under the Multiple Species Conservation Plan for San Diego.

Liquefaction. The process by which sediment that is very wet starts to behave like a liquid. It is often caused by severe shaking, i.e., earthquakes.

Wetlands. Areas that are inundated or saturated by surface or groundwater at a frequency and duration sufficient to support vegetation typically adapted for life in saturated soils. Generally include areas such as swamps, marshes, or bogs.

Appendix A. BMP Sizing

Table of Contents

List of Tables

List of Figures

(This page left intentionally blank.)

1 Analysis of San Diego BMP Sizing Methods

1.1 Purposes of this Appendix

The City of San Diego Stormwater Manual (City of San Diego, 2008) provides a number of different options to determine appropriate sizing of stormwater Best Management Practices (BMPs), including both volume-based and flow-based control practices. The different sizing methods can provide rather different results.

Section 1 of this document provides a detailed analysis of the differences among the current sizing methods. This is done through dynamic analysis of long-term (57-year) precipitation data, simulated runoff, and BMP discharge. The implications of the different sizing methods can then be evaluated in terms of the percent of flow that is successfully treated. Differences among BMP types and in response to potentially important covariates (such as percent imperviousness, local meteorology, and soil type) can also be investigated. Implications for hydromodification management are also considered.

Section 2 of this document consists of a user's manual for a new BMP sizing tool, which implements each of the sizing methods contained in the 2008 Stormwater Manual. The tool uses a public-domain Geographic Information System (MapWindows) and numerical curve-fitting of published sizing curves to automate what were previously manual tasks and ensure consistency in application.

1.2 BMP Sizing Criteria

The San Diego County Municipal Stormwater Permit (Order No. R9-2007-0001) requires all stormwater treatment control practices on Priority Development Projects (see D.1.d.(2) of the permit) to meet either of the following design criteria:

- **Volume-based control practices**: infiltrate, filter, or treat the 24-hr, 85th percentile storm event

  or

- **Flow-based control practices**: infiltrate, filter, or treat the maximum flow rate from 0.2 inch per hour rainfall or *twice* the maximum flow rate from 85th percentile hourly rainfall intensity.

In simplistic terms, these design criteria provide sizing methodologies that allow treatment of frequent small events with low to medium rainfall intensities while bypassing runoff from large storm events and high rainfall intensities. The result is that a large portion of total annual runoff (i.e., runoff from the majority of storms that are smaller than the 85th percentile event) is treated by the BMP without requiring the significant expense of enlarging the BMP to a size necessary to treat the remainder of runoff. These methods are summarized briefly below.

1.2.1 Volume-based Control Practices

The City of San Diego Stormwater Manual (City of San Diego, 2008) details three methods for infiltrating, filtering, or treating stormwater to meet volume criteria:

1. The volume of runoff produced from an 85th percentile storm event. Isopluvial maps for the 85th percentile storm event are provided in the County of San Diego's 85th percentile isopluvial map at http://www.sdcounty.ca.gov/dpw/watersheds/susmp/susmppdf/susmp_85precip.pdf. [Note: Applicants may calculate the 85th percentile storm event using local rain data, when available.]

   or

2. The volume of runoff produced by the 85th percentile storm event, determined as the maximized capture urban runoff volume for the area, from the formula recommended in Urban Runoff Quality Management, WEF Manual of Practice No. 23/ ASCE Manual of Practice No. 87 (1998)

   or

3. The volume of annual runoff based on unit basin storage volume, to achieve 90 percent or more volume treatment by the method recommended in the latest edition of the California Stormwater Best Management Practices Handbook (CASQA, 2003).

1.2.1.1 Volume-based Method 1

Method 1 describes how to obtain or estimate the 85th percentile 24-hour storm, but does not specify the methodology for calculating the runoff volume from the 85th percentile 24-hour storm event. Two runoff volume calculation methods are provided in the San Diego County Hydrology Manual (County of San Diego, 2003) and are adopted in this analysis. These are the Rational Method application for runoff volume estimation described in Section 6 of the Manual, and the Natural Resources Conservation Service (NRCS) hydrologic method (or previously called the Soil Conservation Service (SCS) hydrologic method) described in Section 4 of the Manual. As the Rational Method is recommended for watersheds less than 1 square mile in area, that is the approach that is evaluated here. The Rational Method is implemented as follows:

$$WQV = C * \left(\frac{P_{85}}{12}\right) * A$$

Where,
WQV = BMP water quality storage volume (ft^3),
C = runoff coefficient,
P_{85} is the rainfall depth from the 24-hr, 85th percentile storm (inches),
A = watershed area draining to the BMP (ft^2), and

$$C = C_i * (\%Imp) + C_p * (1 - \%Imp)$$

The value of C_i can be set to 0.90 based on San Diego County Hydrology Manual; C_p will vary by hydrologic soil group. The manual indicates that values for natural pervious cover from Table 3-1 should be used, as follows:

A: 0.2
B: 0.25
C: 0.30
D: 0.35

1.2.1.2 Volume-based Method 2

Volume-based methods 2 and 3 are described in Section 5.5 of the California Stormwater Quality Association's Stormwater Best Management Handbook for New Development and Redevelopment (CASQA, 2003). Volume-based method 2 (WEF/ASCE) is implemented as:

$$WQV = C * a * \left(\frac{P_{85}}{12}\right) * A$$

Where,
C = runoff coefficient, and
a = regression constant associated with drawdown (value provided for 48 hrs is 1.963 based on CASQA guidance).

For the WEF/ASCE method, *C* is not the same as the Rational Method C, but is calculated as:

$$C = 0.858 * (\%Imp)^3 - 0.78 * (\%Imp)^2 + 0.77 * \%Imp + 0.04$$

1.2.1.3 Volume-based Method 3

Volume-based method 3 uses the capture curves published by CASQA (2003; Appendix D), based on application of the STORM continuous simulation model. CASQA recommends use of the 48-hr drawdown curves and selecting the point on the curve for the appropriate Rational Method runoff coefficient corresponding to 90 percent capture of runoff. This yields a unit basin storage volume (inches), which is then multiplied by the actual drainage area to obtain the WQV.

CASQA provides a curve appropriate to the San Diego WSO Airport, which is used in application of this method throughout the City of San Diego. Tetra Tech fit a parametric model to the graphical representation. They were approximated using the following equation (Figure 1):

$$\%Capture = 100 * (1 - e^{-k*UBS}),$$

where *UBS* is in inches, representing unit BMP storage, and *k* is a constant dependent on the runoff coefficient (*C*).

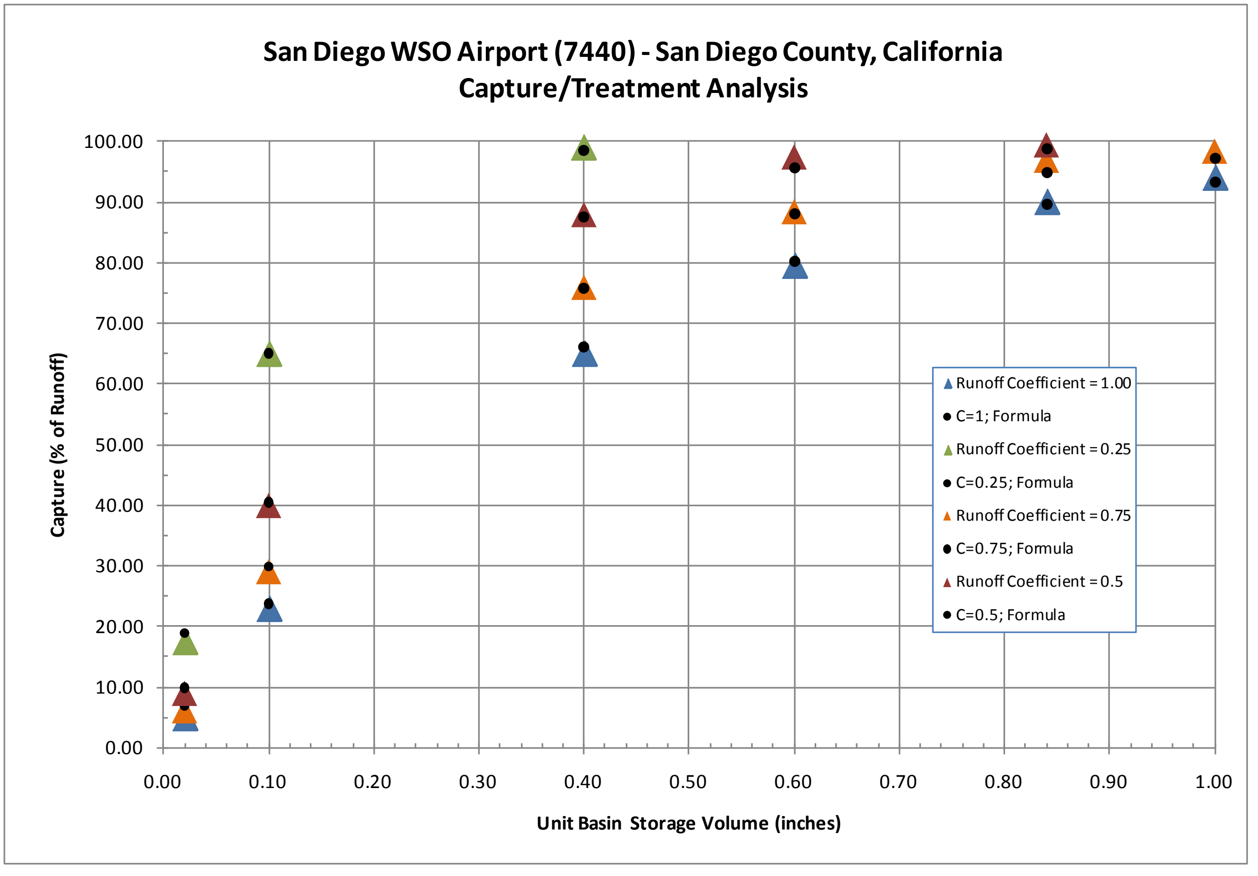


Figure 1 Parametric Fit to CASQA 48-hour Sizing Curves for San Diego WSO Airport

The relationship between *k* and *C* was developed using values of *k* derived from fitting the previous equation to the published CASQA runoff capture curve (Figure 2):

$$k = 2.6785\ C^{-0.98}.$$

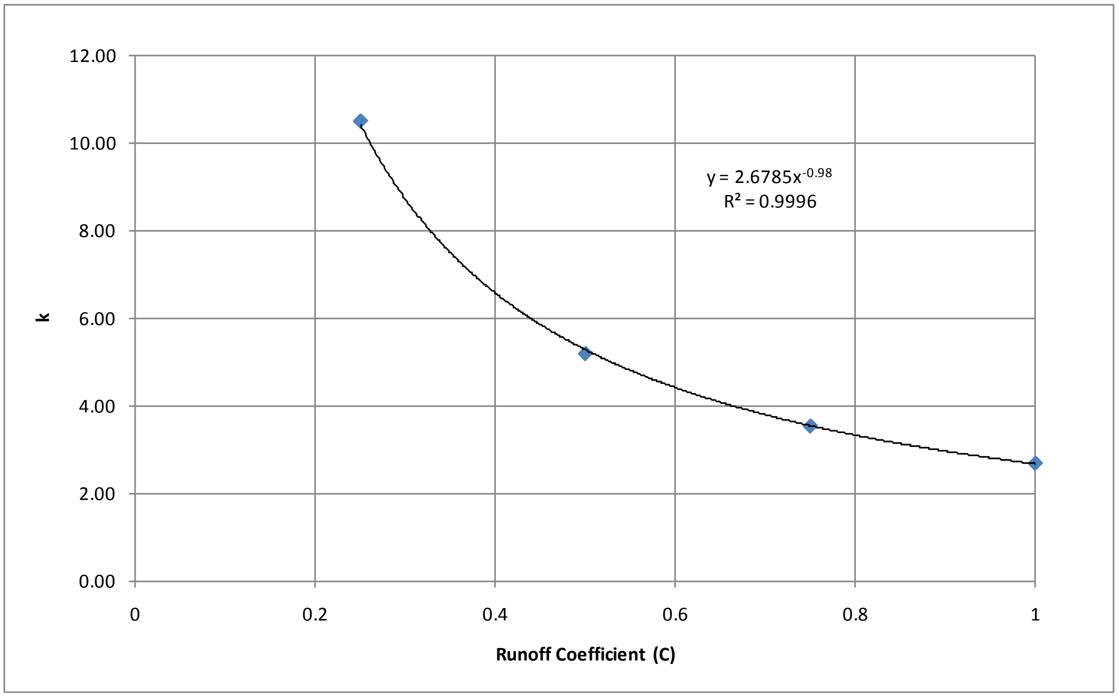


Figure 2 Capture Curve Exponent as a Function of Runoff Coefficient

Combining the equations and solving for *UBS* gives a relationship good for any value of C:

$$UBS = \frac{\ln\left(1-\frac{\%Capture}{100}\right)}{-(2.6785 * C^{-0.98})}.$$

1.2.2 Flow-based Control Practices

The City of San Diego Stormwater Manual (City of San Diego, 2008) details three methods to calculate flow-based sizing criteria for infiltrating, filtering, or treating:

1. The maximum flow rate of runoff produced from a rainfall intensity of 0.2 inch of rainfall per hour for each hour of a storm event

   or

2. The maximum flow rate of runoff produced by the 85th percentile hourly rainfall intensity, as determined from the local historical rainfall record, multiplied by a factor of two

   or

3. The maximum flow rate of runoff, as determined from the local historical rainfall record that achieves approximately the same reduction in pollutant loads and flows as achieved by mitigation of the 85th percentile hourly rainfall intensity multiplied by a factor of two.

Methods 1 and 2 describe how to apply the design rainfall intensity for flow-based control practices (i.e., applying a uniform 0.2 inches per hour intensity or applying the 85th percentile hourly rainfall intensity after multiplying by 2 as a safety factor). Method 3, however, is based on site-specific analysis of rainfall and runoff and presumably requires the creation of a site model. It is thus not amenable to the generic testing procedures used to compare the other methods and is not included in this analysis.

1.2.2.1 Flow-based Method 1

The water quality flow (WQF, cfs) is calculated as

$$WQF = C * 0.2 * \frac{A}{43{,}560},$$

where *C* is the rational method coefficient, as described above in Section 1.2.1.1, 0.2 is the assumed rainfall intensity of 0.2 in/hr, and *A* is the drainage area in acres.

1.2.2.2 Flow-based Method 2

Flow-based method 2 is similar to method 1, except that the flow is based on the 85th percentile value from a local rainfall method (*i*85), multiplied by a safety factor:

$$WQF = C * (i85 * 2) * \frac{A}{43{,}560}.$$

1.2.3 BMP Representation

The hydraulic performance of BMPs is simulated using HSPF model Functional Tables (FTables), which represent volume-stage-discharge relationships for one or multiple outputs. For the purpose of evaluating actual treatment fraction, these BMPs are implemented in the model on a unit-area basis. However, when needed, time of concentration for peak flows is evaluated on a more representative drainage area. This section describes the details of the representation of the three selected BMPs as HSPF FTables.

1.2.4 Dry Detention Basins

Dry detention basins are designed consistent with City of San Diego and CASQA (2003) guidance as a function of required water quality volume (WQV), using the following assumptions:

- Depth at WQV: 4 feet.
- Side slope ratio: 3 (W/H)
- Drawdown time for WQV: 48 hours[1]
- Overflow spillway and emergency spillway represented as trapezoidal weirs
- Freeboard between WQV and emergency spillway: 1 foot
- Pass 25-year peak flow at 0.3 feet over weir
- Pass 100-year peak flow at 0.2 feet over emergency spillway

Representation of flow through the orifice depends on the WQV and the drawdown time requirement. The time to drain a basin or "tank" by means of an orifice from depth h_1 to depth h_2 can be approximated for conditions of constant surface area and no inflow, by

[1] The San Diego SUSMP Appendix F recommends a drawdown time of 24 to 72 hours for extended detention; however CASQA recommends a maximum drawdown time of 48 hours to avoid nuisance vector growth. Therefore, a drawdown time of 48 hours is used in the simulations.

$$t = \frac{2\, A_t}{c\, A_o\, \sqrt{2\, g}} \left(\sqrt{h_1} - \sqrt{h_2} \right),$$

where A_t is the surface area, A_o is the cross-sectional area of the orifice, c is the orifice coefficient, g is acceleration due gravity, and h_i is the depth at time i. For the case of full drainage, $h_2 = 0$ and

$$t_{drain} = \frac{2\, A_t}{c\, A_o\, \sqrt{2\, g}} \left(\sqrt{h_{WQV}} \right),$$

where t_{drain} is the time required for drainage and h_{WQV} is the depth at the water quality volume. The equation provides a conservative estimate of drawdown time, as A_t actually becomes smaller as depth declines toward zero. Expressed in terms of the water quality volume, $A_t = V_{WQV}/h_{WQV}$, this yields

$$t_{drain} = \frac{2}{c\, A_o\, \sqrt{2\, g}} \left(\frac{V_{WQV}}{\sqrt{h_{WQV}}} \right).$$

Defining the "complex coefficient" $K = c\, A_o\, \sqrt{(2g)}/2$, this becomes

$$t_{drain} = \left(\frac{V_{WQV}}{K \sqrt{h_{WQV}}} \right),$$

and a value of K can be determined to achieve a desired drainage time.

Outflow rate through the orifice is then given by the general equation

$$Q = c\, A_o\, \sqrt{2\, g\, h} = 2\, K\, \sqrt{h}\, .$$

For representation in the FTable, to provide smooth transitions under conditions of variable elevation, $\sqrt{h}$ is represented by a central-difference averaging operator as:

$$\sqrt{h_i} = \frac{\sqrt{h_{i+1/2}} + \sqrt{h_{i-1/2}}}{2}.$$

Flow through the orifice is capped at a constant value when the depth exceeds the water quality volume. Actual flow will increase with increased head; however, the residence time will decrease, limiting treatment capacity. Therefore, assumption of capped flow through the orifice helps prevent overprediction of treatment efficiency.

Flows across the overflow spillway and emergency spillway are calculated with the Cipolletti trapezoidal weir formula:

$$Q = 3.367\, b\, H^{3/2},$$

where b is the length of the weir crest (in feet). The weir lengths are optimized to achieve the depth requirements for the 25-year and 100-year storms.

The detention basin can also lose water by infiltration, which is assumed to occur at a constant rate based on soil characteristics. This results in an FTable with three exits – for infiltration, orifice flow, and overflow (combined flow through the overflow and emergency spillways).

The flow volume considered treated is defined as the difference between inflow and untreated outflow, where the untreated outflow is given by the third (overflow) outlet in the FTable. An example FTable for a dry detention basin is shown below:

```
  FTABLE    112
 ***Det Ftable, B soils
  rows cols                         ***
   18    6
   DEPTH     AREA  VOLUME  INFILT     ORIFICE    OVERFLOW ***
      ft        ac        ac-ft         cfs           cfs           cfs            ***
     0.000   0.00050 0.0000000 0.0000000 0.0000000 00.000000
     0.500   0.00136 0.0004649 0.0010162 0.0066783 00.000000
     1.000   0.00262 0.0015625 0.0010162 0.0096997 00.000000
     1.500   0.00430 0.0036025 0.0010162 0.0119332 00.000000
     2.000   0.00639 0.0068950 0.0010162 0.0138006 00.000000
     2.500   0.00890 0.0117498 0.0010162 0.0154404 00.000000
     2.733   0.01020 0.0146328 0.0010162 0.0157978 00.000000
     3.000   0.01181 0.0184769 0.0010162 0.0169207 00.000000
     3.500   0.01515 0.0273861 0.0010162 0.0182806 00.000000
     4.000   0.01889 0.0387874 0.0010162 0.0193058 00.000000
     4.100   0.01969 0.0413940 0.0010162 0.0197979 00.371581
     4.200   0.02050 0.0441152 0.0010162 0.0197979 01.050991
     4.300   0.02133 0.0469533 0.0010162 0.0197979 01.930793
     4.400   0.02218 0.0499111 0.0010162 0.0197979 03.594309
     4.500   0.02305 0.0529908 0.0010162 0.0197979 05.912720
     4.600   0.04105 0.0955686 0.0010162 0.0197979 08.691337
     5.000   0.16464 0.4128518 0.0010162 0.0197979 23.263697
     5.300   0.31150 0.8268016 0.0010162 0.0197979 37.075368
  END FTABLE112
```

1.2.5 Bioretention

Representation of bioretention is more complex than extended detention because of the multiple layers involved. The design is not fully described in existing City and CASQA manuals, so the specifications are taken from the draft City of San Diego manual under development.

In general, bioretention consists of three layers representing: (1) surface storage, (2) the planting medium, and (3) an underlying gravel layer that may or may not include an underdrain. Each of these layers is represented by a separate FTable. These components can be constructed in a variety of different ways. For the case represented here the following assumptions are made.

Surface storage layer:

- 9" maximum surface ponding depth
- Maximum drawdown time for surface ponding of 48 hours

- Sizing is determined by the WQV, which is set equal to the volume contained in the 9" ponding depth plus the available void space (depth times effective porosity minus field capacity) in the planting medium
- Aspect ratio (L:W) of 2
- Overflow in excess of the ponding depth occurs via a level spreader with length equal to the width of the bioretention cell. A riser that discharges to the gravel layer is not used.
- Side slope ratio above the ponding depth of 3:1 (L:H)
- *Maximum* infiltration (determined by the planting medium) is 2 in/hr (see below for calculation of actual infiltration)

Planting Medium Layer

- Planting medium depth: 3 feet
- Effective porosity: 41.2 percent, typical of sandy loam (Maidment, 1993)
- Residual water content: 4.1 percent
- Area equal to the bottom of the surface storage area, with vertical sides
- Evapotranspiration occurs from planting layer

Gravel Layer

- Gravel layer thickness: 1.5 feet
- Effective porosity: 41.2 percent
- Infiltration from base: Dependent on soil characteristics (2 in/hr B soils; 0.1 in/hr D soils)
- Underdrain: Required for C and D soils only, with the following characteristics:
    - Underdrain diameter: 6 in
    - Slotted drain with a slot area of at least 1 in/ft
    - Invert of underdrain: 6 in. above base of gravel layer to allow dead space for denitrification.

The surface layer has two flow outlets: overflow and infiltration. When the ponding depth in the surface layer is exceeded, overflow occurs across the level spreader, represented as a trapezoidal weir using the Cipolletti equation, as described above:

$$Q = 3.367\, b\, H^{3/2}$$

The process of infiltration into partially saturated soils is complex, and accurate solutions (e.g., Philip or Green-Ampt equation) do not have closed forms, depend on time and initial conditions, and must be solved iteratively – and are thus not convenient for use in an FTable representation. The long-term model, however, operates on a 1-hour time step, and the initial wetting phase tends to asymptote toward a steady rate for times longer than 1 hour (Viessman et al., 1989). Therefore, a simplified approach is taken in which infiltration from the ponding layer into the soil medium occurs at the nominal infiltration rate but is limited to a maximum equivalent to the unfilled pore volume of the soil medium. This limitation on infiltration is implemented through HSPF SPECIAL ACTIONS which calculate the available pore space for each time step and reset the flow demand for the infiltration outlet from the ponding layer when sufficient pore space is not available to achieve the maximum infiltration rate.

The planting medium layer receives inflow from the surface layer, and has one flow outlet (in addition to evapotranspiration): infiltration to the gravel layer. This infiltration begins after field capacity for the entire planting medium column is satisfied. Infiltration rate is then determined as a fraction of the maximum (saturated) infiltration rate via the relationship of Brooks and Corey (1964):

$$\frac{K(\theta)}{K_s} = \left(\frac{\theta - \theta_r}{\phi - \theta_r}\right)^n ,$$

in which $K(\theta)$ is the hydraulic conductivity or infiltration rate of water content θ, θ_r is the residual water content, φ is the effective porosity, and $n = 3 + 2/\lambda$. For sandy loam, $\lambda = 0.378$ and $n = 8.291$.

In cases where an underdrain is used in the gravel layer, flow patterns are again theoretically complex and would require a drainage equation (such as the Hooghoudt equation) for detailed analysis. However, the underdrains for bioretention are purposely oversized and the hydraulic conductivity of the gravel layer is high. Therefore, a simplified approach is used in which the flow resulting from an orifice equation applied to the underdrain, and flow from a weir equation applied to the wetted slot area are compared and the lower value chosen.

This approach results in three linked FTables for bioretention (upper, middle, and lower), as shown in the following example:

```
  FTABLE    241
***BR upper, D soils
 rows cols                          ***
   17    5
  DEPTH   AREA    VOLUME  OVERFL     NOM INFILT  ***
    ft          ac         ac-ft          cfs              cfs               ***
    0.000   0.02190 0.0000000 000.00000 0.0000000
    0.188   0.02190 0.0041069 000.00000 0.0441717
    0.375   0.02190 0.0082137 000.00000 0.0441717
    0.563   0.02190 0.0123206 000.00000 0.0441717
    0.750   0.02190 0.0164275 000.00000 0.0441717
    0.800   0.02212 0.0176928 000.58139 0.0441717
    0.850   0.02233 0.0189795 001.64442 0.0441717
    0.950   0.02275 0.0216165 004.65111 0.0441717
    1.050   0.02318 0.0243387 008.54464 0.0441717
    1.150   0.02361 0.0271460 013.15534 0.0441717
    1.250   0.02403 0.0300383 018.38515 0.0441717
    1.350   0.02446 0.0330157 024.16790 0.0441717
    1.450   0.02488 0.0360783 030.45504 0.0441717
    1.550   0.02531 0.0392259 037.20892 0.0441717
    1.650   0.02573 0.0424586 044.39927 0.0441717
    1.750   0.02616 0.0457764 052.00104 0.0441717
    1.850   0.02658 0.0491793 059.99307 0.0441717
  END FTABLE241
***
```

```
  FTABLE    251
***Bioretention media layer, D soils
 rows cols                          ***
   8    4
  DEPTH   AREA    VOLUME   PERCOLATION***
      ft       ac        ac-ft          cfs           ***
     0.000   0.02190 0.0000000 0.0000000
     0.299   0.02190 0.0026941 0.0000000
     2.026   0.02190 0.0182838 0.0010847
     2.364   0.02190 0.0213311 0.0047662
     2.701   0.02190 0.0243784 0.0167288
     2.900   0.02190 0.0261701 0.0323092
     3.000   0.02190 0.0270725 0.0441717
     3.100   0.02190 0.0541450 0.0597070
  END FTABLE251
***
  FTABLE    261
***Bioretention lower layer Ftable, D soils
 rows cols                          ***
   9    5
  DEPTH   AREA    VOLUME   INFILT     UNDERDRAIN  ***
     ft        ac        ac-ft          cfs            cfs ***
     0.000   0.00000 0.0000000 0.0000000 0.0000000
     0.250   0.02190 0.0022560 0.0022086 0.0000000
     0.500   0.02190 0.0045121 0.0022086 0.0000000
     0.667   0.02190 0.0060161 0.0022086 0.2559985
     0.833   0.02190 0.0075201 0.0022086 0.3620366
     1.000   0.02190 0.0090242 0.0022086 0.4434025
     1.167   0.02190 0.0105282 0.0022086 0.5119971
     1.333   0.02190 0.0120322 0.0022086 0.5724301
     1.500   0.02190 0.0270725 0.0022086 0.9914781
  END FTABLE261
```

1.2.6 Vegetated Swales

Unlike the previous two BMPs, vegetated swales are sized according to a flow-based requirement – a water quality flow (WQF). The design follows CASQA (2003, TC-30). Basic assumptions for the swale simulation are as follows:

- Treatment depth: 4 in., at the WQF
- Infiltration: dependent on native soil, through the flat bottom layer only
- Manning's coefficient (for WQF): 0.25
- Length: 50 ft. (for example; generally required to be less than 100 ft.)
- Side slope ratio: 3:1
- Channel slope: 2 % (required to be < 2.5%)
- Width determined by requirement to achieve a residence time of > 10 min at the WQF
- Release treated WQF through V-notch weir

- Flow in excess of WQF released via a trapezoidal weir with width of 4.5 ft.
- Total swale size is sufficient to safely pass the 100-year runoff event

The key factor for sizing is achieving the residence time requirement at the WQF. For steady uniform flow in a channel, the flow rate (cfs) can be calculated using the Manning formula:

$$Q_{channel} = A \cdot V = A \cdot \left(\frac{1.486}{n}\right) \cdot R^{2/3} \cdot S^{1/2},$$

where A is the cross-sectional area, V is the flow velocity, n is the Manning coefficient, R is the hydraulic radius, and S is the channel slope. $Q_{channel}$ must be greater than the WQF at the treatment depth. The actual rate of flow is then restricted by the V-notch weir. The residence time (t) at the treatment depth is

$$t = \frac{L}{V_{WQF}} = \frac{L}{(WQF - I)/A_{TD}},$$

where L is the channel length, V_{WQF} is the velocity at the WQF, I is the infiltration loss (as cfs), and A_{TD} is the cross-sectional area at the treatment depth of 4 in. A_{TD} is a function of channel bottom width and side slope ratio, and the channel bottom width is solved iteratively to achieve t slightly greater than 10 minutes.

Once the channel dimensions are set, the weir is designed to achieve the desired outflow rate at the treatment depth. The general equation for a V-notch weir is

$$Q = m\,H^{5/2},$$

where H is the elevation and m is a factor that depends on the angle of the notch. Substituting Q = (WQF – I) and H = 4 in. yields a value of m that satisfies the retention requirement for the WQF.

When flow exceeds the WQF outflow is calculated with the Cipolletti trapezoidal weir formula:

$$Q = 3.367\,b\,H^{3/2},$$

where b is the length of the weir crest (4.5 feet) and H is the elevation over the weir. After the 4 in. treatment depth is exceeded, treated flow through the V-notch weir is assumed to remain constant.

The resulting FTable has three exits: infiltration, treated flow through the V-notch weir, and untreated overflow, as shown in the following example:

```
  FTABLE    131
***Swale Ftable - B soils; infilt to ground
 rows cols                               ***
   23    6
  DEPTH    AREA    VOLUME   INFILT      TREATED OVERFLOW  ***
     ft    ac       ac-ft    cfs          cfs        cfs          ***
    00.00   00.0059 00.000000 00.000000 00.000000 00.000000
    00.03   00.0061 00.000199 00.011806 00.000532 00.000000
    00.07   00.0063 00.000406 00.011806 00.003009 00.000000
    00.10   00.0065 00.000620 00.011806 00.008291 00.000000
    00.13   00.0068 00.000842 00.011806 00.017020 00.000000
    00.17   00.0070 00.001071 00.011806 00.029733 00.000000
    00.20   00.0072 00.001309 00.011806 00.046902 00.000000
    00.23   00.0075 00.001553 00.011806 00.068954 00.000000
    00.27   00.0077 00.001806 00.011806 00.096280 00.000000
    00.30   00.0079 00.002066 00.011806 00.129246 00.000000
    00.33   00.0081 00.002334 00.011806 00.168194 00.000000
    00.37   00.0084 00.002609 00.011806 00.168194 00.092209
    00.40   00.0086 00.002893 00.011806 00.168194 00.260807
    00.43   00.0088 00.003183 00.011806 00.168194 00.479132
    00.47   00.0091 00.003482 00.011806 00.168194 00.737673
    00.50   00.0093 00.003788 00.011806 00.168194 01.030929
    00.53   00.0095 00.004102 00.011806 00.168194 01.355191
    00.57   00.0098 00.004423 00.011806 00.168194 01.707736
    00.60   00.0100 00.004752 00.011806 00.168194 02.086454
    00.70   00.0107 00.005785 00.011806 00.168194 03.364053
    00.80   00.0114 00.006887 00.011806 00.168194 04.830208
    00.90   00.0121 00.008058 00.011806 00.168194 06.463193
    01.00   00.0127 00.009298 00.011806 00.168194 08.247432
  END FTABLE131
```

1.2.7 Model Implementation

Performance of different BMP sizing criteria were evaluated through continuous simulation (at a 1-hour time step) over the 57-year period for which the required meteorological input (hourly precipitation and potential evapotranspiration) are readily available in the BASINS4 meteorological data set. The general setup of the HSPF model followed the parameters used in the calibrated Los Peñasquitos LSPC/HSPF model. Simulation was done on a unit-area basis, using the BMP representation techniques described in Section 1.2.3.

Tetra Tech designed the simulation experiments to test a number of possible confounding factors or co-factors in addition to the sizing methods themselves. These included:

- Three different precipitation regimes were tested, using long-term precipitation records from (in order of declining average annual rainfall) La Mesa, Chula Vista, and San Diego WSO.
- Two hydrologic soil groups were included, representing B and D soils.
- The drainage area was assumed to consist of impervious surfaces and urban pervious surfaces. Combinations were tested at four levels (100 percent, 85 percent, 50 percent, and 20 percent impervious).

When combined with three BMP types and either three sizing methods (for volume-based sizing) or two sizing methods (for flow-based sizing) this results in a total of 192 57-year simulation runs.

The three meteorological stations were selected because they had long periods of record, with computed evapotranspiration by the Hamon method, and because they represent the range of rainfall experienced across the City of San Diego – although Chula Vista and La Mesa are just outside the city limits (Figure 3). The common period of precipitation data available in BASINS4 for these stations is 1 October 1948 to 30 September 2005. A series of daily irrigation demands (IRRDEM) for urban grass were created for Chula Vista and La Mesa after correcting for the precipitation total on the current and previous two days as

$$IRRDEM = (PET \cdot Kc) - PSum,$$

where PET is the potential evapotranspiration on the day, PSum is the sum of the precipitation on the current and previous two days, and Kc is a crop coefficient of 0.6 for warm season turf grass from the WUCOLS III manual (UCCE, 2000). When applied in the model, the actual irrigation demand is adjusted by a factor of 0.824, reflecting an assumed application to 70 percent of the area divided by an application efficiency of 0.85. The irrigation demand is assumed to be met with imported water. PET and irrigation demand for Chula Vista are also applied to the San Diego WSO weather station, as continuous PET estimates are not available there for earlier periods.

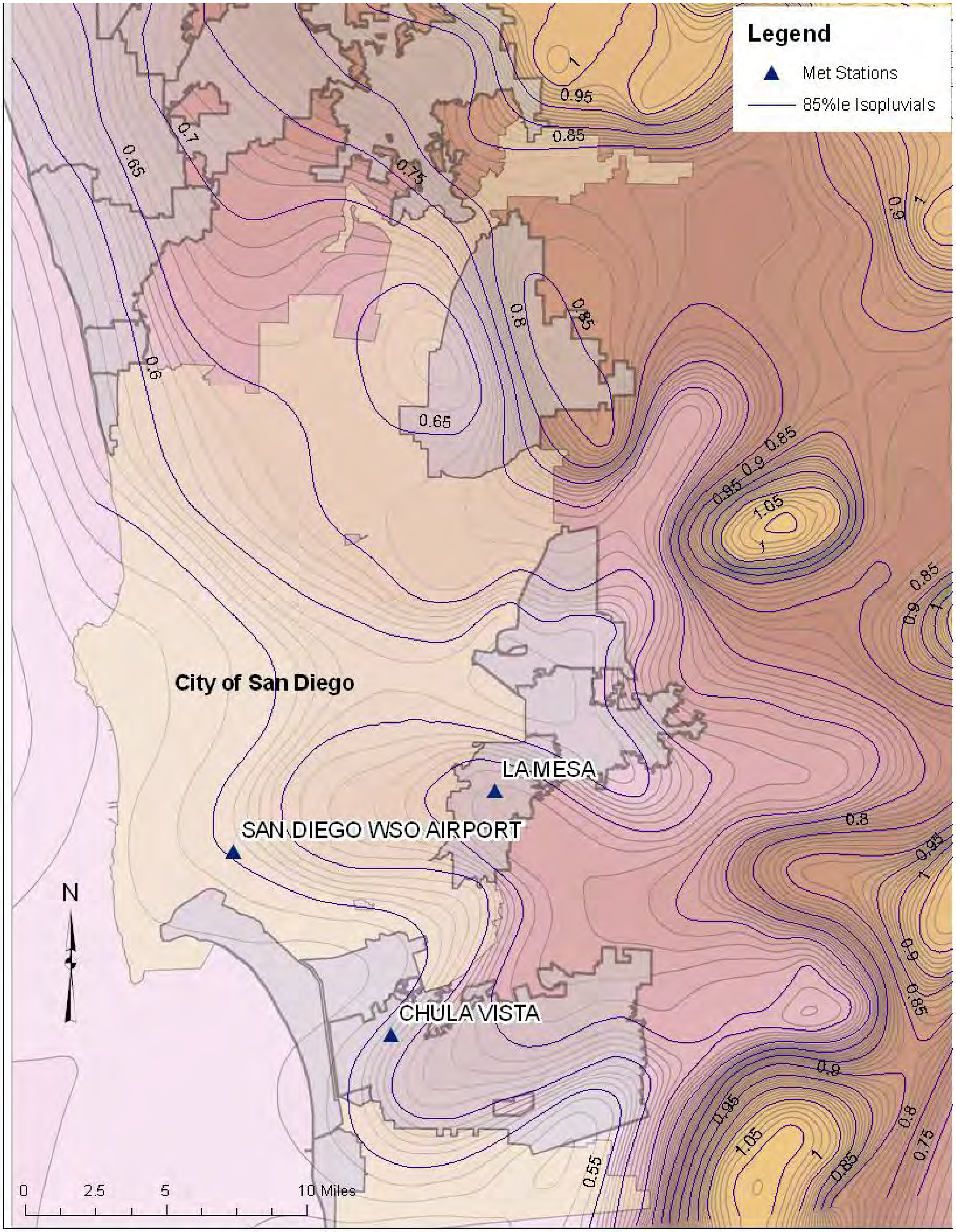


Figure 3 Meteorological Stations and 85th Percentile 24-hour Isopluvials

Basic statistics for the three meteorological stations over the application period of Water Years 1949 – 2005 are summarized in Table 1. La Mesa has the higher average annual precipitation. While San Diego WSO and Chula Vista have similar long-term precipitation, storm event precipitation intensity is somewhat greater at Chula Vista as shown by the difference in the isopluvials.

Table 1 Meteorological Series, Water Years 1949 - 2005

Station	Precipitation (in/yr)	Potential Evapotranspiration (in/yr)	Irrigation Demand (in/yr)
San Diego WSO	9.92	30.21	16.26
Chula Vista	9.44	30.21	16.26
La Mesa	12.65	33.05	17.81

Example results of simulated BMP response to storm events of February 6 – 8, 1998 are shown in Figure 4 through Figure 6, using sizing methods 2 with La Mesa precipitation. A small rainfall event occurred on February 6, followed by a larger event on the night of February 7 – 8 with intensities greater than 0.40 in/hr.

The detention basin BMP (Figure 4) captured, treated, and released the entire volume of the first, smaller event. During the larger event the capacity reached the spillway and a short period of untreated runoff occurred, followed by a long, slowly declining period of treated release.

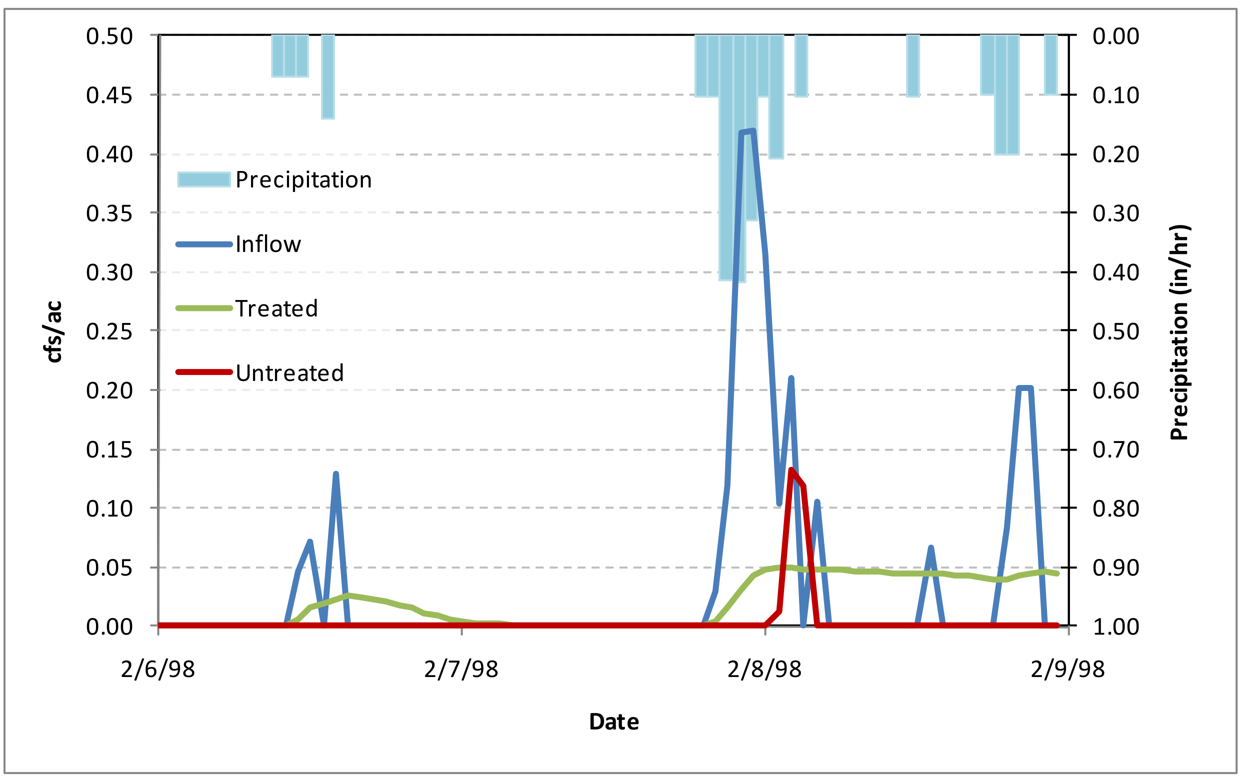


Figure 4 Dry Detention Basin BMP Simulation Example (La Mesa Precipitation Series, Volume-based Sizing Method 2, 100% Impervious)

The bioretention BMP (Figure 5) was able to absorb the entire amount of the smaller event without producing any outflow. However, during the intense larger event, the surface storage capacity was overwhelmed, resulting in a large amount of untreated runoff. In contrast, the water quality swale (Figure 6) provides little storage, so inflows track outflows. The treatment capacity of the swale is also rapidly overwhelmed during the intense event of 2/8/1998.

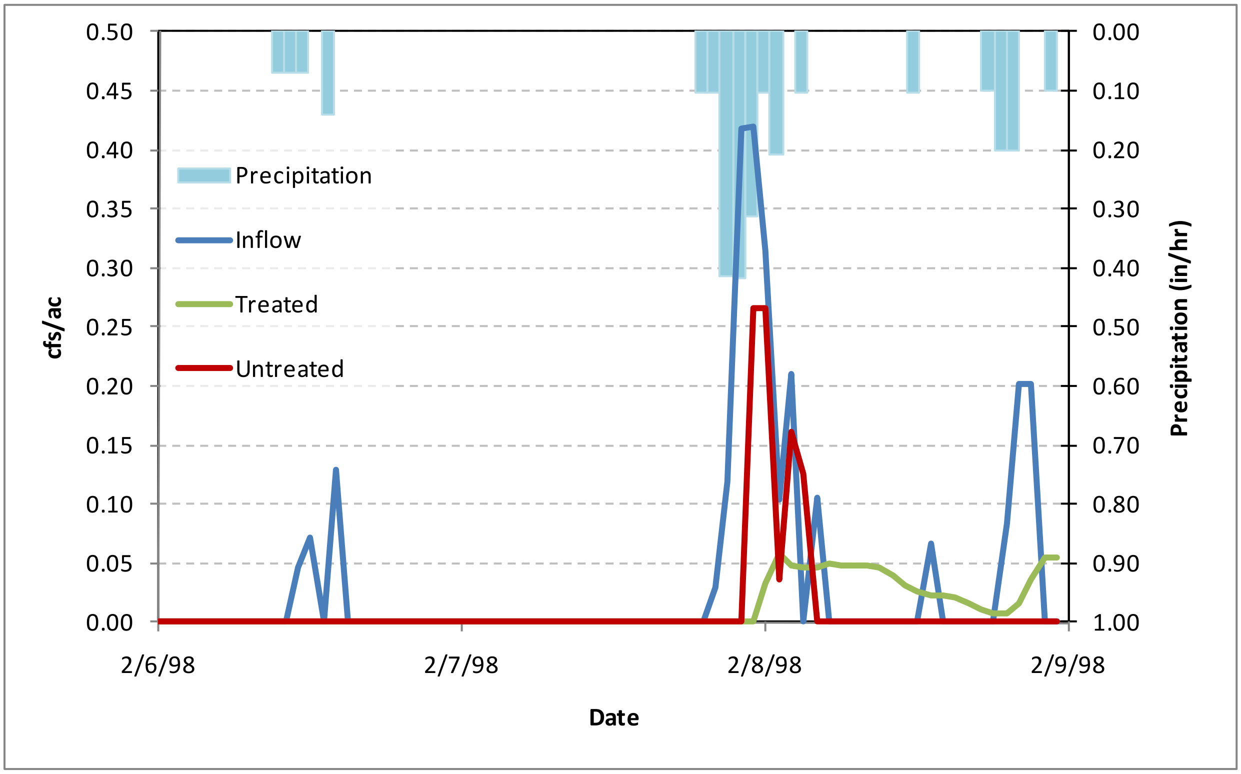


Figure 5 Bioretention BMP Simulation Example (La Mesa Precipitation Series, Volume-based Sizing Method 2, 100% Impervious)

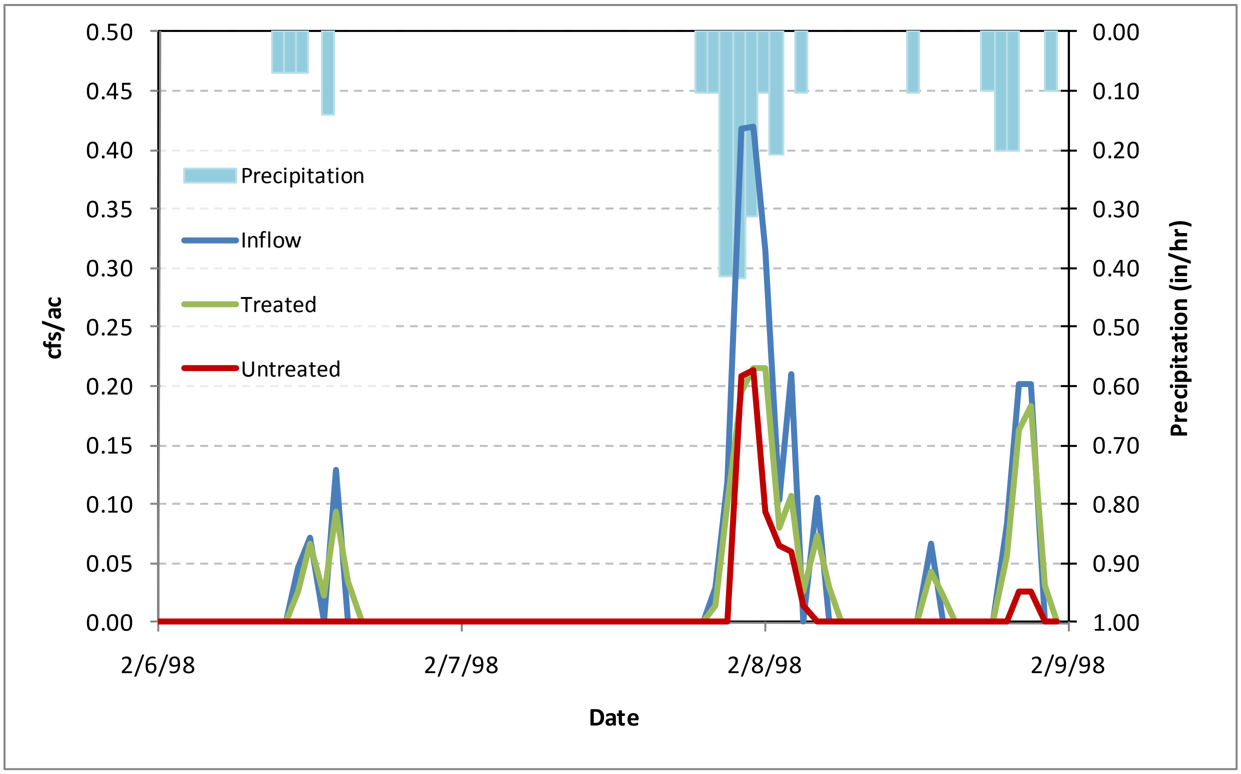


Figure 6 Water Quality Swale BMP Simulation Example (La Mesa Precipitation Series, Flow-based Sizing Method 2, 100% Impervious)

Results for this specific set of storms and sizing methods are summarized in Table 2. For these conditions, dry detention provides the highest degree of treatment, with only 10 percent of the inflow untreated. However, bioretention provides the greatest reduction in flows transmitted downstream.

Table 2 Comparison of BMP Results for Storms of 2/6 – 2/8/1998 (La Mesa Precipitation Series, Sizing Method 2, 100% Impervious)

Component	Dry Detention	Bioretention	Water Quality Swale
Precipitation (in)	2.82	2.82	2.82
Inflow (in/ac)	2.60	2.60	2.60
Treated Outflow (in/ac)	2.28	1.19	1.89
Untreated Outflow (in/ac)	0.26	0.85	0.70
Retention (in/ac)	0.06	0.57	0.01

1.3 Results of Simulation Analyses

1.3.1 BMP Sizing

Calculated BMP sizing criteria for B and D soils, different percent imperviousness, and different weather stations are shown in Table 3 and

Table 4. The resulting range of results varies significantly by method. For volume-based sizing, flow-based method 2 requires nearly double the sizing of method for 100 percent impervious contributing area. However, method 3 requires the largest volume for imperviousness of 50 percent or smaller. For the flow-based methods, method 2 requires larger capacity unless the precipitation series matches the default from San Diego WSO.

Table 3 Unit Area Volume-Based BMP Sizing (ft^3/ac)

Percent Impervious	Sizing Method	B soils			D soils		
		Chula Vista	La Mesa	San Diego WSO	Chula Vista	La Mesa	San Diego WSO
100%	1	1,895	2,222	1,830	1,895	2,222	1,830
	2	3,670	4,303	3,543	3,670	4,303	3,543
	3	2,814	2,814	2,814	2,814	2,814	2,814
85%	1	1,690	1,981	1,631	1,721	2,018	1,662
	2	2,719	3,188	2,625	2,719	3,188	2,625
	3	2,515	2,515	2,515	2,561	2,561	2,561
50%	1	1,211	1,419	1,169	1,316	1,543	1,271
	2	1,394	1,634	1,346	1,394	1,634	1,346
	3	1,814	1,814	1,814	1,969	1,969	1,969
20%	1	800	938	772	986	1,135	935
	2	701	822	677	701	822	677
	3	1,209	1,209	1,209	1,458	1,458	1,458

Table 4 Unit Area Flow-Based BMP Sizing (ft^3/ac)

Percent Impervious	Sizing Method	B soils			D soils		
		Chula Vista	La Mesa	San Diego WSO	Chula Vista	La Mesa	San Diego WSO
100%	1	0.180	0.180	0.180	0.180	0.180	0.180
	2	0.198	0.216	0.180	0.198	0.216	0.180
85%	1	0.161	0.161	0.161	0.164	0.164	0.164
	2	0.177	0.193	0.161	0.180	0.196	0.164
50%	1	0.115	0.115	0.115	0.125	0.125	0.125
	2	0.127	0.138	0.115	0.138	0.150	0.125
20%	1	0.076	0.076	0.076	0.092	0.092	0.092
	2	0.084	0.091	0.076	0.101	0.110	0.092

1.3.2 Basis of Sizing Method Performance Comparison

The long-term performance of sizing method and BMP combinations is evaluated on the basis of the percent of inflow volume that is treated by the BMP (percent capture). The treated volume consists of water that is either returned to the atmosphere or discharged after sufficient retention to allow pollutant treatment and removal. In the case of detention ponds, the treated discharge is that portion of the flow that exits through the orifice designed to provide the desired retention time, while for bioretention any water released by an underdrain is a treated discharge. In the case of water quality swales, treated discharge is that portion of the flow that is retained for a minimum of 10 minutes within the 4-inch grass layer. Analysis of the percent capture is most easily estimated from the untreated or bypassed volume, as (Influent – Bypass)/Influent volume.

Comparison can be made on both a relative and an absolute basis. The San Diego Regional Board Order No. R9-2007-0001 (San Diego Regional Board, 2007, D.1.d(6)(c)) does not define a specific target for percent capture; rather, it refers to the BMP sizing criteria, such as those contained in the City of San Diego’s (2008) guidance and describe in Section 1. The 2002 model Standard Urban Storm Water Mitigation Plan (SUSMP) and the 2009 draft model SUSMP (San Diego Copermittees, 2002, 2009) also are phrased in terms of BMP sizing criteria, rather than capture fraction. CASQA (2003) states that the “knee of the curve” for benefit versus cost in sizing BMPs is equivalent to 75 to 85 percent capture of the annual runoff, and recommends using a percent capture target of 85 percent in cases where there are no local recommendations. They also demonstrate that the WEF (1998) method should approximately yield a percent capture of 82 to 88 percent.

San Diego’s Stormwater Standards (City of San Diego, 2008) list the CASQA methodology as one of three volume-based sizing options, but specify a percent capture of 90 percent: “The volume of annual runoff based on unit basin storage volume, to achieve 90 percent or more volume treatment by the method recommended in the latest edition of the California Stormwater Best Management Practices Handbook.” Therefore, for the City of San Diego a percent capture of 90 percent is taken as a quantitative target for the BMP analysis. However, percent capture in the range of 85 – 90 percent may also be acceptable.

Finally, the role of BMPs in hydromodification should also be considered. Volume-based BMPs typically clip the peak of the hydrograph and limit extreme flows. However, they may also extend the trailing limb of the hydrograph through gradual release of the event volume, leading to extended periods of moderate flows. If the resulting flows are within the range in which effective work is done on the bed and bank sediments of the receiving channel these extended flows may promote channel degradation relative to natural conditions. The City is still in the process of developing a hydromodification management plan and quantitative goals for hydrograph matching have not been adopted. The current simulations, however, enable an examination of the relative effect on the hydrograph of the BMP types and sizing criteria.

1.3.3 Percent Capture Results

The average percent capture over all simulations was 84.6 percent, which is slightly less than the target percent capture of 90 percent. The results, however, very significantly according to BMP type and sizing rule (Table 5).

Table 5 Percent Capture Results for BMPs and Sizing Methods over all Meteorological Stations and Land Use Combinations

Sizing Method	Detention Basin	Water Quality Swale	Bioretention	Method Average (all BMPs)
Volume 1/ Flow 1	85.74%	82.06%	73.46%	80.42%
Volume 2/ Flow 2	92.88%	84.16%	82.68%	86.58%
Volume 3	93.81%	--	84.57%	89.19%
BMP Average (all sizing methods)	90.81%	83.11%	80.24%	84.92%

In terms of sizing methods, method 1 (volume produced by 85th percentile rainfall event using Rational Method, or maximum flow rate produced from a rainfall intensity of 0.2 in/hr) produced the lowest percent capture, with an average (across all BMP types) of 80.4 percent. Volume-based method 1, in particular, appears to result in undersized BMPs relative to the 90 percent capture target.

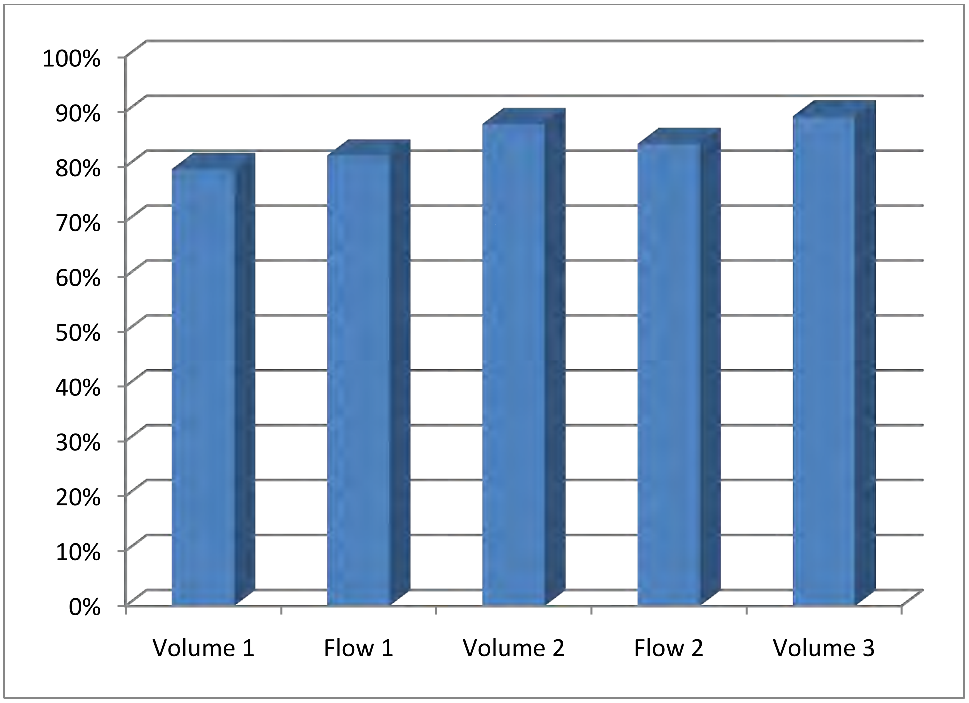


Figure 7 Percent Capture as a Function of Sizing Method

For BMP types, the detention basin achieves the greatest percent capture under current sizing methods (Figure 8), with an overall average of 90.8 percent. This makes some sense in that existing sizing methods are focused on traditional capture BMPs. Bioretention achieves the lowest percent capture under current sizing methods (average of 80.2 percent), suggesting that the sizing methods might need to be revised for bioretention.

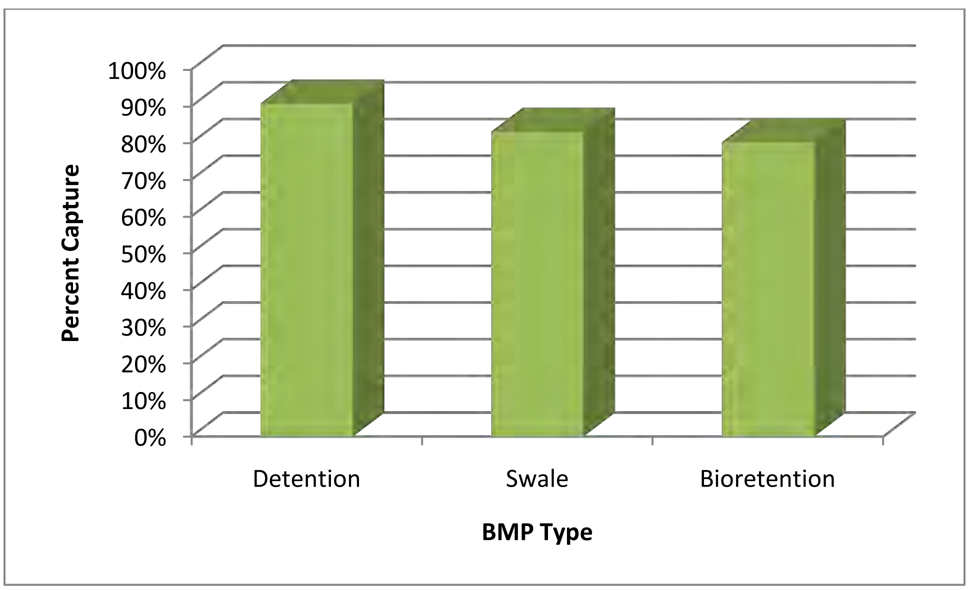


Figure 8 Percent Capture as a Function of BMP Type

Several potential confounding factors were also investigated. Changes in percent capture by weather station (Figure 9) are minimal, with only a few percentage points difference. However, percent capture increases as the fraction of the drainage area that is impervious decreases (Figure 10). This suggests that the sizing methods are biased in their representation of pervious versus impervious runoff in the San

Diego area. A more detailed examination (Figure 11) shows that this increase in percent capture with declining imperviousness occurs with all sizing methods except for volume-based method 2. This is the WEF/ASCE method, which uses a non-linear regression against percent imperviousness to estimate the runoff coefficient. This apparently corrects for the bias that occurs when the rational method for the runoff coefficient is applied to sites with lower imperviousness.

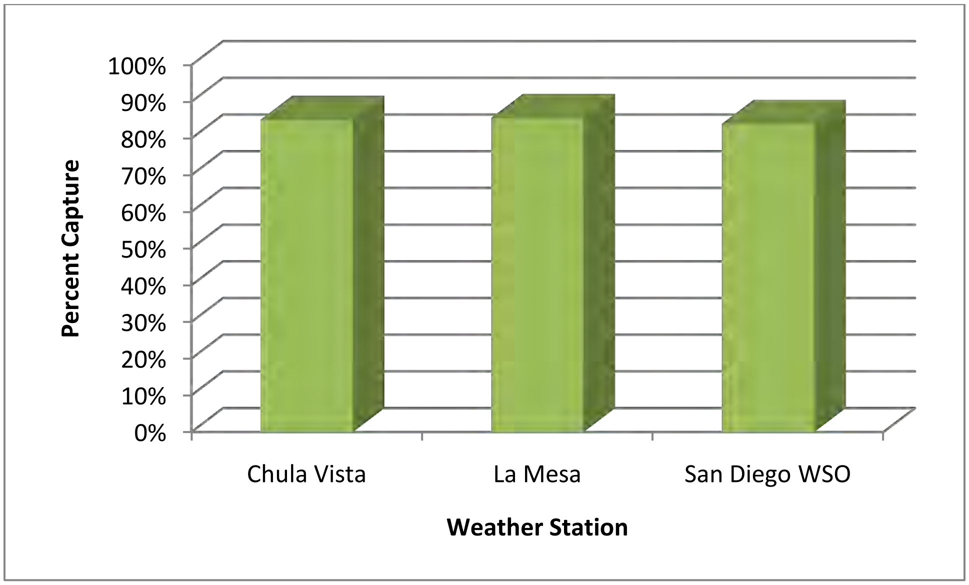


Figure 9 Percent Capture as a Function of Weather Station

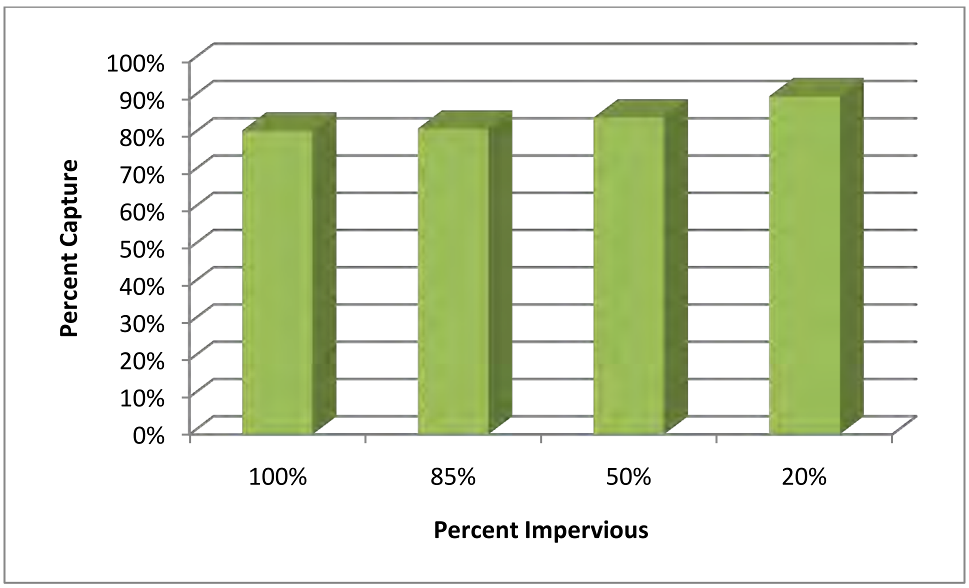


Figure 10 Percent Capture as a Function of Impervious Percentage

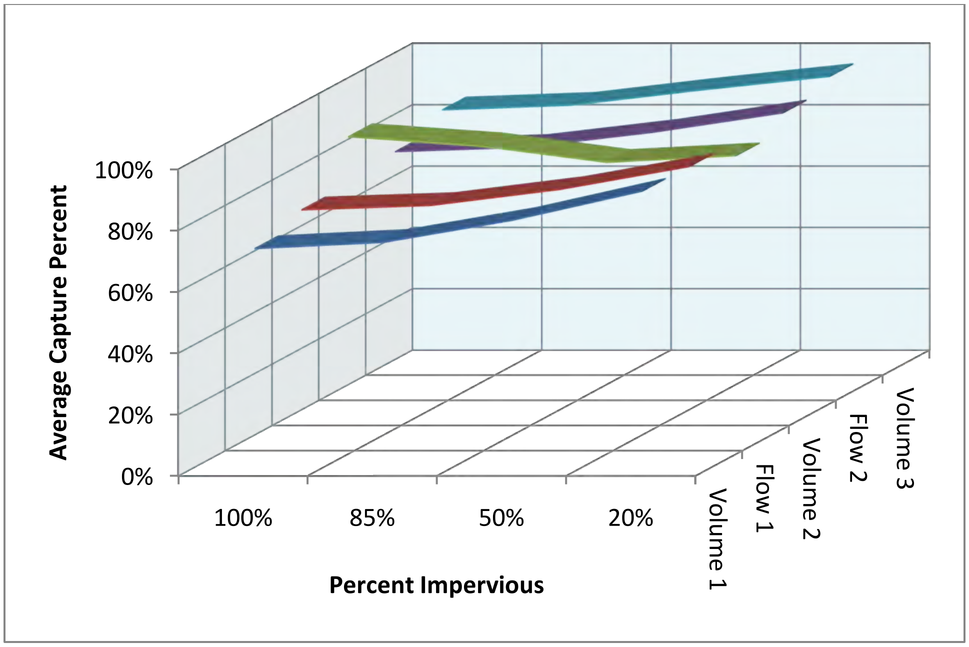


Figure 11 Percent Capture as a Function of Impervious Percentage and Sizing Method

1.3.4 Hydromodification Management

The current BMP design specifications and sizing criteria (as described in Section 1.2.3) are not optimized to address hydromodification – the changes in the stream hydrograph that result from development and increased impervious surface area. Traditional BMP design focuses on controlling peak flows, with less attention to the flows in the declining limb of the hydrograph. The general concern is that storage BMPs, while clipping peak flows, can provide extended periods of moderate flows that continue to do work on sediments in the channel. The BMP simulations described in this section can also be used to examine the hydromodification issue.

The flow-duration analysis displayed in Figure 12 (which shows simulations for 100 percent impervious area, D soils, using sizing method 2 with La Mesa precipitation as unit runoff in cfs/ac) demonstrates that the volume-based BMPs (detention and bioretention) clearly reduce the peak flows (by about 0.05 cfs/ac) relative to "unmitigated" runoff without BMPs. They differ in that bioretention retains many of the smaller flows, whereas detention basins release these gradually. Flow-based swales have only a small impact on the total hydrograph.

In contrast, Figure 13 compares the flow-duration curves from BMP outflows to pre-development hydrology (assumed to be 100 percent pervious grass on D soils without irrigation). Clearly, none of the BMP designs wholly match pre-development hydrology.

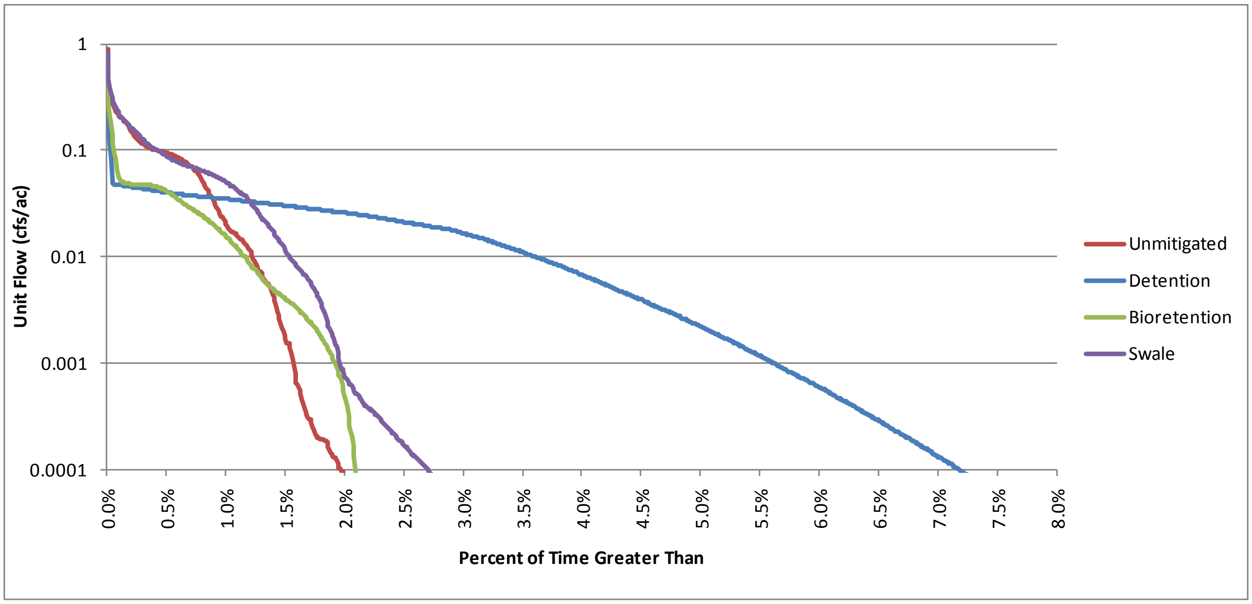


Figure 12 Flow-Duration Analysis of Hydrograph Impacts by BMP, Type D soils

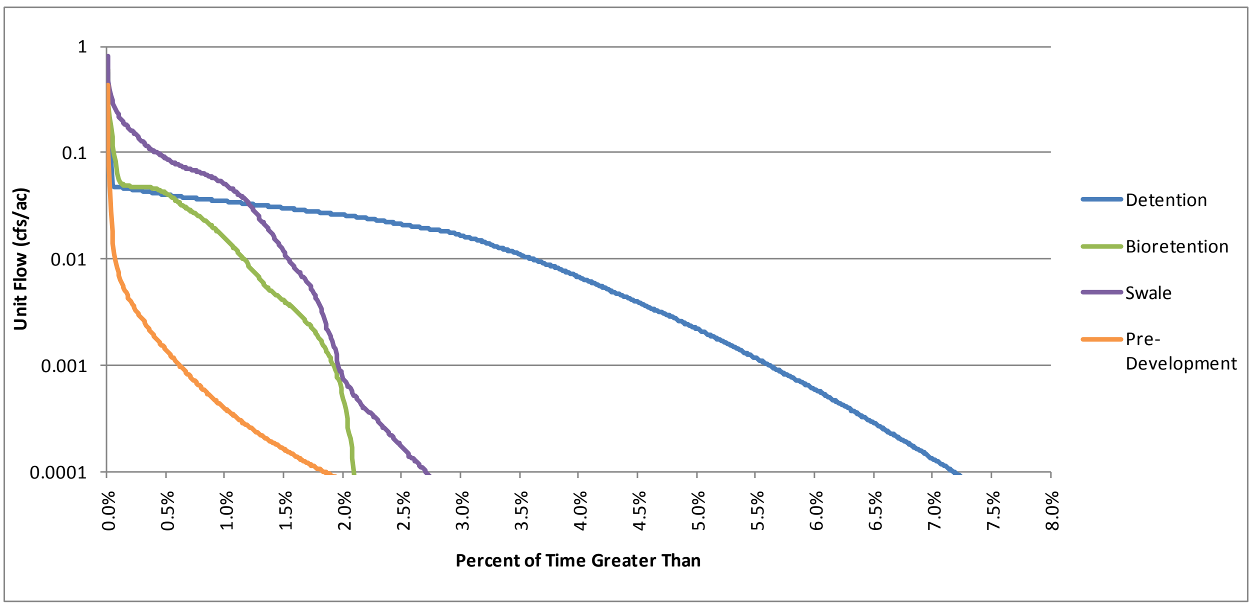


Figure 13 BMP Outflow Hydrographs Compared to Pre-Development Hydrograph, D soils

The range of flows that will need to be addressed for hydromodification management has not yet been finally determined for San Diego. Typically, flows must be controlled down to a low frequency of recurrence as a majority of the cumulative effective work on channels is accomplished by flows that recur with a frequency of less than 2 years. Intensive analysis in the San Francisco Bay region resulted in hydromodification rules that require approximating the pre-development hydrograph between one-tenth of the Q2 (2-year recurrence) flow and the Q10 flow (e.g., San Francisco Regional Board, 2005). A recent memorandum prepared for the County of San Diego (Dubin and Mosolgo, 2010) recommends that flow rates from one-tenth of the Q2 to the Q10 should not deviate by more than 10 percent from pre-development conditions.

To evaluate the Q2 in the context of the BMP simulations, a partial duration series analysis was undertaken. Use of partial duration series (rather than annual maxima) is important for accurate analysis of more frequent events (Stedinger et al., 1992). Constructing the partial duration series requires selection of a minimum time between flows that are considered distinct events and a threshold flow above which peaks are assembled for analysis. For time between distinct events, Bulletin 17B (Interagency Committee, 1982) states that successive flood events should be separated by at least as many days as five plus the natural logarithm of square miles of basin area. For the unit-area simulations considered here this simplifies to an inter-event time of at least 5 days. Selection of an appropriate threshold is important for any parametric analysis of flood frequency (Lang et al., 1999; Bequeria, 2005). Selecting a threshold so that events are identified at an average rate of about 2.5 per year appears to give optimal results and has been used here, although parametric extreme value analysis has not been pursued at this time.

The partial duration analysis of peak flow recurrence frequencies using La Mesa precipitation is shown in Figure 14 and the resulting potential breakpoints are summarized in Table 6. For HSG B soils, significant runoff is predicted to be infrequent in the San Diego area, and it appears unlikely that matching of the hydrograph all the way down to 10 percent of the Q2 runoff rate would be necessary to prevent geomorphic instability.

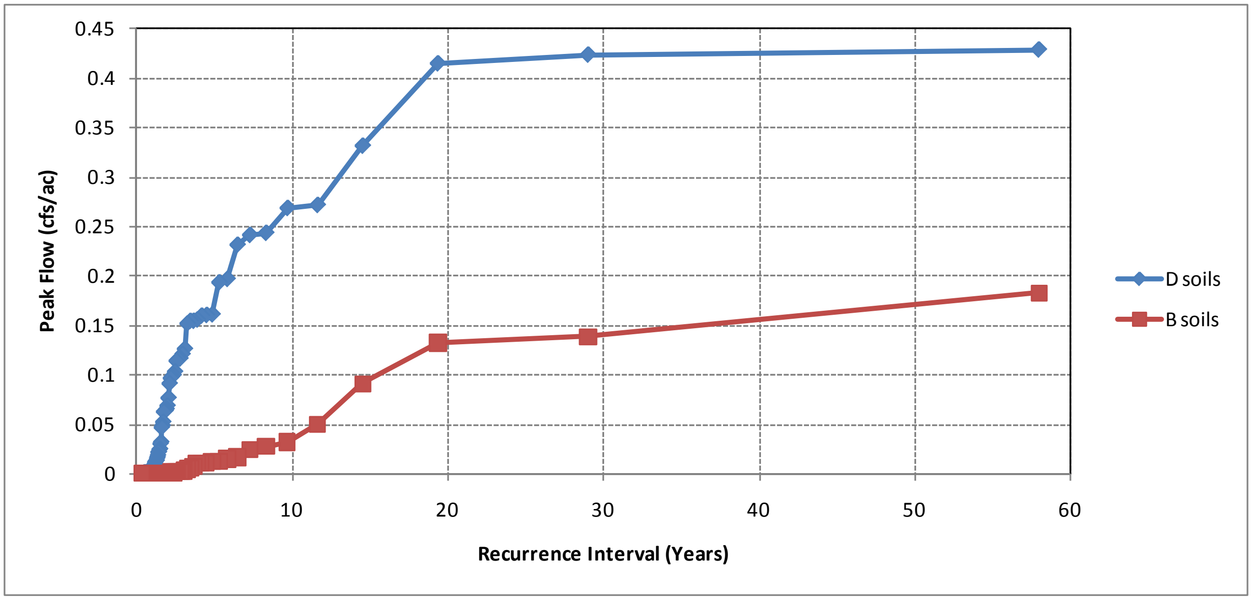


Figure 14 Partial Duration Analysis of Simulated Peak Flow Frequency for Pre-Development Conditions, La Mesa Precipitation

Table 6 Potential Flow Breakpoints (cfs/ac) for Hydromodification Management based on Analysis of Pre-Development Peak Flows with La Mesa Precipitation

	HSG B Soils	HSG D Soils
Q10	0.0351	0.269
Q2	0.00088	0.076
10% of Q2	0.000088	0.0076
10% of Q2 with 10% allowance	0.000097	0.0084

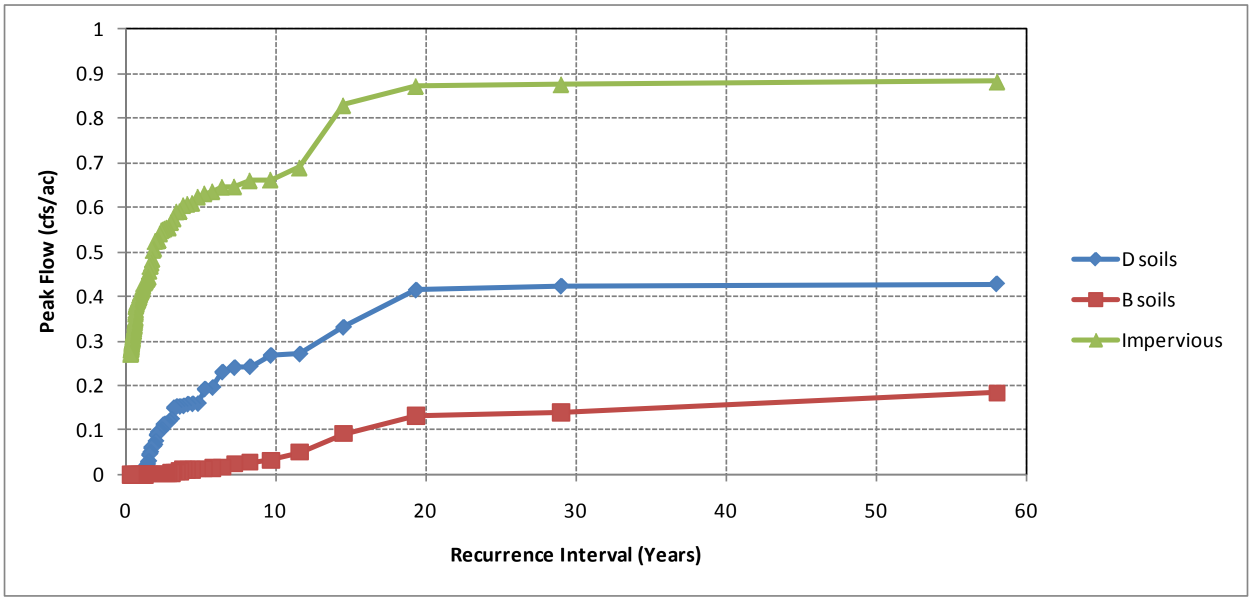


Figure 15 Peak Flow Frequency for Pre-Development Conditions Compared to Unmitigated Impervious Area Runoff, La Mesa Precipitation

The potential implications of the proposed flow ranges for hydromodification management are explored in Figure 16 and Figure 17. There are some striking differences between B and D soils. For B soils (Figure 16), results are shown for volume-based sizing method 3. These soils produce limited natural runoff, and the detention basin achieves almost no control within the range of 0.1 Q2 – Q10 for predevelopment conditions due to the specification of a 48-hour drawdown time. A drastically slower drawdown time (and consequent larger storage volume) for detention basins would be needed to convert the hydrograph from impervious areas to the pre-development hydrograph. In contrast, bioretention on B soils exceeds control requirements on the lower portion of the hydrograph, as water is converted to infiltration. However, here again greater surface storage would be needed to match the hydrograph between the Q2 and Q10.

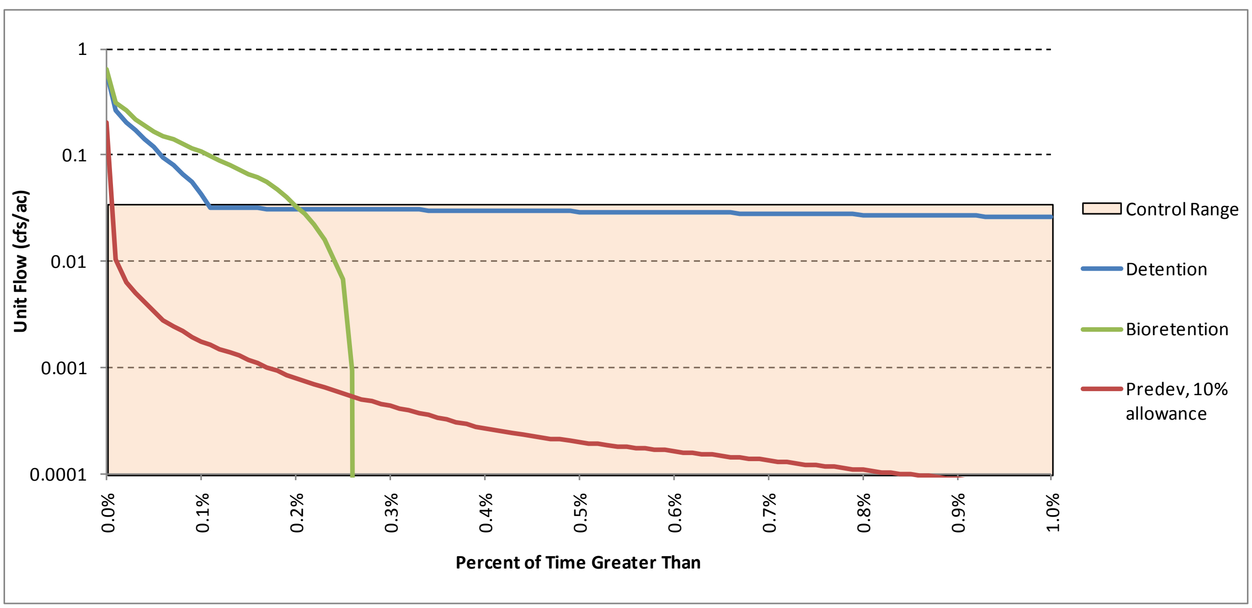


Figure 16 Potential Hydromodification Control for Impervious Area Runoff, B Soils, La Mesa Precipitation, Volume-based Sizing Method 3

For D soils, using volume-based method 2 (Figure 17), bioretention and detention BMPs fail to match the pre-development hydrograph (with 10 percent allowance) in any portion of the 0.1 Q2 – Q10 control range. In this case, the advantages of bioretention over detention are less obvious. This is because bioretention on D soils requires an underdrain, which is specified with a large capacity, resulting in an extension of the duration of flows in the range around 0.5 cfs/ac.

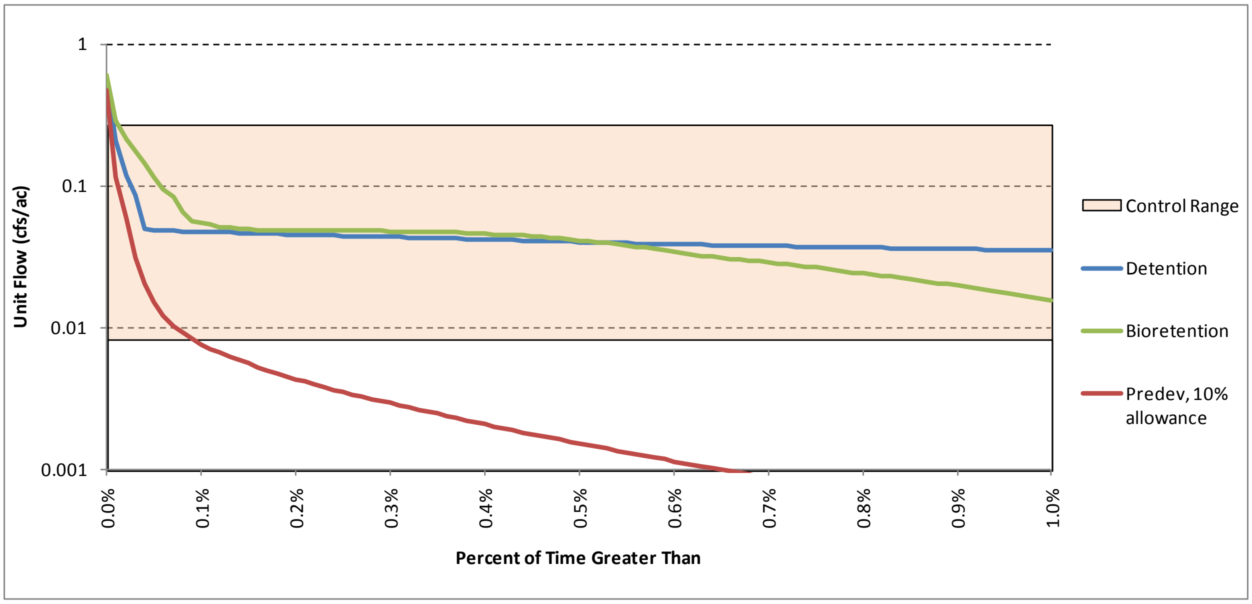


Figure 17 Potential Hydromodification Control for Impervious Area Runoff, D Soils, La Mesa Precipitation

1.4 CONCLUSIONS

The analyses presented above demonstrate that the different sizing methods contained in the 2008 Stormwater Manual can result in a wide discrepancy in water quality volume requirements for BMPs, and that the percent of runoff treated varies correspondingly. A more consistent approach is desirable, as the current options appear to provide an incentive for developers to select the method yielding the smallest size, which may not achieve the desired level of treatment in the long-term. Specific conclusions include the following:

1. Volume-based sizing method 1 does not achieve 90 percent capture and results in BMP storage volumes that are undersized relative to this goal. This method should be considered for removal from the Stormwater Manual. Method 2 is of equal simplicity and could be used in its stead.
2. Flow-based method 1 essentially reflects precipitation intensity at San Diego WSO. In areas of the city with higher rainfall intensity, use of this method results in progressively lower treatment capacity. Given the availability of 85^{th} percentile isopluvial maps, this method should be dropped as unnecessary.
3. Current sizing methods (when implemented with the proposed design criteria summarized in Section 1.2.5) result in a lower percent capture of flows for bioretention than for detention BMPs. The application of the sizing criteria likely needs to be revised for bioretention. Specifically, it is recommended that the available void space in the planting media should not be counted in full toward achieving the WQV. A possible alternative is counting only the water that can infiltrate into the planting media in a specified time period in addition to the surface storage in the design to meet the WQV sizing requirement.

4. Existing sizing criteria are not adequate to address hydromodification management. Although the range of flows to be matched for hydromodification management in San Diego has not been finally determined, it is clear that larger WQVs and longer drawdown times would be needed to achieve a match (even with a 10 percent variance) to the pre-development hydrograph across the range of flow recurrences that do effective work on the channel. Use of BMPs in series (e.g., bioretention followed by detention) may be useful here.

2 BMP Sizing Tool – User's Guide

As described in Section 1.2, the City of San Diego Stormwater Manual (City of San Diego, 2008) requires stormwater treatment control practices on Priority Development Projects to meet either volume-based or flow-based sizing criteria. Three methods for estimating BMP sizes are described in each category.

Application of these methods has often relied on hand calculations, reference to published maps, and visual examination of published capture curves. To streamline the process and ensure uniformity, the existing methods have been incorporated in a unified geographical information system (GIS) format as the City of San Diego BMP Sizing Tool. This tool allows complete implementation of the three volume-based sizing methods and the first and second flow-based method. It does not include flow-based method 3 as this is based on site-specific analysis of rainfall and runoff.

The BMP Sizing Tool is implemented in the VB.net language with MapWindow extension. MapWindow (www.mapwindow.org) is a free, open-source GIS platform that uses ActiveX controls to provide a fully extensible interface with calling programs. Use of MapWindow means that the compiled tool can be freely distributed and operated without proprietary GIS software.

The Tool at this time (version 1.0) is fully functional. However, some enhancements may be made at a later date.

2.1 INSTALLING THE BMP SIZING TOOL

The tool is distributed as a compressed archive, BMPSizingTool.zip. The user should extract the two files contained in this archive (SD_Setup.msi and setup.exe) to a temporary directory. If previous versions of the program have been installed they should be removed before proceeding. The user should then run setup.exe (note, you may need to supply Administrator credentials). The program may be placed in any directory; however, the default location is C:\Program Files\City of San Diego BMP Sizing Tool\.

Once installed, the program may be accessed from the Start menu under City of San Diego BMP Sizing Tool.

2.2 USER'S GUIDE FOR THE BMP SIZING TOOL

The methods implemented by the tool are described in detail in Section 1.2. This section addresses the use of the tool interface and associated controls.

2.2.1 Starting the Tool

On initiating the tool a welcome screen appears:

Clicking "Next" on the welcome screen opens the main interactive map window. By default, this displays the boundaries of the City of San Diego with a full street map. A panel for user input and output is at the right, and the top toolbar contains several GIS controls (Figure 18).

Figure 18 Interactive Map Window

2.2.2 GIS Controls Toolbar

Seven functions are implemented on the toolbar, as follows:

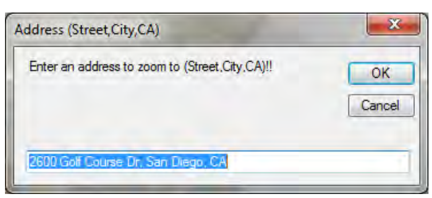
 - Zoom In. Street names will appear as the view is zoomed in.

 - Zoom Out

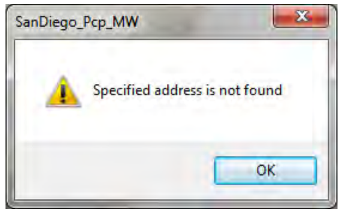
 - Zoom to full extent

 - Pan

 - Search/Zoom using an address: The program will automatically geocode addresses within the City of San Diego. On clicking this button a pop-up appears where the user can input the address in the requested format. The display zooms to the entered address, if valid, on clicking the **OK** button.



If the address is not valid, the following message is displayed.



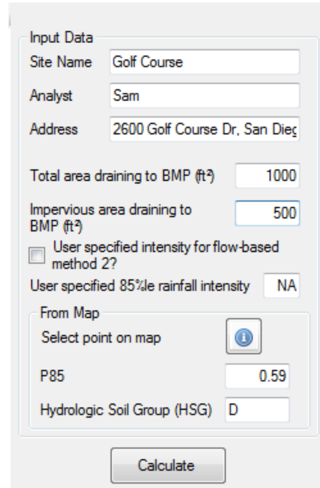
- Show or hide 85th percentile isopluvial layer

- Show or hide Hydrologic Soil Group (HSG) layer

Clicking the buttons labeled **P** and **S** on the toolbar show the isopluvial layer and the Hydrologic Soil Group (HSG) layer, respectively (these are hidden by default). For example, the 85th percentile isopluvial layer is shown in Figure 19. This layer has been interpolated from the County of San Diego coverage (provided at a resolution of 0.05 in) to 0.01 in contours. The actual isopluvial values are not shown at this time; this will be fixed in a later release of the Tool.

Figure 19 85th Percentile Isopluvial Layer

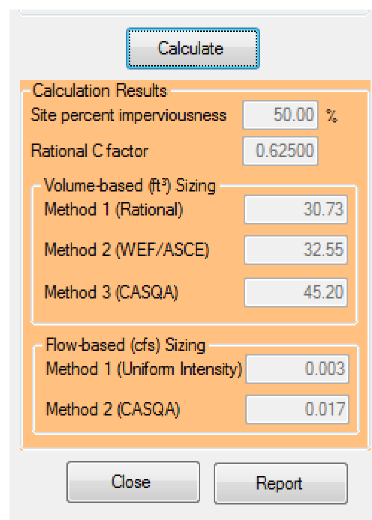
2.2.3 Input/Output Panel



The area to the right of the map is used for input and output. At the top, the user is required to enter the Site Name, Analyst Name, and Address of the site for which the analysis is to be carried out. At this time the address line in the input/output panel is not automatically linked to the Search/Zoom using an address function. Instead, the user must locate the site on the map either by using the Search/Zoom function or by manually zooming and selecting the relevant point on the map by using the button.

The user is also required to provide information on the total area draining to the BMP that is to be sized and the amount of impervious area draining to the BMP (both specified in square feet). The program will not allow the impervious area to be greater than the total drainage area.

The three volume-based methods and two flow-based methods are always implemented; however, there are two ways in which flow-based method 2 can be applied. If **User-specified intensity for flow-based method 2** is checked, the user is required to enter the intensity in the **User-specified 85%le rainfall intensity** cell. If the box is not checked, method 2 is calculated using the intensity estimate from the 85th percentile isopluvial. In that case, the user-specified intensity is shown as **NA**.



After all the data are entered, clicking the **Calculate** button will cause results to be shown in the lower portion of the input/output panel. This displays the site percent imperviousness and the corresponding Rational method C factor, along with the corresponding sizing results.

At the bottom of the input/output panel, clicking on **Report** will display a separate window, showing the results, with an option for printing. Clicking on **Close** will exit the program.

3 References

Begueria, S. 2005. Uncertainties in partial duration series modeling of extremes related to the choice of the threshold value. *Journal of Hydrology*, 303: 215-230.

Brooks, R.H. and A.T. Corey. 1964. Hydraulic Properties of Porous Media. Hydrology Paper 3. Colorado State University, Fort Collins, CO.

CASQA. 2003. Stormwater Best Management Practice Handbook, New Development and Redevelopment. California Stormwater Quality Association. http://www.cabmphandbooks.com/documents/Development/DevelopmentHandbook.pdf

City of San Diego. 2008. Land Development Manual-Storm Water Standards: A Manual for Construction & Permanent Storm Water Best Management Practices Requirements. March 24, 2008. http://www.sandiego.gov/development-services/news/pdf/stormwatermanual.pdf

County of San Diego. 2003. San Diego County Hydrology Manual. County of San Diego, Department of Public Works, Flood Control Section. June 2003. http://www.sdcounty.ca.gov/dpw/floodcontrol/floodcontrolpdf/hydro-hydrologymanual.pdf

Dubin, T. and E. Mosolgo. 2010. San Diego County Hydromodification Management Plan. Memorandum to Sarah Agahi, San Diego County from Brown and Caldwell, San Diego, CA.

Interagency Committee. 1982. Guidelines for Determining Flood Flow Frequency. Bulletin 17B. Interagency Advisory Committee on Water Data, U.S. Geological Survey, Washington, DC.

Lang, M., T.B.M.J. Ouarda, and B. Bobée. 1999. Towards operational guidelines for over-threshold modeling. *Journal of Hydrology*, 225: 103-117.

Maidment, D.R., ed. 1993. *Handbook of Hydrology*. McGraw-Hill, New York.

San Diego Copermittees. 2002. Model Standard Urban Storm Water Mitigation Plan for San Diego County, Port of San Diego, and Cities in San Diego County. Project Clean Water. http://www.projectcleanwater.org/pdf/final_susmp.pdf

San Diego Regional Board. 2007. Order No. R9-2007-0001, NPDES No. CAS0108758, Waste Discharge Requirements for Discharges of Urban Runoff from the Municipal Separate Storm Sewer Systems (MS4s) Draining the Watersheds of the County of San Diego, the Incorporated Cities of San Diego County, the San Diego Unified Port District, and the San Diego County Regional Airport Authority. California Regional Water Quality Control Board San Diego Region, San Diego, CA.

San Francisco Regional Board. 2005. Order No. R2-2005-0035, NPDES Permit No. CAS029718, Amendment Revising Order No. 01-119 for Santa clara Valley Water District, County of Santa Clara, City of Campbell, City of Cupertino, city of Los Altos, Town of Los Altos Hills, Town of Los Gatos, City of Milpitas, City of Monte Sereno, City of Mountain View, City of Palo Alto, City of San Jose, City of Santa Clara, City of Saratoga, and City of Sunnyvale, which have joined together to form the Santa clara Valley Urban Runoff Pollution Prevention Program. California Regional Water Quality Control Board San Francisco Bay Region, San Francisco, CA.

Stedinger, J.R., R.M. Vogel, and E. Foufoula-Georgiou. 1992. Frequency Analysis of Extreme Events. Chapter 18 in D.R. Maidment, ed., *Handbook of Hydrology*, McGraw-Hill, New York.

Thomas, H.R. Jr. 1948. Frequency of minor floods. *Boston Soc. Civil Eng.*, 34: 425-442.

UCCE. 2000. A Guide to Estimating Irrigation Water Needs of Landscape Plantings in California, The Landscape Coefficient Method and WUCOLS III. University of California Cooperative Extension. California Department of Water Resources, August 2000.

USWRC. 1976. Guidelines for Determining Flood Flow Frequency. Bulletin 17B. Hydrology Committee, U.S. Water Resources Council, Washington, DC.

Viessman, W. Jr., G.L. Lewis, and J.W. Knapp. 1989. *Introduction to Hydrology, 3rd Edition.* HarperCollins, New York.

WEF. 1998. Urban Runoff Quality Management. WEF Manual of Practice No. 23; ASCE Manual of Practice No. 87. Water Environment Federation, Reston, VA.

Appendix B. BMP Design Guidance

This page intentionally left blank

Contents

Figures

1 Bioretention Areas

Location: Park Boulevard between G and F Streets, San Diego, CA (rendering)

1.1 Description

Bioretention BMPs are small-scale, shallow, vegetated, depressed areas with a soil (often engineered soil) media and plant-based filtration device that removes pollutants through a variety of physical, biological, and chemical treatment processes. Such BMPs usually consist of a grass buffer strip, media bed, ponding area, mulch layer, and planting soil media. The depressed area is planted with small- to medium-sized vegetation including trees, shrubs, and groundcover that can withstand urban environments and tolerate periodic inundation and dry periods. Pretreatment of storm water flowing into bioretention BMPs is recommended to remove large debris, trash, and larger particulates and ponding areas can be designed to increase flow retention and flood control capacity.

1.1.1 Advantages

- Efficient removal of suspended solids, heavy metals, adsorbed pollutants, nitrogen, phosphorus, and pathogens
- Can effectively reduce peak runoff rates for relatively frequent storms, reduce runoff volumes, and recharge groundwater if soil conditions allow
- Flexible to adapt to urban retrofits

- Well suited for use in small areas, and multiple, distributed units can provide treatment in large drainage areas
- Can be integrated naturally into landscaping to enhance aesthetics

1.1.2 Disadvantages

- Surface soil layer can clog over time (though it can be restored)
- Frequent trash removal might be required, especially in high-traffic areas
- Vigilance in protecting native soils from compaction during construction is essential
- Single units can serve only small drainage areas
- Requires maintenance of plant material and mulch layer

1.1.3 Major Design Elements

- Sizing must take into account all runoff at ultimate build-out including off-site drainage. (For volume calculations, see City of San Diego *Storm Water Standards*.)
- Drainage areas should be less than 5 acres.
- Side slopes stabilized with vegetation must be no steeper than 3:1.
- Either a bypass or an internal overflow is required for bypassing storms in excess of the design storm.
- Bioretention facilities must not be used where the seasonally high water table or confining layer is less than 10 feet below bottom of the BMP (City's *Storm Water Standards*).
- Media permeability must be at least 0.5 inch per hour (in/hr) (City's *Storm Water Standards*).
- Inflow must be non-erosive sheet flow (1 foot per second [ft/sec] for mulch cells, 3 ft/sec for grass cells) or use energy dissipating devices.
- Infiltration BMPs must be a minimum of 100 feet from water supply wells and septic drain fields and 10 feet from any structural foundations (City's *Storm Water Standards*).
- Bioretention facilities must not be used where slopes draining to the BMP are greater than 15 percent, or in areas that are not permanently stabilized drainage areas.
- Slope within the bioretention area must not exceed 2 percent
- Ponding depth must be 12 inches or less, with 9 inches preferred.
- Media depth must be 2 feet minimum for grassed cells and 3 feet minimum for shrub/tree cells.
- Media should meet the specifications listed in Design Step 4: *Determine the depth and type of soil media*.
- Ponded water must completely drain into the soil within 24 hours, with 12 hours preferred as a safety factor. It must drain to a level below the soil media (2 to 3 feet) within 48 hours.

- An underdrain must be installed if in situ soil drainage is less than 0.5 in/hr. The underdrain pipe should be at least 4 inches in diameter and installed at a 0.5 percent minimum slope.
- An underdrain must be installed if the bioretention area is within 50 feet of a sensitive, steep slope.
- Cleanout pipes must be provided if underdrains are required.
- Grassed bioretention areas can be used; however, grassed bioretention must be sodded, and the sod must not be grown in soil with an impermeable (clay) layer.
- Finely shredded hardwood mulch 2 to 4 inches deep (3 inches preferred) must be used in all mulched bioretention areas (for details, see section 1.2.8).

1.1.4 Characteristics and Function

Bioretention areas are vegetated and mulched or grassed (i.e., landscaped), shallow depressions that capture and temporarily store storm water runoff. The captured runoff infiltrates through the bottom of the depression and a layer of planting soil, approximately 2 to 4 feet deep, that has an infiltration rate capable of draining the bioretention area (to the bottom of the planting soil) within a specified design drawdown time (usually 12 to 72 hours). The planting soil provides treatment through filtration, adsorption, and biological uptake.

After the storm water infiltrates through the soil media, it percolates into the subsoil, if site conditions allow for adequate infiltration and slope protection. Filtered water is directed toward a storm water conveyance system or other storm water runoff BMP via underdrain pipes, if site conditions do not allow for adequate infiltration or slope protection.

Bioretention areas are designed to capture a specified design volume and can be configured as online or offline systems. Online bioretention areas require an overflow system for passing larger storms. Offline bioretention areas do not require an overflow system but do require some freeboard (the distance from the overflow device and the point where storm water would overflow the system).

If an underdrain is not needed because infiltration rates are greater than 0.5 in/hr and slope is not a concern, the remaining storm water passes through the planting soil and percolates into the subsoil. Partial infiltration (approximately 20 to 25 percent, depending on soil conditions) can still occur when underdrains are present as long as an impermeable interface is not present between the soil media and subsoil. Partial infiltration occurs in those cases because some of the storm water bypasses the underdrain and percolates into the subsoil (Strecker et al. 2004; Hunt et al. 2006).

Bioretention areas are typically planted with grasses, shrubs, and trees that can withstand short periods of saturation (i.e., 12 to 72 hours) followed by longer periods of drought. Bioretention areas are generally not applicable in areas with slopes steeper than 15 percent.

1.1.5 Applicability and Performance

Chapter 2 describes the process for selecting and integrating BMPs into the site design. Bioretention areas are volume-based BMPs intended, primarily, for water quality treatment and, depending on site slope and soil conditions, can provide high-volume reduction. Where site conditions allow, the volume-reduction capability of bioretention areas can be enhanced for achieving additional credit toward meeting the volume-reduction requirement by omitting underdrains and providing a gravel drainage layer beneath the bioretention area. Bioretention areas can be used to help meet the peak runoff discharge requirement.

Bioretention areas remove pollutants through physical, chemical, and biological mechanisms. Specifically, they use absorption, microbial activity, plant uptake, sedimentation, and filtration. Bioretention areas provide relatively consistent and high pollutant removal for sediment, metals, and organic pollutants (e.g., hydrocarbons). Most of the sediment removal occurs in the top mulch layer (Li and Davis 2008), while metals removal commonly occurs within the first 18 inches of the planting soil (Hsieh and Davis 2005; Hunt and Lord 2006). Removal of nitrogen and phosphorus species is less consistent. Total phosphorus percent removal has been found to vary between a 240 percent increase (production) and a 99 percent decrease (removal) (Davis 2007; Hunt et al. 2006; Hsieh and Davis 2005). Greater total phosphorus removal can be achieved by using soil media with total phosphorus concentrations below 15 parts per million (ppm) (Hunt and Lord 2006). Nitrate removal has been found to vary between a 1 and 80 percent decrease (Kim et al. 2003; Hunt et al. 2006). Total Kjeldhal nitrogen (TKN) has been found to vary between a 5 percent increase and 65 percent decrease (Kim et al. 2003; Hunt and Lord 2006). Greater nitrate and TKN removal can be achieved by reducing the infiltration rate within the planting soil to 1–2 in/hr and ensuring that the soil media is at least 3 feet deep (Hunt and Lord 2006). Greater nitrate removal can also be achieved by incorporating a saturated layer within the soil media to promote anaerobic conditions for denitrification (Kim et al. 2003; Hunt and Lord 2006; Passeport et al. 2009). Limited data exist for bacteria removal in bioretention areas although most scientists and engineers agree that bacteria die-off occurs at the surface where storm water is exposed to sunlight and the soil can dry out; dense vegetation in the bioretention area can limit the penetration of sunlight and removal of bacteria (Hathaway et al. 2009; Hunt et al. 2008; Hunt and Lord 2006). But those internal areas could also be home to bacteriavores that consume bacteria resulting in a reduction in the number of bacteria.

1.2 Design

The design of a bioretention area can be broken down to a nine-step process:

1. BMP Configuration
    a. Determine how to incorporate bioretention into the layout of the site
    b. Determine and incorporate the necessary BMP components
2. Determine the volume of water to treat (see Appendix A)
3. Calculate the surface area required
4. Determine the depth and type of soil media
5. Design inlet configuration
6. Determine if an underdrain pipe is necessary
7. Select the appropriate overflow or bypass method
8. Select mulch and vegetation
9. Additional considerations

1.2.1 Determine BMP Configuration

Bioretention is a versatile storm water BMP in that it can effectively reduce pollutants and can be integrated into site plans with various configurations and components. Storm water treatment should be considered as an integral component and incorporated in the site design and layout from conception. Many times, determining how the bioretention area will be included in the site design is a critical and required first step. How the water is routed to the bioretention area and the available space will be key components in determining how the bioretention area is configured. Site assessment, planning, and site design are discussed in detail in chapter 2. The following is a list of settings where bioretention can be incorporated to meet more than one project-level or watershed-scale objective:

- Landscaped parking lot islands
- Common landscaped areas
- In parks and along open space edges
- Within rights-of-way along roads

How the bioretention area is configured will determine the required components. Pretreatment at some level is always required to remove gross solids where possible and reduce flows to a non-erosive rate. Curb cuts could be required to allow storm water to enter the bioretention area while providing some delineation in high traffic areas. Bioretention areas can serve the dual purpose of storm water management and landscape design and can significantly enhance the aesthetics of a site. Figure 1 shows an example of the components of a typical bioretention area. Bioretention areas generally have multiple components including the following:

- Filter strip or grass buffer for pretreatment
- Soil Media bed for filtration
- Ponding area for storage
- Plants for pollutant uptake and landscaping

In addition, bioretention areas can be combined with other basic and storm water runoff BMPs to form a treatment train that can provide enhanced water quality treatment and reductions in runoff volume and rate. For example, runoff can be collected from a roadway in a vegetated swale that then flows to a bioretention area. Both facilities can be reduced in size on the basis of demonstrated performance for meeting the storm water runoff requirements as outlined in Chapter 2 and addressing targeted pollutants of concern.

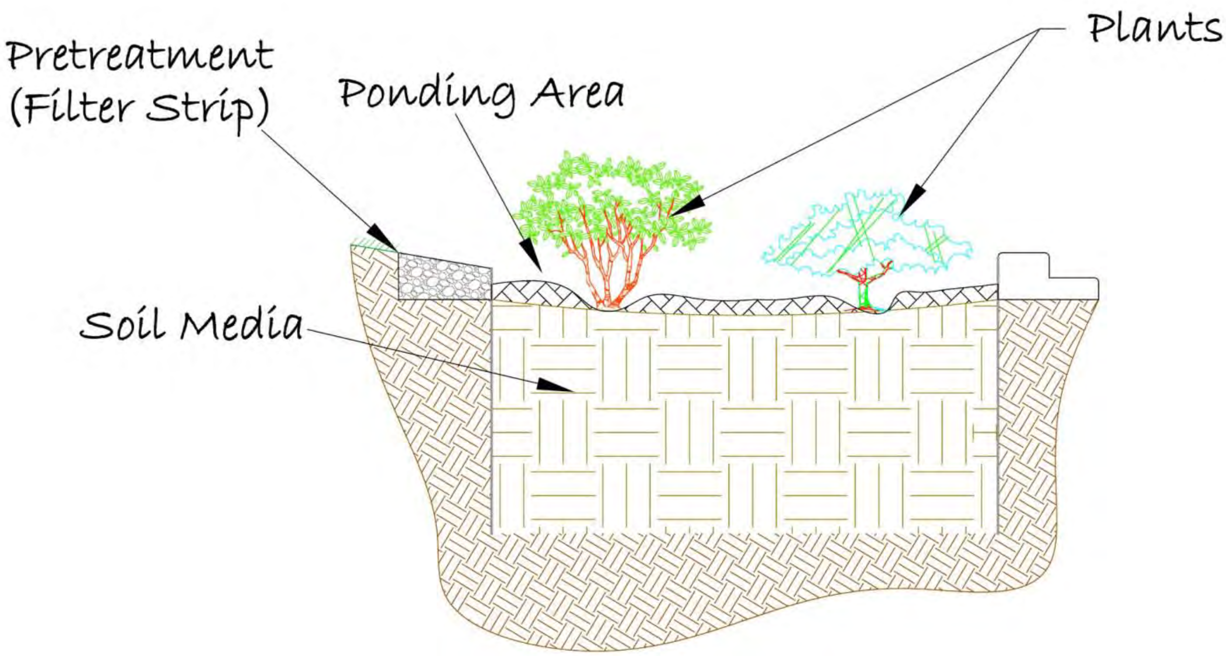


Figure 1. Bioretention components.

1.2.1.1 Parking Lots

Bioretention areas can be used in parking lot islands or along the edge of the parking lot where water can be diverted into the bioretention area. Linear bioretention can also be used in the median areas between the parking spaces. Pretreatment is important for parking lot areas to remove large sediments and to slow the runoff to non-erosive flow rates (1 in/hr for mulch and 3 in/hr for sod). Pretreatment typically consists of a gravel verge followed by turf. Pretreatment can also be provided by a grassed or gravel forebay typically designed to be 10 percent of the total bioretention area. Figure 2 shows an example of a median used as a bioretention area, and Figure 3 is an example of how bioretention can be implemented in parking lots.

Location: Mission Valley Library, San Diego, CA (rendering)

Figure 2. Parking lot island bioretention.

Location: Bressi Ranch Medical Center, Carlsbad, CA.

Figure 3. Parking lot median bioretention area.

1.2.1.2 Roads

Bioretention can also be integrated into the right-of-way of roads. Similar concepts apply to roads as parking lots. Some pretreatment could be required to remove large particles and slow the runoff to non-erosive flows. Bioretention can be used along the edge of roads or in medians as shown in Figure 4 and Figure 5.

Location: J Street between 6th and 7th Avenues, San Diego, CA (rendering)

Figure 4. Roadside bioretention.

Location: Columbia Memorial Learning Center, Downey, CA

Figure 5. Road median bioretention.

Bioretention designs can be incorporated into the edge of roadways using horizontal deflections, (chicanes or chokers), pop-outs, and the furnishing zone (the areas between the edge of the roadway and the sidewalk). Figure 6 shows an example of bioretention incorporated into a horizontal deflector, Figure 7 is an example of how bioretention can be incorporated into a pop-out.

Location: Upas Street between Arizona Street and Arnold Avenue, San Diego, CA (rendering)

Figure 6. Horizontal deflectors.

Location: Park Boulevard and Adams Avenue, San Diego, CA (rendering)

Figure 7. Bioretention in a pop-out.

For standard horizontal deflector and furnishing zone specifications, see the City's *Street Design Manual* (2002). The maximum width right-of-way and curb-to-curb spacing should be used to most effectively implement bioretention areas in horizontal deflectors and in the furnishing zone. Bioretention can be incorporated into a variety of configurations using horizontal deflectors, pop-outs, and furnishing zones with street-side parking and varying widths of the right-of-way. Landscaping is often required or expected in horizontal deflectors, which can be converted to a bioretention area to treat storm water runoff from the paved surfaces.

Further details and design templates for bioretention areas in the right-of-way are provided in Appendix C, BMP Design Templates.

1.2.1.3 Landscape

Bioretention can also be integrated into the landscape of a site in any open or common areas. Runoff can be routed into the bioretention areas from rooftops, sidewalks, or any impervious areas on a site. Energy dissipation is important to prevent erosion in the bioretention and can be accomplished with pretreatment or an energy dissipater. When bioretention is integrated into landscapes, it is important to consider any effects that could be made to surrounding structures from infiltration. Bioretention incorporating infiltration should be at least 10 feet from any structure. Figure 8 shows a bioretention area that was integrated into the common area of a building used in open space.

Location: Courtyard in Liberty Station, Womble Road, and Historic Decator Road, San Diego, CA (rendering)

Figure 8. Bioretention in a common area with gravel pretreatment.

1.2.2 Determine the Volume of Water or Flow to Treat

The bioretention area must be sized to treat the required design storm. The methods for calculating the volume required for treatment are outlined in the City's *Storm Water Standards* and the *San Diego County Hydrology Manual* as well as in Appendix A.

1.2.3 Determine the Surface Area Required

1.2.3.1 Geometry and Size

1. Bioretention areas should have a maximum ponding depth of 12 inches, with 9 inches preferred.

2. Soil media should be a minimum of 2 feet, although 3 feet is preferred. The soil media provides a beneficial root zone for the chosen plant palette and adequate water storage for the water quality design volume. A deeper soil media depth will provide a smaller surface area footprint. Pollutant removal occurs at different depths. Two feet provides the accepted pollutant removal performance, but some studies have shown that deeper media depths can provide improved nutrient removal performance (Hunt and Lord 2006).

3. Bioretention areas are intended to drain to below the surface in less than 24 hours but should be designed to drain in 12 hours or less as a safety factor and below the soil media depth in less than 48 hours. If a gravel drainage layer is included beneath the bioretention area soil media, stored runoff in the drainage layer must drain in less than 72 hours. The soils must be allowed to dry out periodically to restore hydraulic capacity to receive flows from subsequent storms, maintain infiltration rates, maintain adequate soil oxygen levels for healthy soil biota and vegetation, and to provide proper soil conditions for biodegradation and retention of pollutants.

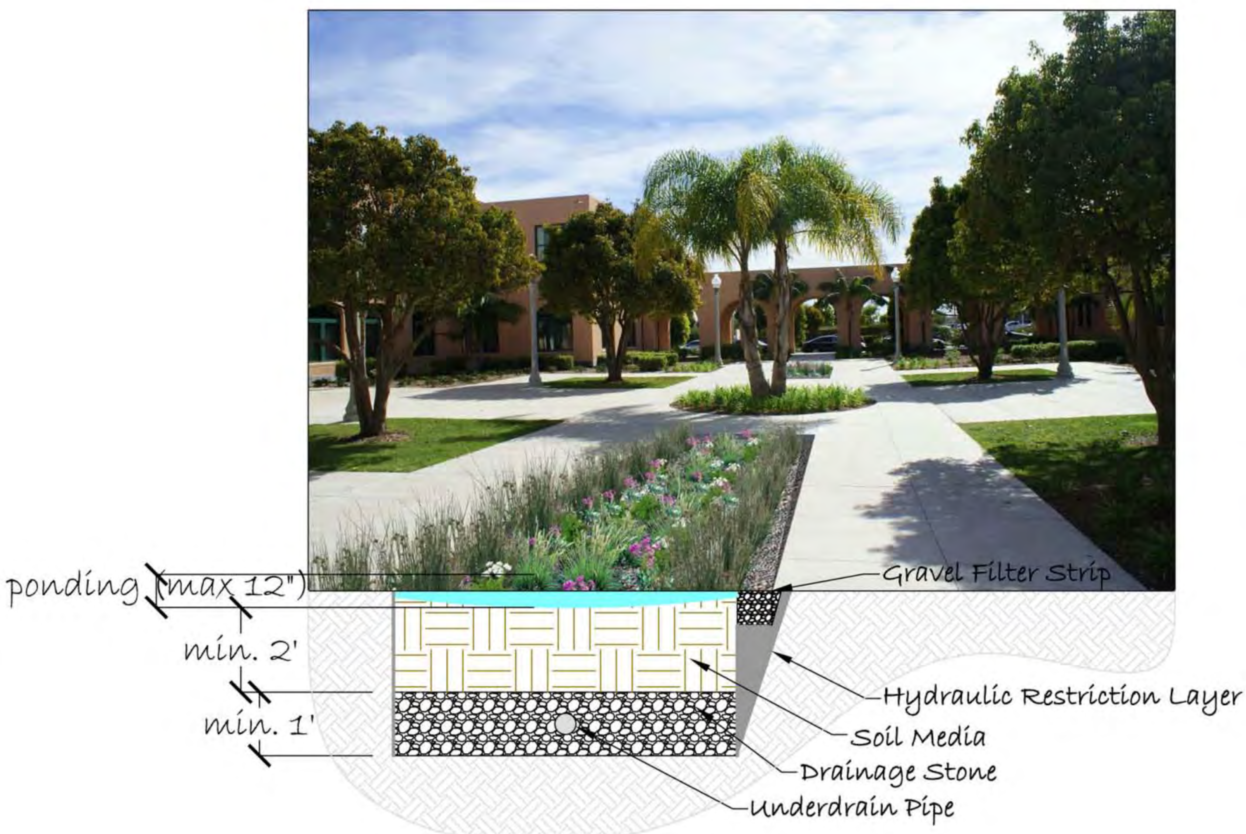


Figure 9. Bioretention area geometry and profile.

1.2.3.2 Sizing Methodology

Bioretention areas are to be sized to capture and treat the volume produced by the design storm and, where site conditions allow, will be sized to infiltrate the volume reduction requirement. For the storm water runoff requirements and calculations, see Appendix A. Procedures for sizing infiltration BMPs will be in accordance with the sizing methodology developed for the City's *Storm Water Standards.*

1.2.4 Determine the Depth and Type of Soil Media

1.2.4.1 Depth of soil media

Different pollutants are removed in various zones of the bioretention cell using several mechanisms. Total suspended solids (TSS) are removed both in pretreatment and on the surface of the cell itself. For that reason, TSS removal is not a major factor in depth of the cell design. Depth, however, is an issue for other pollutants. Metals are removed in the top layer of mulch and within the first 18 inches of media because they are often bound to sediment (Davis et al. 2003; Li and Davis 2008). Bacterial, viral, and protozoan pathogens can be killed on the surface and removed throughout the cell by several mechanisms: sun exposure, drying, sedimentation, and filtration (Hathaway et al. 2009). Media depth should be 30 inches to optimize nitrogen removal and 24 inches for phosphorus (Hunt and Lord 2006). Considering the target pollutant, the depth of the media in a bioretention cell should be between 2 and 4 feet. That range reflects the fact that most of the pollutant removal occurs within the first 2 feet of soil, and excavations deeper than 4 feet become more expensive. The depth should accommodate the desired vegetation (shrubs or trees). If the minimum depth of 2 feet is used, only shallow-rooted plants should be planted. Grassed bioretention cells can be as shallow as 2 feet. Bioretention facilities where shrubs or trees are planted can be as shallow as 3 feet. If large trees are to be planted in deep fill media, take care to ensure that they will be stable and not fall over. Stakes and guy lines might be required during tree establishment.

1.2.4.2 Type

The soil media within the bioretention cell should meet the requirements as set by the City in its *Storm Water Standards*. Soils at infiltration sites must have the following properties: Organic Content (OC) > 5 percent, pH between 6–8, Cation exchange capacity (CEC) > 5 milliequivalent (meq)/100 g soil, infiltration rates of 0.5 in/hr or greater. Soil media must have an appropriate amount of organic material to support plant growth (e.g., loamy sand mixed thoroughly with an organic material). If the existing soils meet the criteria, it can be used as the soil media. If the existing soils do not meet the criteria, a substitute media must be used. Soil media that is brought to the site must meet the standards set in the *Storm Water Standards* as well as the following criteria:

1. Soil media consists of 85 percent washed course sand, 10 percent fines (range: 8–12 percent; 8 percent = 2 in/hr infiltration rate, 12 percent = 1 in/hr infiltration rate), and 5 percent organic matter.

2. The sand portion should consist of concrete sand (passing a one-quarter-inch sieve). Mortar sand (passing a one-eighth-inch sieve) is acceptable as long as it is thoroughly washed to remove the fines.

3. Fines should pass a # 270 (screen size) sieve.

4. Organic matter is considered an additive to assist vegetation in initial establishment and contributes to sorption of pollutants but generally should be minimized (5 percent). Organic materials will oxidize over time causing an increase in ponding that could adversely affect the performance of the bioretention area. Organic material should consist of aged bark fines, or similar organic material. Organic material should not consist of manure or animal compost. Studies have also shown newspaper mulch to be an acceptable additive (Kim et al. 2003; Davis 2007).

5. High levels of phosphorus in the media have been identified as the main cause of bioretention areas exporting nutrients (Hunt and Lord 2006). All bioretention media should be analyzed for background levels of nutrients. Total phosphorus should not exceed 15 ppm.

1.2.5 Inlet Configuration

Inlets must be designed to convey the design storm volume into the bioretention area while limiting ponding or flooding at the entrance to the bioretention area and protecting the interior of the bioretention area from damage. Several options are available depending on the configuration of the bioretention area.

1.2.5.1 Pretreatment

Ideally, runoff will pass over a filter strip where flow can be dispersed and gross solids removed before it enters the bioretention area as shown in Figure 9. That is not always possible, especially in retrofit situations were space might not be available. In those situations, the designers should attempt to disperse flow across the system as evenly as possible. Bioretention areas that treat runoff from residential roofs or other *cleaner* surfaces might not require pretreatment for trash or sediment but should include flow reduction as much as possible.

Runoff can be routed to a bioretention area through a vegetated swale or forebay to pretreat incoming flows from impervious surfaces where space is available.

If sheet flow is conveyed to the treatment area over stabilized grassed areas, the site must be graded in such a way that minimizes erosive conditions. Sheet flow velocities should not exceed 3 ft/sec.

1.2.5.2 Curb Cuts

When bioretention is incorporated into highly impervious areas, such as parking lots and in road rights-of-way, curb cuts could be required to allow surface runoff to enter the bioretention area. Curb cuts are designed such that the design storm can pass through the curbing without causing water to pond in the travel lanes. Further detail for curb cuts is provided in section 10.1 of this Appendix B.

Some pretreament flow reduction can be provided by using multiple, smaller curb cuts to minimize the flow at each opening and by armoring the curb opening from the back of the curb to the base elevation of the bioretention area.

1.2.6 Determine if an Underdrain Pipe is Necessary

A geotechnical investigation should be performed by a licensed soil scientist or geotechnical engineer, and a report should be prepared in accordance with the City's *Guidelines for Geotechnical Reports*. The investigation should determine the infiltration rate of the soils and the depth to the seasonally high groundwater table. If the infiltration rate of the soils on which the bioretention area will be installed is less than 0.5 in/hr, underdrains will be required. Section 10.2 of this Appendix B provides guidance on the design of underdrains.

1.2.7 Select the Appropriate Outlet or Bypass Method

Two design configurations can be used for treating storms that are larger than the bioretention area is designed to store:

1. Offline: An offline bioretention area can be designed such that storm water bypasses the BMP once the capacity has been exceeded as shown in Figure 10. A structure can also be designed that diverts into the bioretention only the volume of storm water for which the bioretention area is designed. For more details on diversion structures, see section 10.3 of this Appendix B.

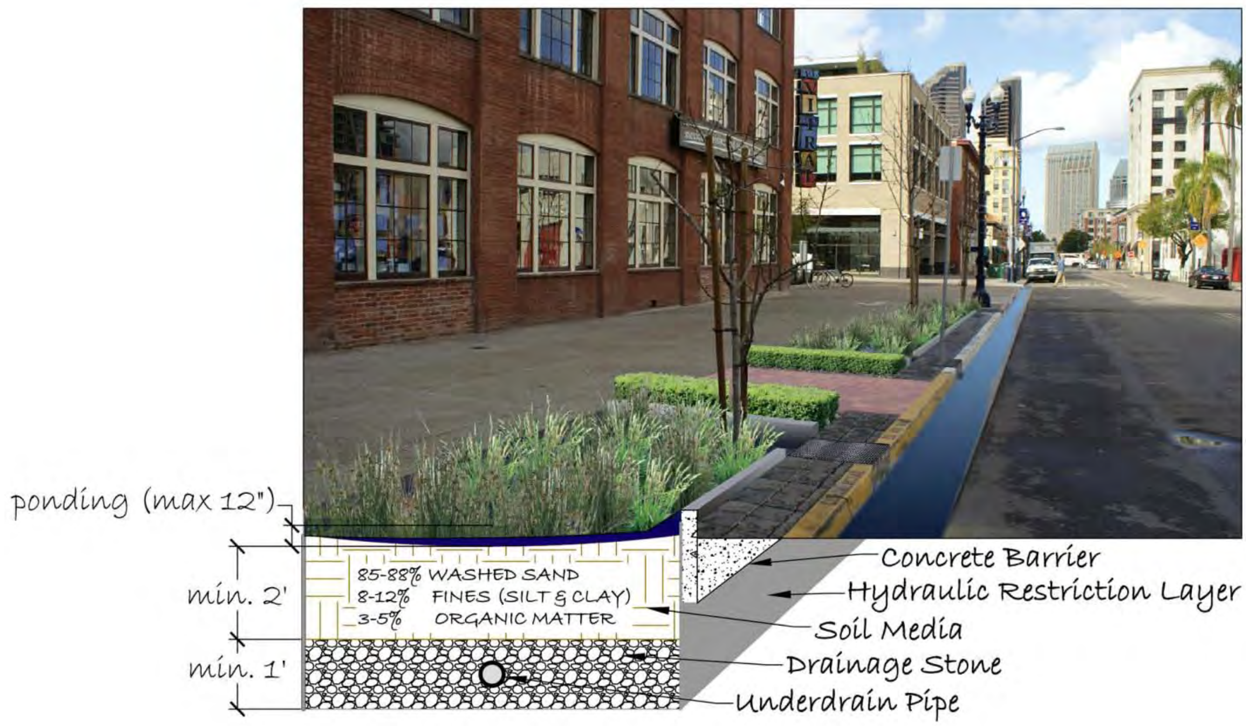


Figure 10. Bypassing a bioretention area.

2. Online: All runoff enters the bioretention area with an outlet or overflow for volumes exceeding the design storm. Outlet systems for online bioretention areas can be designed to provide some peak flow mitigation in addition to storing the design volume. There are two basic options for outlets or overflow for online bioretention systems:

Option 1: Vertical riser

1. A vertical polyvinyl chloride (PVC) pipe that is connected to the underdrain or directly to the drainage system.

2. The outlet riser(s) is 4 inches or greater in diameter, so it can be cleaned without damage to the pipe. The vertical pipe will provide access to cleaning the underdrains.

3. The inlet to the riser should be set at the ponding depth of 9 to 12 inches and be capped with a spider cap. Figure 11 shows an example of an online bioretention area with a vertical riser overflow design.

4. Additional peak flow reduction can be provided by designing a variable flow outlet riser. Some additional water can be retained in the system above the design volume for a short period without affecting the vegetation. The riser should be designed to mitigate for the required peak flow without exceeding the maximum ponding time of 24 hours. The vertical riser should be designed with a series of orifices to control peak flows with an overflow, as previously described, to allow larger storms to pass. An example of a variable flow vertical riser is shown in Figure 11.

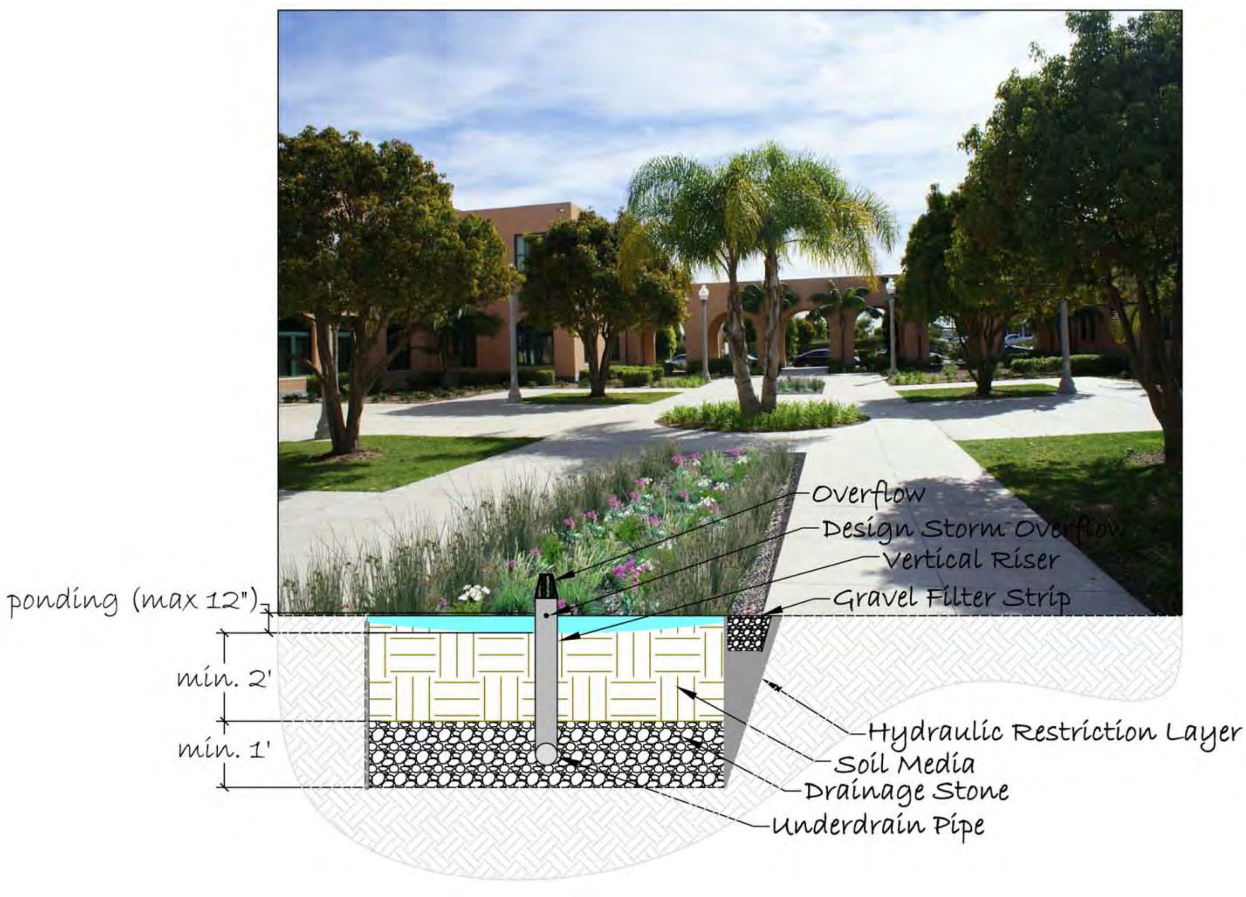


Figure 11. Online bioretention area with a vertical riser overflow with a variable flow outlet structure.

Option 2: Flow spreader

1. A flow spreader can be used to diffuse overflows from the bioretention area and should be installed along the exit edge or outflow section of the bioretention area. The flow spreader can be earthen covered with sod or any stable material.

2. The top surface of the flow spreader should be installed at a height equal to the ponding depth, or slightly greater if in conjunction with a vertical riser, to allow runoff exceeding the capacity of the bioretention area to safely pass.
3. The flow spreader can be designed as a weir to allow for varied outlet flows providing some peak flow mitigation.

For online systems, take care to avoid scouring of media. Figure 11 shows an example of a variable flow outlet structure that is a type of vertical riser. An orifice is designed to control peak flow above the design volume with an overflow for large events.

Typically, bioretention areas constructed in the right-of-way should be designed as offline storm water treatment facilities. Once a bioretention area constructed in the right-of-way has reached capacity, storm water flows should bypass the system and continue flow in the existing storm water drainage system or continue to the next BMP. If a bioretention area constructed in the right-of-way requires underdrains, a vertical riser overflow system can be incorporated as the primary overflow method in addition to the bypass.

1.2.8 Select Mulch and Vegetation

1.2.8.1 Mulch

Mulch is a critical component of the bioretention area because it provides a food source and habitat for many of the biological organisms critical to the function of the bioretention area. Much of the metals and TSS removal is believed to occur in the mulch layer. The bioretention area should be covered with mulch when constructed and annually replaced to maintain adequate mulch depth. Mulch is also important to sustain nutrient levels, suppress weeds, retain moisture for the vegetation, and maintain infiltrative capacity. Mulch must meet the following criteria:

- Well-aged shredded hardwood material. Well-aged mulch is defined as mulch that has been stockpiled or stored for at least 12 months.
- Free of weed seeds, soil, roots, and other material that is not hardwood material.
- Mulch depth will be 2 to 4 inches thick, with 3 inches preferred (thicker applications can inhibit proper oxygen and carbon dioxide cycling between the soil and atmosphere).
- Grass clippings, pine nuggets, or pure bark cannot be used as mulch.

Note: Shredded redwood mulch is appropriate for bioretention areas and is readily available in Southern California. Shredded redwood mulch is known as *gorilla hair* in the landscaping community. Figure 12 shows an example of gorilla hair.

Figure 12. Gorilla hair mulch.

1.2.8.2 Vegetation

One advantage of bioretention areas is that they can be used for the dual purpose of storm water treatment and landscaping or be integrated into the existing landscape. For bioretention areas to function properly as storm water treatment and blend into the landscape, vegetation selection is crucial. Appropriate vegetation will have the following characteristics:

1. Plant materials must be tolerant of summer drought, ponding fluctuations, and saturated soil conditions for 10 to 48 hours.

2. It is recommended that a minimum of three tree, three shrubs, and three herbaceous groundcover species be incorporated to protect against facility failure from disease and insect infestations of a single species. Plant rooting depths cannot damage the underdrain, if present. Slotted or perforated underdrain pipe must be more than 5 feet from tree locations (if space allows).

3. Native plant species or hardy cultivars that are not invasive and do not require chemical inputs are recommended to be used to the maximum extent practicable. Only native non-invasive species will be selected for areas in the Multiple Habitat Planning Area (MHPA) or in areas designated as natural open space.

4. Shade trees should be free of branches below the following heights:

Caliper (in)	Height (ft)
0.5 to 2.5	5
3	6

5. A list of native plants appropriate for San Diego is in Appendix E.

Many options exist for vegetation arrangement and will most likely depend on the landscaping of the area around the bioretention. Size-limited landscaping could be required for bioretention areas in the right-of-way to maintain the required sight distances.

1.2.9 Additional Considerations

1.2.9.1 Hydraulic restriction layers

Infiltration pathways might need to be restricted because of the close proximity of roads, foundations, other infrastructure, or hotspot locations as determined in the geotechnical investigation. In some conditions, lateral seepage can cause damage to surrounding structures depending on the type of soils in the area. Areas that have a potential for settling under saturated conditions should be protected from lateral flows. Types of clay that have a high potential for expansion when saturated should be protected from moisture in load bearing conditions. Section 10.4 of this Appendix B provides details on hydraulic restriction layers.

1.2.9.2 Utilities

Utilities should be avoided where possible when implementing bioretention areas. In many cases, bioretention areas can be shifted in the landscape to prevent implementation over utilities. In cases where utilities cannot be avoided, take care to prevent impact from infiltration or saturation by using hydraulic restricting layers to direct infiltration away from the utility. For further details, see section 10.4 of this Appendix B.

1.3 Operation and Maintenance

Bioretention areas require regular plant, soil, and mulch layer maintenance to ensure optimum infiltration, storage, and pollutant-removal capabilities. In general, bioretention maintenance requirements are typical landscape care procedures and consist of the following:

1. Watering: Plants must be selected to be drought tolerant and not require watering after establishment (2 to 3 years). Watering could be required during prolonged dry periods after plants are established.

2. Erosion control: Inspect flow entrances, ponding area, and surface overflow areas periodically during the rainy season, and replace soil, plant material, or mulch layer in areas if erosion has occurred (for a bioretention inspection and maintenance checklist, see Appendix F). Properly designed facilities with appropriate flow velocities should not have erosion problems except perhaps in extreme events. If erosion problems occur, the following must be reassessed: (1) flow velocities and gradients within the cell, and (2) flow dissipation and erosion protection strategies in the pretreatment area and flow entrance. If sediment is deposited in the bioretention area, immediately determine the source within the contributing area, stabilize, and remove excess surface deposits.

3. Inlet: The inlet of the bioretention area should be inspected after the first storm of the season, then monthly during the rainy season to check for sediment accumulation and erosion. Sediment can accumulate especially at inlets where curb cuts or bypass structures are used and should be

inspected regularly. Any accumulated sediment that impedes flow into the bioretention area should be removed and properly disposed of.

4. Overflow and underdrains: Sediment accumulation in the overflow device or underdrain system can cause prolonged ponding and potential flooding. Excess ponding can have adverse effects on vegetation and vector control. Overflow and underdrain systems should be inspected after the first storm of the season, then monthly during the rainy season to remove sediment and prevent mulch accumulation around the overflow. The underdrain system should be designed so that it can be flushed and cleaned as needed. If water is ponded in the bioretention area for more than 72 hours, the underdrain system should be flushed with clean water until proper infiltration is restored.

5. Plant material: Depending on aesthetic requirements, occasional pruning and removing dead plant material might be necessary. Replace all dead plants, and if specific plants have a high mortality rate, assess the cause and, if necessary, replace with more appropriate species. Periodic weeding is necessary until plants are established. The weeding schedule can become less frequent if the appropriate plant species and planting density have been used and, as a result, undesirable plants are excluded.

6. Nutrient and pesticides: The soil mix and plants are selected for optimum fertility, plant establishment, and growth. Nutrient and pesticide inputs should not be required and can degrade the pollutant processing capability of the bioretention area and contribute pollutant loads to receiving waters. By design, bioretention areas are located in areas where phosphorous and nitrogen levels are often elevated, and they should not be limiting nutrients. If in question, have the soil analyzed for fertility.

7. Mulch: Replace mulch annually in bioretention areas where heavy metal deposition is likely (e.g., contributing areas that include industrial and auto dealer/repair parking lots and roads). In areas where metal deposition is not a concern, add mulch as needed to maintain a 2- to 3-inch depth. Mulch should be replaced every 2 to 5 years.

8. Soil: Soil mixes for bioretention areas are designed to maintain long-term fertility and pollutant processing capability. Estimates from metal attenuation research suggest that metal accumulation should not present an environmental concern for at least 20 years in bioretention systems. Replacing mulch in bioretention areas where heavy metal deposition is likely provides an additional level of protection for prolonged performance. If in question, have the soil analyzed for fertility and pollutant levels.

Task	Frequency	Maintenance notes
Pruning	1–2 times/year	Nutrients in runoff often cause bioretention vegetation to flourish.
Mowing	2–12 times/year	Frequency depends on location and desired aesthetic appeal.
Mulching	1–2 times/year	
Mulch removal	1 time/2–3 years	Mulch accumulation reduces available water storage volume. Removal of mulch also increases surface infiltration rate of fill soil.
Watering	1 time/2–3 days for first 1–2 months. Sporadically after establishment	If droughty, watering after the initial year might be required.
Fertilization	1 time initially	One-time spot fertilization for *first year* vegetation.
Remove and replace dead plants	1 time/year	Within the first year, 10 percent of plants can die. Survival rates increase with time.
Inlet inspection	Once after first rain of the season, then monthly during the rainy season	Check for sediment accumulation to ensure that flow into the bioretention is as designed. Remove any accumulated sediment.
Outlet inspection	Once after first rain of the season, then monthly during the rainy season	Check for erosion at the outlet and remove any accumulated mulch or sediment.
Miscellaneous upkeep	12 times/year	Tasks include trash collection, plant health, spot weeding, removing invasive species, and removing mulch from the overflow device.

1.4 References

Davis, A.P., M. Shokouhian, H. Sharma, C. Minami, and D. Winogradoff. 2003. Water quality improvement through bioretention: Lead, copper, and zinc. *Water Environment Research* 75(1):73–82.

Davis, A.P. 2007. Field performance of bioretention: Water quality. *Environmental Engineering Science* 24(8):1048–1063.

Hathaway, J.M., W.F. Hunt, and S.J. Jadlocki. 2009. Indicator bacteria removal in storm water best management practices in Charlotte, North Carolina. *Journal of Environmental Engineering* 135(12):1275–1285.

Hsieh, C.H., and A. Davis. P. 2005. Evaluation and optimization of bioretention media for treatment of urban storm water runoff. *Journal of Environmental Engineering* 131(11):1521–1531.

Hunt, W.F., and W.G. Lord. 2006. *Bioretention performance, design, construction, and maintenance*, North Carolina Cooperative Extension, Raleigh, NC.

Hunt, W.F., A.R. Jarrett, J.T. Smith, and L.J. Sharkey. 2006. Evaluating bioretention hydrology and nutrient removal at three field sites in North Carolina. *Journal of Irrigation and Drainage Engineering* 132(6):600–608.

Hunt, W.F., J.T. Smith, S.J. Jadlocki, J.M. Hathaway, and P.R. Eubanks. 2008. Pollutant removal and peak flow mitigation by a bioretention cell in urban Charlotte, NC. *Journal of Environmental Engineering* 134(5):403–408.

Kim, H., E.A. Seagren, and A.P. Davis. 2003. Engineered bioretention for removal of nitrate from stormwater runoff. *Water Environment Research* 75(4):355–367.

Li, H., and A.P. Davis. 2008. Urban particle capture in bioretention media. I: Laboratory and field studies. *Journal of Environmental Engineering* 143(6):409–418.

Passeport, E., W.F. Hunt, D.E. Line, R.A. Smith, and R.A. Brown. 2009. Field study of the ability of two grassed bioretention cells to reduce stormwater runoff pollution. *Journal of Irrigation and Drainage Engineering* 135(4):505–510.

Strecker, E.W., M.M. Quigley, B. Urbonas, and J. Jones. 2004. Analyses of the Expanded EPA/ASCE International BMP Database and Potential Implications for BMP Design. In *Proceedings of the World Water and Environmental Resources Congress*, American Society of Civil Engineers, Salt Lake City, UT, June 27–July 1, 2004.

2 Bioswales

Location: Bressi Ranch Medical Center, El Camino Real and Town Garden Road, Carlsbad, CA.

2.1 Description

Bioswales are shallow, open channels, often referred to as linear bioretention, that are designed to treat runoff primarily through infiltration and remove larger pollutants by filtering water through vegetation in the channel. Bioswales can serve as conveyance for storm water and can be used in place of traditional curbs and gutters; however, when compared to traditional conveyance systems, the primary objective of bioswales is infiltration and water quality enhancement rather than conveyance (except for excessive flow). Bioswales can have ranges of design variations with or without check dams, subsurface storage media, and underdrains. Bioretention media can be added to a bioswale to improve water quality, reduce the runoff volume, and modulate the peak runoff rate, while also providing conveyance of excess runoff.

2.1.1 Advantages

- Efficient removal of suspended solids, heavy metals, adsorbed pollutants, nitrogen, phosphorus, and pathogens
- Can effectively reduce peak runoff rates for relatively frequent storms, reduce runoff volumes, and recharge groundwater if soil conditions allow

- Flexible to adapt to urban retrofits including bordering parking lots and linearly along impervious surfaces
- Well suited for use in small areas, and multiple, distributed units can provide treatment in large drainage areas
- Can be integrated naturally into landscaping to enhance aesthetics

2.1.2 Disadvantages

- Surface soil layer can clog over time (though it can be restored)
- Frequent trash removal might be required, especially in high-traffic areas
- Vigilance in protecting native soils from compaction during construction is essential
- Single units can serve only small drainage areas
- Require maintenance of plant material and mulch layer

2.1.3 Major Design Elements

- Sizing must take into account all runoff at ultimate build-out including off-site drainage. (For volume calculations, see the City's *Storm Water Standards* and Appendix A.)
- Minimum width of 2 feet.
- Drainage areas should be less than 2 acres.
- Side slopes stabilized with vegetation must be no steeper than 3:1.
- Either a bypass or an internal overflow is required for bypassing storms in excess of the design storm.
- Bioswales must not be used where the seasonally high water table or confining layer is less than 10 feet below bottom of the BMP (City's *Storm Water Standards*).
- Soil media permeability must be at least 0.5 in/hr (City's *Storm Water Standards*).
- Inflow must be non-erosive sheet flow (1 ft/sec for mulch cells, 3 ft/sec for grass cells) or use energy dissipating devices. Diversion structures should be used in areas where inlet velocity could exceed the maximum flow.
- Infiltration BMPs must be a minimum of 100 feet from water supply wells and septic drain fields and 10 feet from any structures.
- Bioswales must not be used in watersheds where slopes are greater than 15 percent or in areas that are not permanently stabilized drainage areas.
- Ponding depth must be 12 inches or less; 9 inches is preferred.
- Soil media depth must be 2 feet minimum for grassed cells and 3 feet minimum for shrub/tree cells.
- Soil media should meet the specifications listed in section 2.2.8.

- Ponded water must completely drain into the soil within 24 hours, 12 hours preferred as a safety factor. It must drain to a level below the soil media (2 to 3 feet) within 48 hours.
- An underdrain must be installed if in situ soil drainage is less than 0.5 in/hr. The underdrain pipe should be at least 4 inches in diameter and installed at a 0.5 percent minimum slope.
- An underdrain must be installed if the bioswale is within 50 feet of a sensitive, steep slope.
- Cleanout pipes must be provided if underdrains are required.
- Grassed bioswales can be used; however, grassed cells must be sodded, and the sod must not be grown in soil with an impermeable (clay) layer.
- Finely shredded hardwood mulch 2 to 4 inches deep (3 inches preferred) must be used in all mulched bioswales (for details, see Section 2.2.8)
- Longitudinal slope should not exceed 2 percent. Slope can exceed 2 percent if check dams are installed such that one continuous section does not exceed 2 percent. Overall slope should not exceed 5 percent.

2.1.4 Characteristics and Function

Bioswales share the same functions as bioretention areas in that they are vegetated and mulched or grassed (i.e., landscaped) shallow depressions that capture and temporarily store storm water runoff but are designed to be narrow and linear to fit within certain site constraints. The captured runoff infiltrates through the bottom of the depression and a layer of soil media, approximately 2 to 4 feet deep, that has an infiltration rate capable of draining the bioretention area (to the bottom of the media) within a specified design drawdown time (usually 12 to 48 hours). The soil media provides treatment through filtration, adsorption, and biological uptake.

After the storm water infiltrates through the soil media, it percolates into the subsoil, if site conditions allow for adequate infiltration and slope protection. If site conditions do not allow for adequate infiltration or slope protection, filtered water is directed toward a storm water conveyance system or other storm water runoff BMP via underdrain pipes.

Bioswales are designed to capture a specified design volume and can be configured as online or offline systems. Online bioswales require an overflow system for passing larger storms. Offline bioswales do not require an overflow system but do require some freeboard (the distance from the overflow device and the point where storm water would overflow the system).

If an underdrain is not needed because infiltration rates are adequate and slope is not a concern, the remaining storm water passes through the soil media and percolates into the subsoil. Partial infiltration (approximately 20 to 25 percent, depending on soil conditions) can still occur when underdrains are present as long as there is not an impermeable barrier between the soil media and subsoil. Partial infiltration occurs in such cases because some of the storm water bypasses the underdrain and percolates into the subsoil (Strecker et al. 2004; Hunt et al. 2006).

Bioswales are typically planted with grasses, shrubs, and trees that can withstand short periods of saturation (12 to 72 hours) followed by longer periods of drought.

2.1.5 Applicability and Performance

Chapter 2 describes the process for selecting BMPs on the basis of pollutants of concern. Bioswales are volume-based BMPs intended primarily for water quality treatment and, depending on site slope and soil conditions, can provide high volume reduction. Where site conditions allow, the volume-reduction capability can be enhanced for achieving additional credit toward meeting the volume-reduction requirement by omitting underdrains and providing a gravel drainage layer beneath the bioswale.

Bioswales remove pollutants through physical, chemical, and biological mechanisms. Specifically, they use absorption, microbial activity, plant uptake, sedimentation, and filtration. Bioswales provide relatively consistent and high pollutant removal for sediment, metals, and organic pollutants (e.g., hydrocarbons). Most of the sediment removal occurs in the top mulch layer (Li and Davis 2008) while metals removal commonly occurs within the first 18 inches of the soil media (Hsieh and Davis 2005; Hunt and Lord 2006). Removal of nitrogen and phosphorus species is less consistent. Total phosphorus percent removal has been found to vary between a 240 percent increase (production) and a 99 percent decrease (removal) (Davis 2007; Hunt et al. 2006; Hsieh and Davis 2005). Greater total phosphorus removal can be achieved by using soil media with total phosphorus concentrations below 15 ppm (Hunt and Lord 2006). Nitrate removal has been found to vary between a 1 and 80 percent decrease (Kim et al. 2003; Hunt et al. 2006). TKN has been found to vary between a 5 percent increase and 65 percent decrease (Kim et al. 2003; Hunt and Lord 2006). Greater nitrate and TKN removal can be achieved by reducing the infiltration rate within the soil media to 1–2 in/hr and ensuring that the soil media is at least 3 feet deep (Hunt and Lord 2006). Greater nitrate removal can also be achieved by incorporating a saturated layer within the soil media to promote anaerobic conditions for denitrification (Kim et al. 2003; Hunt and Lord 2006; Passeport et al. 2009). Limited data exist for bacteria removal in bioswales; although, most scientists and engineers agree that bacteria die-off occurs at the surface where storm water is exposed to sunlight and the soil can dry out. Dense vegetation within the bioswale can limit the penetration of sunlight and removal of bacteria (Hathaway et al. 2009; Hunt et al. 2008; Hunt and Lord 2006).

2.2 Design

The design of a bioswale is very similar to a bioretention area and can be broken down to a nine-step process:

1. Determine BMP configuration
   a. Determine how to incorporate bioswales into the layout of the site
   b. Determine and incorporate the necessary BMP components
2. Determine the volume of water to treat (See the City's *Storm Water Standards* and the *San Diego County Hydrology Manual*)
3. Determine the surface area required
4. Decide the depth and type of soil media
5. Inlet configuration
6. Determine if an underdrain pipe is necessary
7. Select the appropriate overflow or bypass method

8. Select mulch and vegetation
9. Additional considerations

2.2.1 Determine BMP Configuration

Bioswales are intended to provide the same function as a bioretention area with the same pollutant-removal capacity with a narrow width to be more easily configured into the site plan for parking lot edges and narrow rights-of-way. Bioswales are a versatile storm water BMP because they can effectively reduce pollutants and can be integrated into the site plan with various configurations and components. Storm water treatment should be considered as an integral component and incorporated in the site design and layout from conception. Many times, determining how the bioswale will be included in the site design is a critical and required first step. How the water is routed to the bioswale and the available space will be key components in determining how the bioswale will be configured. Site assessment, planning, and site design are discussed in detail in chapter 2. The following is a list of settings where bioswales can be incorporated to meet more than one project-level or watershed-scale objective:

- Along the edge and between parking stalls in parking lots
- Within rights-of-way along roads

How the bioswale is configured determines the required components. Pretreatment at some level is always recommended to remove gross solids where possible and reduce flows to a non-erosive rate. Curb cuts can be required to allow storm water to enter the bioswale, while providing some delineation in high-traffic areas. Bioswales can serve the dual purpose of storm water management and landscape design and can significantly enhance the aesthetics of a site. Figure 13 shows an example of the components of a typical bioswale. Bioswales typically have multiple components including the following:

- Filter strip or grass buffer for pretreatment
- Media layer for filtration
- Ponding area for storage
- Plants for pollutant uptake and landscaping

In addition, bioswales can be combined with other basic and storm water runoff BMPs to form a treatment train that can provide enhanced water quality treatment and reductions in runoff volume and rate. For example, runoff can be collected from a roadway or a parking lot in a bioswale that then overflows to a bioretention area. Both facilities can be reduced in size on the basis of demonstrated performance for meeting the storm water runoff requirements as outlined in Chapter 2 and addressing targeted pollutants of concern.

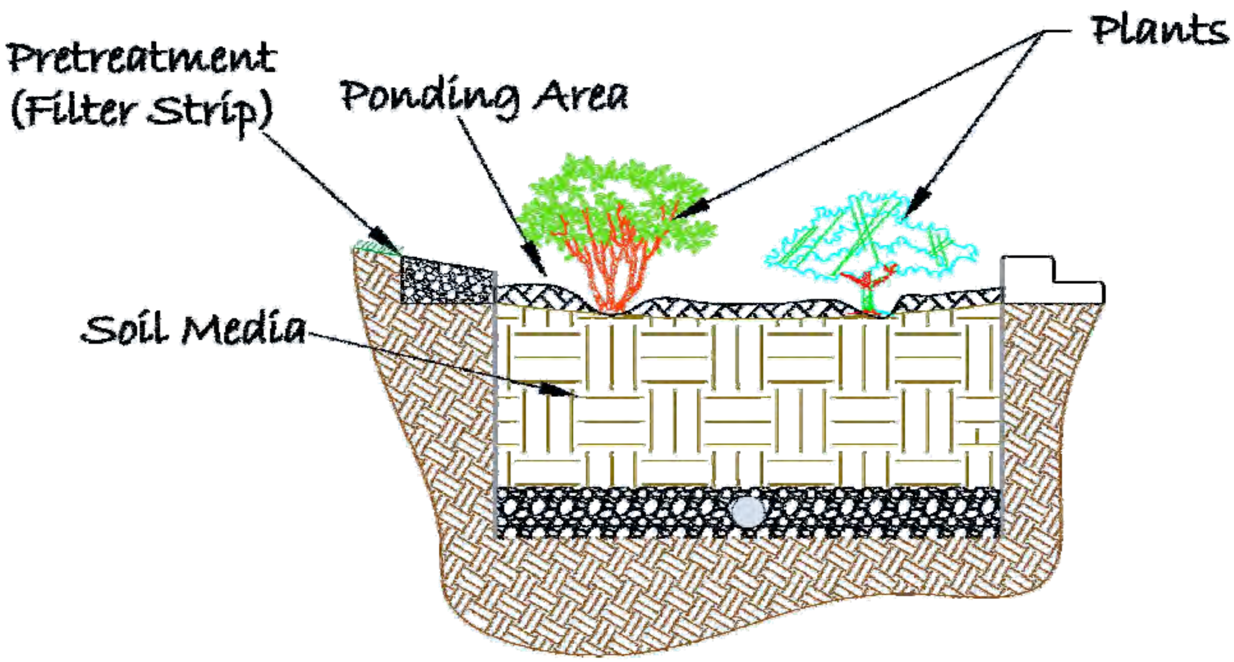


Figure 13. Bioswale components.

2.2.1.1 Pretreatment

1. Bioswales should use a filter strip to pretreat incoming flows from impervious surfaces where space is available. Bioswales that treat runoff from residential roofs or other *cleaner* surfaces will not require pretreatment for trash or sediment but should include flow reduction as much as possible.

2. If sheet flow is conveyed to the treatment area over stabilized grassed areas, the site must be graded so as to minimize erosive conditions. Sheet flow velocities must not exceed 3 ft/sec.

2.2.1.2 Curb Cuts

Because bioswales are often incorporated into highly impervious areas, such as parking lots and in road rights-of-way, curb cuts could be required to allow surface runoff to enter the bioswale while providing delineation from the travel lanes. Curb cuts are designed such that the design storm can pass through the curbing without causing water to pond in the travel lanes. Further detail for curb cuts is provided in section 10.1 of this Appendix B.

Some pretreament flow reduction can be provided by using multiple, smaller curb cuts to minimize the flow at each opening and by armoring the curb opening from the back of the curb to the base elevation of the bioswale.

2.2.1.3 Parking Lots

Bioswales are especially useful along the edge of parking lots or between facing parking stalls where not much space is available for storm water treatment. Pretreatment is important for parking lot areas to remove large sediments and to slow the runoff to non-erosive flow rates (1 in/hr for mulch and 3 in/hr for sod). Pretreatment typically consists of a gravel verge followed by turf. Figure 14 shows an example of how a bioswale can be incorporated into the area between facing parking stalls and along the edge of a parking lot.

Location: Bressi Ranch Medical Center, El Camino Real and Town Garden Road, Carlsbad, CA.

Figure 14. Parking lot bioswale.

2.2.1.4 Roads

Bioswales can also be integrated into the right-of-way and medians of roads. Similar concepts apply to roads as parking lots. Some pretreatment could be required to remove large particles and slow the runoff to non-erosive flows. Bioswales can be used along the edge of roads or in medians as shown in Figure 15.

Location: Columbia Memorial Learning Center, Downey, CA

Figure 15. Road median bioswale.

For standard median and right-of-way specifications, see the City's *Street Design Manual*. The maximum width right-of-way and curb-to-curb spacing should be used to most effectively implement bioswales.

2.2.2 Determine the Volume of Water or Flow to Treat

The volume of water that must be treated is equal to the design storm. The methods for calculating the volume required for treatment are outlined in the City's *Storm Water Standards*, the *San Diego County Hydrology Manual*, and Appendix A.

2.2.3 Determine the Surface Area Required

2.2.3.1 Geometry and Size

1. Bioswales have similar standards to bioretention areas except that they are typically long and narrow with widths between 2 and 8 feet (Figure 16).

2. Bioswales have a maximum ponding depth of 12 inches, with 9 inches preferred.

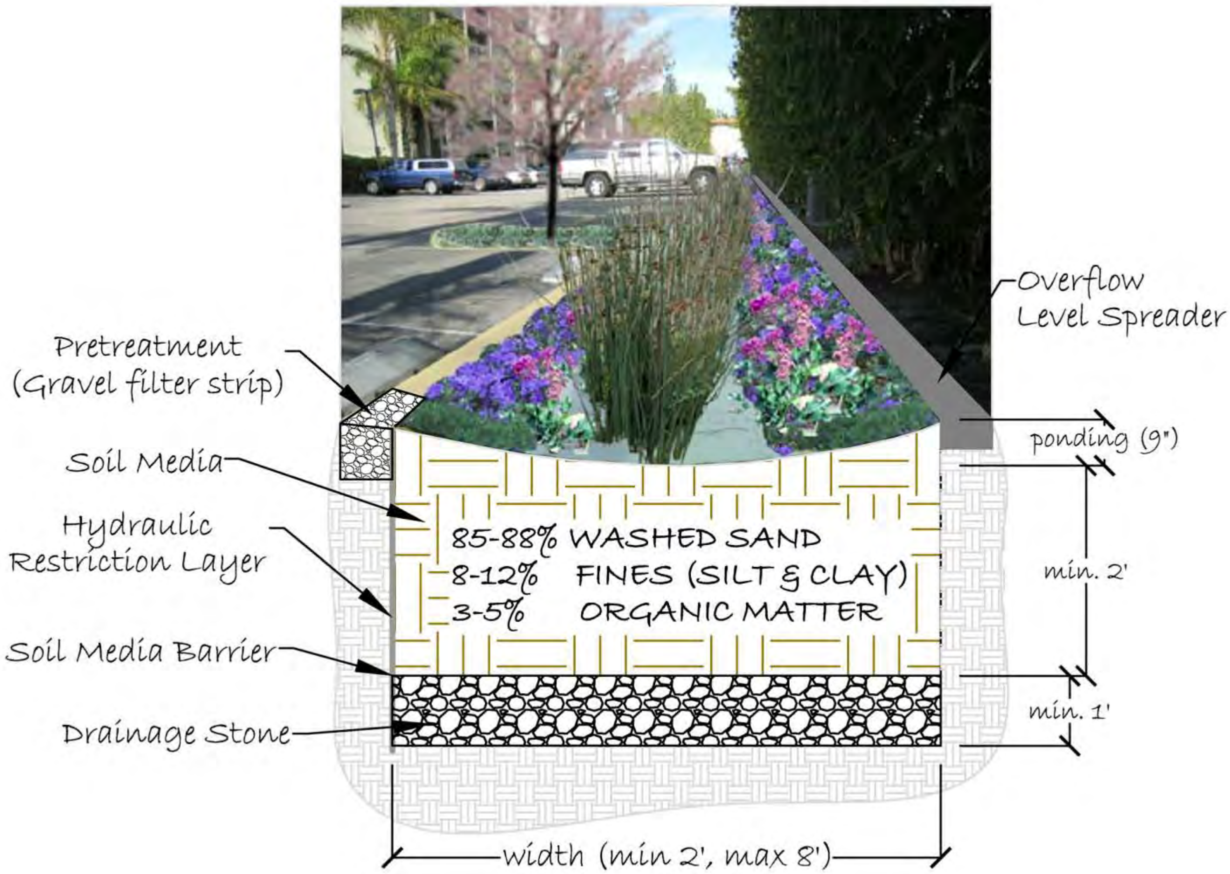


Figure 16. Bioswale area geometry and profile.

3. Soil media should be a minimum of 2 feet, although 3 feet is preferred. The soil media provides a beneficial root zone for the chosen plant palette and adequate water storage for the water quality design volume. A deeper soil media depth will provide a smaller surface area footprint. Pollutant removal occurs at different depths. Two feet provides the accepted pollutant-removal performance, but studies have shown that deeper media depths can provide improved nutrient removal performance (Hunt and Lord 2006).

4. Bioswales are designed to drain to below the surface in less than 12 hours (the standard is 24 hours, but 12 hours is preferred as a safety factor) and below the soil media depth in less than 48 hours. If a gravel drainage layer is included beneath the bioswale soil media, stored runoff in the drainage layer should drain in less than 72 hours. The soils must be allowed to dry out periodically to restore hydraulic capacity to receive flows from subsequent storms, maintain infiltration rates, maintain adequate soil oxygen levels for healthy soil biota and vegetation, and to provide proper soil conditions for biodegradation and retention of pollutants.

2.2.3.2 Sizing Methodology

Bioswales are to be sized to capture and treat the volume produced by the design storm and, where site conditions allow, should also be sized to infiltrate the volume-reduction requirement. For the storm water runoff requirements and calculations, see Appendix A. Procedures for sizing infiltration BMPs will be in accordance with the sizing methodology developed for the City's *Storm Water Standards*.

2.2.4 Determine the Depth and Type of Soil Media

2.2.4.1 Depth of Soil Medium

Different pollutants are removed in various zones of the bioswale using several mechanisms. TSS is removed both in pretreatment and on the surface of the cell itself. For that reason, TSS removal is not a major factor in depth of the cell design. Depth, however, is an issue for other pollutants. Metals are removed in the top layer of mulch and within the first 18 inches of media because they are often bound to sediment (Davis et al. 2003; Li and Davis 2008). Bacterial, viral and protozoan pathogens can be killed on the surface and removed throughout the cell by several mechanisms: sun exposure, drying, sedimentation, and filtration (Hathaway et al. 2009). Media depth should be 30 inches to optimize nitrogen removal and 24 inches for phosphorus (Hunt and Lord 2006). Considering the target pollutant, the depth of the media in a bioswale should be between 2 and 4 feet. That range reflects the fact that most of the pollutant removal occurs within the first 2 feet of soil, and excavations deeper than 4 feet become more expensive. The depth should accommodate the desired vegetation (shrubs or trees). If the minimum depth of 2 feet is used, only shallow-rooted plants can be planted. Grassed bioswales can be as shallow as 2 feet and where shrubs or trees are planted can be as shallow as 3 feet. If large trees are to be planted in deep soil media, take care to ensure that they will be stable and not fall over.

2.2.4.2 Type

The soil media within the bioretention cell should meet the requirements as set by the City's *Storm Water Standards*. Soils at infiltration sites must have the following properties: OC > 5 percent, pH between 6–8, CEC > 5 meq/100 g soil, infiltration rates of 0.5 in/hr or greater. The soil media in the bioswale should be highly permeable (at least 0.5 in/hr) and have an appropriate amount of organic material to support plant growth. If the existing soils meet those criteria, they can be used as the soil media. If the existing soils do not meet the criteria, a substitute media must be used. Soil media that is brought to the site must meet the following criteria:

1. Soil media consists of 85 percent washed course sand, 10 percent fines (range: 8–12 percent. 8 percent = 2 in/hr infiltration rate, 12 percent = 1 in/hr infiltration rate), and 5 percent organic matter.
2. The sand portion should consist of concrete sand (passing a one-quarter-inch sieve). Mortar sand (passing a one-eighth-inch sieve) is acceptable as long as it is thoroughly washed to remove the fines.
3. Fines should pass a # 270 sieve.
4. Organic matter is considered an additive to assist vegetation in initial establishment and should be minimized. Organic materials will oxidize over time causing an increase in ponding that can adversely affect the bioswale's performance. Organic material should consist of aged bark fines,

or similar organic material. Organic material should not consist of manure or animal compost. Studies have also shown newspaper mulch to be an acceptable additive (Kim et al. 2003; Davis 2007).

5. High levels of phosphorus in the soil media have been identified as the main cause of the exportation of nutrients (Hunt and Lord 2006). All soil media should be analyzed for background levels of nutrients. Total phosphorus should not exceed 15 ppm.

2.2.5 Inlet Configuration

Inlets must be designed to convey the design storm volume into the bioswale while limiting ponding or flooding at the entrance and protecting the interior from damage. Several options are available depending on the configuration of the bioswale. Ideally, runoff will pass over a filter strip where flow can be dispersed and gross solids removed before it enters the bioswale as shown in Figure 16. That is not always possible, especially in retrofit situations were space might not be available. Typical inlet configurations are described in section 10.1 of this Appendix B.

2.2.6 Determine if an Underdrain Pipe is Necessary

A geotechnical investigation should be performed by a licensed soil scientist or geotechnical engineer, and a report should be prepared in accordance with the City's *Guidelines for Geotechnical Reports*. The investigation should determine the infiltration rate of the soils and the depth to the seasonally high groundwater table. If the infiltration rate of the soils on which the bioswale will be installed is less than 0.5 in/hr or the depth of the seasonally high groundwater table is less than 10 feet but greater than 2 feet, underdrains should be installed. For details on installing underdrains, see section 10.2 of this Appendix B.

2.2.7 Select the Appropriate Outlet or Bypass Method

Two design configurations can be used for treating storms that are larger than the bioswale is designed to store:

1. Offline: Design a structure that diverts into the bioswales only the volume of storm water for which the bioswale is designed. Further details for diversion structures are in section 10.3 of this Appendix B.
2. Online: All runoff enters the bioswale with an outlet or overflow for volumes exceeding the design storm. Outlet systems for online bioswales can be designed to provide some peak flow mitigation in addition to storing the design volume.

When flows through a bioswale could exceed the recommended maximum flow rates, regardless of whether a system is designed to be online or offline, a bypass structure is recommended to prevent erosion in the bioswale. The flow velocity in a mulched system should not exceed 1 ft/sec, and flow in a grassed system should not exceed 3 ft/sec. Flows can be greater (up to 14 ft/sec) with the use of reinforced turf matting and will depend on the matting selected. A bypass structure should be used to ensure that flows through the system do not exceed the recommended design flow.

If the bioswale is online, an outlet or overflow device is required at the 12-inch maximum ponding depth. Two options are provided:

Option 1: Vertical riser

1. A vertical PVC pipe that is connected to the underdrain or directly to the drainage system.
2. The outlet riser(s) is 4 inches or greater in diameter, so it can be cleaned without damage to the pipe. The vertical pipe will provide access to cleaning the underdrains.
3. The inlet to the riser should be 12 inches above the soil media and be capped with a spider cap. Figure 17 shows a schematic of an online bioswale with a vertical riser overflow design.

Option 2: Flow spreader

1. A flow spreader can be installed along a section of the exit edge or outflow section of the bioswale. The flow spreader can be earthen covered with sod or any stable material.
2. The top surface of the flow spreader must 12 inches above the surface of the bioswale. Figure 16 shows a bioswale with a concrete flow spreader.
3. The flow spreader can be designed as a weir to allow for varied outlet flows providing some peak flow mitigation.

2.2.8 Select mulch and vegetation

2.2.8.1 Mulch

Bioswales intended to be mulched must be covered with mulch when constructed and annually replaced to maintain adequate mulch depth. Mulch can help sustain nutrient levels, suppress weeds, and maintain infiltrative capacity. Mulch should be

- Well-aged shredded hardwood material. Well-aged mulch is defined as mulch that has been stockpiled or stored for at least 12 months.
- Free of weed seeds, soil, roots, and other material that is not hardwood material.
- The mulch should be maintained at depth of 2 to 4 inches, with 3 inches preferred. Thicker applications can inhibit proper oxygen and carbon dioxide cycling between the soil and atmosphere.
- Grass clippings or pure bark cannot be used as mulch.

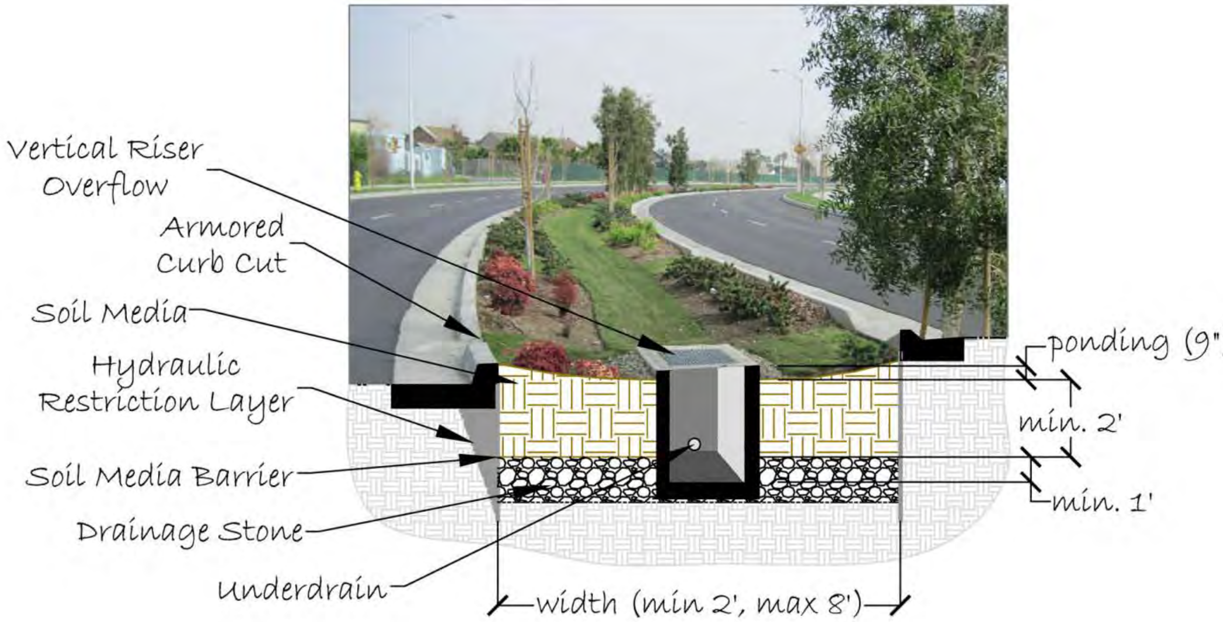


Figure 17. Online bioswale with a vertical riser overflow.

Note: Shredded redwood mulch is appropriate for bioswales and is readily available in Southern California. Shredded redwood mulch is known as gorilla hair in the landscaping community. Figure 18 shows an example of gorilla hair.

Figure 18. Gorilla hair mulch.

2.2.8.2 Vegetation

One advantage of a bioswale, similar to bioretention areas, is that they can be used for the dual purpose of storm water treatment and landscaping or be integrated into the existing landscape. For bioswales to function properly as storm water treatment and blend into the landscaping, vegetation selection is crucial. Appropriate vegetation will have the following characteristics:

1. Plant materials must be tolerant of summer drought, ponding fluctuations, and saturated soil conditions for 10 to 48 hours.
2. It is recommended that a minimum of three tree, three shrubs, and three herbaceous groundcover species be incorporated to protect against facility failure from disease and insect infestations of a single species. Plant rooting depths must not damage the underdrain, if present. Slotted or perforated underdrain pipe must be more than 5 feet from tree locations (if space allows).
3. Native plant species or hardy cultivars that are not invasive and do not require chemical inputs are recommended to be used to the maximum extent practicable. Only native non-invasive species will be selected for areas in the MHPA or in areas designated as natural open space.
4. Shade trees should be free of branches below the following heights:

Caliper (in)	Height (ft)
0.5 to 2.5	5
3	6

5. A list of native plants appropriate for San Diego is in Appendix E.

There are endless options for vegetation arrangement, and they will most likely depend on the landscaping of the area around the bioswale.

2.2.9 Additional Considerations

2.2.9.1 Hydraulic Restriction Layers

Because of the narrow configuration of a bioswale and its intended use along the edges of parking lots and roads, infiltration pathways will most likely need to be restricted to prevent unintended effects on roads, foundations, other infrastructure, or hotspot locations. In some conditions, lateral seepage can cause damage to surrounding structures depending on the type of soils in the area. Areas that have a potential for settling under saturated conditions, as determined in the geotechnical investigation, should be protected from lateral flows. Types of clay that have a high potential for expansion when saturated should be protected from moisture in load-bearing conditions. For details on hydraulic restriction layers, see section 10.4 of this Appendix B.

2.2.9.2 Check Dams

Bioswales can be used as conveyance systems, especially when used in a treatment train system to route runoff to another BMP such as a bioretention area. The longitudinal slope should be minimized to prevent erosion in the bioswale. Flow velocity should not exceed 1 ft/sec in mulched swales and 3 ft/sec in grassed swales. The longitudinal slope should not exceed 2 percent. Bioswales can be used effectively in areas with slopes from 2 to 5 percent by installing check dams to prevent erosive flow velocities. Check dams should be constructed as required such that the slope of each section between check dams does not exceed 2 percent (Figure 19). Overall slope should not exceed 5 percent.

Figure 19. Bioswale with a check dam.

2.2.9.3 Utilities

Utilities should be avoided where possible when implementing bioswales. In many cases, bioswales can be shifted in the landscape to prevent implementation over utilities. In cases where utilities cannot be avoided, take care to prevent impact from infiltration or saturation by using hydraulic restricting layers to direct infiltration away from the utility. For details on using hydraulic restriction layers to prevent effects on utilities, see section 10.5 of this Appendix B.

2.3 Operation and Maintenance

Bioswales, similar to bioretention areas, require regular plant, soil, and mulch layer maintenance to ensure optimum infiltration, storage, and pollutant-removal capabilities. In general, bioswale maintenance requirements are typical landscape care procedures and consist of the following:

1. Watering: Drought-tolerant plants should be selected to reduce watering after establishment (2 to 3 years). Watering might be required during prolonged dry periods after plants are established.

2. Erosion control: Inspect flow entrances, ponding area, and surface overflow areas periodically during the rainy season, and replace soil, plant material, or mulch layer in areas if erosion has occurred (for a bioswale inspection and maintenance checklist, see Appendix F). Properly designed facilities with appropriate flow velocities will not have erosion problems except perhaps in extreme events. If erosion problems occur, the following must be reassessed: (1) flow velocities and gradients within the cell, and (2) flow dissipation and erosion protection strategies in the pretreatment area and flow entrance. If sediment is deposited in the bioswale, immediately determine the source in the contributing area, stabilize, and remove excess surface deposits.

3. Inlet: The inlet area should be inspected after the first storm of the season, then monthly during the rainy season to check for sediment accumulation and erosion. Sediment can accumulate especially at inlets where curb cuts or bypass structures are used and should be inspected regularly. Any accumulated sediment that impedes flow into the bioswale should be removed and properly disposed of.

4. Overflow and underdrains: Sediment accumulation in the overflow device or underdrain system can cause prolonged ponding and potential flooding. Excess ponding can have adverse effects on vegetation and vector control. Overflow and underdrain systems should be inspected after the first storm of the season, then monthly during the rainy season to remove sediment and prevent mulch accumulation around the overflow. The underdrain systems should be designed so that it can be flushed and cleaned as needed. If water is ponded in the bioswale for more than 72 hours, the underdrain system should be flushed with clean water until proper infiltration is restored.

5. Plant material: Depending on aesthetic requirements, occasional pruning and removing of dead plant material might be necessary. Replace all dead plants, and if specific plants have a high mortality rate, assess the cause and, if necessary, replace with more appropriate species. Periodic weeding is necessary until plants are established. The weeding schedule could become less frequent if the appropriate plant species and planting density have been used and, as a result, undesirable plants are excluded.

6. Nutrient and pesticides: The soil mix and plants are selected for optimum fertility, plant establishment, and growth. Nutrient and pesticide inputs should not be required and can degrade the pollutant processing capability of the bioswale, as well as contribute pollutant loads to receiving waters. By design, bioswales are located in areas where phosphorous and nitrogen levels are often elevated, and those should not be limiting nutrients. If in question, have the soil analyzed for fertility.

7. Mulch: Replace mulch annually where heavy metal deposition is likely (e.g., contributing areas that include industrial and auto dealer/repair parking lots and roads). In areas where metal deposition is not a concern, add mulch as needed to maintain a 2- to 3-inch depth. Mulch should be replaced every 2 to 5 years.

8. Soil: Soil mixes are designed to maintain long-term fertility and pollutant processing capability. Estimates from metal attenuation research suggest that metal accumulation should not present an environmental concern for at least 20 years. Replacing mulch where heavy metal deposition is likely provides an additional level of protection for prolonged performance. If in question, have soil analyzed for fertility and pollutant levels.

Task	Frequency	Maintenance notes
Pruning	1–2 times/year	Nutrients in runoff often cause vegetation to flourish.
Mowing	2–12 times/year	Frequency depends on location and desired aesthetic appeal.
Mulching	1–2 times/year	

Task	Frequency	Maintenance notes
Mulch removal	1 time/2–3 years	Mulch accumulation reduces available water storage volume. Removal of mulch also increases surface infiltration rate of fill soil.
Watering	1 time/2–3 days for first 1–2 months. Sporadically after establishment	If droughty, watering after the initial year might be required.
Fertilization	1 time initially	One-time spot fertilization for first year vegetation.
Remove and replace dead plants	1 time/year	Within the first year, 10 percent of plants can die. Survival rates increase with time.
Inlet inspection	Once after first rain of the season, then monthly during the rainy season	Check for sediment accumulation to ensure that flow is as designed. Remove any accumulated sediment.
Outlet inspection	Once after first rain of the season, then monthly during the rainy season	Check for erosion at the outlet and remove any accumulated mulch or sediment.
Miscellaneous upkeep	12 times/year	Tasks include trash collection, spot weeding, and removing mulch from overflow device.

2.4 References

Davis, A.P., M. Shokouhian, H. Sharma, C. Minami, and D. Winogradoff. 2003. Water quality improvement through bioretention: Lead, copper, and zinc. *Water Environment Research* 75(1):73–82.

Davis, A.P. 2007. Field performance of bioretention: Water quality. *Environmental Engineering Science* 24(8):1048–1063.

Hathaway, J.M., W.F. Hunt, and S.J. Jadlocki. 2009. Indicator bacteria removal in stormwater best management practices in Charlotte, North Carolina. *Journal of Environmental Engineering* 135(12):1275–1285.

Hsieh, C.H., and A.P. Davis. 2005. Evaluation and optimization of bioretention media for treatment of urban storm water runoff. *Journal of Environmental Engineering* 131(11):1521–1531.

Hunt, W.F., and W.G. Lord. 2006. *Bioretention performance, design, construction, and maintenance*, North Carolina Cooperative Extension, Raleigh, N.C.

Hunt, W.F., A.R. Jarrett, J.T. Smith, and L.J. Sharkey. 2006. Evaluating bioretention hydrology and nutrient removal at three field sites in North Carolina. *Journal of Irrigation and Drainage Engineering* 132(6):600–608.

Hunt, W.F., J.T. Smith, S.J. Jadlocki, J.M. Hathaway, and P.R. Eubanks. 2008. Pollutant removal and peak flow mitigation by a bioretention cell in urban Charlotte, NC. *Journal of Environmental Engineering* 134(5):403–408.

Kim, H., E.A. Seagren, and A.P. Davis. 2003. Engineered bioretention for removal of nitrate from stormwater runoff. *Water Environment Research* 75(4):355–367.

Li, H., and A.P. Davis. 2008. Urban particle capture in bioretention media. I: Laboratory and field studies. *Journal of Environmental Engineering*, 143(6):409–418.

Passeport, E., W.F. Hunt, D.E. Line, R.A. Smith, and R.A. Brown. 2009. Field study of the ability of two grassed bioretention cells to reduce storm-water runoff pollution. *Journal of Irrigation and Drainage Engineering* 135(4):505–510.

Strecker, E.W., M.M. Quigley, B. Urbonas, and J. Jones. 2004. Analyses of the Expanded EPA/ASCE International BMP Database and Potential Implications for BMP Design. In *Proceedings of the World Water and Environmental Resources Congress*, American Society of Civil Engineers, Salt Lake City, UT, June 27–July 1, 2004.

3 Permeable Pavement

3.1 Description

Conventional pavement results in increased surface runoff rates and volumes. However, permeable pavements work by allowing streets, parking lots, sidewalks, and other impervious covers to retain their natural infiltration capacity while maintaining the structural and functional features of the materials they replace. Permeable pavements contain small voids that allow water to drain through the pavement to an aggregate reservoir and then infiltrate into the soil. If the native soils below the permeable pavements do not have enough percolation capacity, underdrains can be included to direct the storm water to other downstream storm water control systems. Permeable pavement BMPs can be developed using modular paving systems (e.g., concrete pavers, grass-pave, or gravel-pave) or poured in place solutions (e.g., porous concrete or permeable asphalt).

3.1.1 Advantages

- Replaces completely impervious surfaces with partially impervious surfaces
- Reduces storm water runoff rate and volume
- Reduces loads of some pollutants in surface runoff by reducing the volume of storm water leaving a site
- Saves area by using treatment area for parking/driving
- Reduces runoff temperature

- Reduces peak discharges and stress on storm sewers
- Increases groundwater recharge

3.1.2 Disadvantages

- Potential for clogging of porous media by sediment, which could lead to reduced effectiveness without proper maintenance
- Not applicable for high-traffic areas or for use by heavy vehicles
- Permeable pavement should be installed only by contractors qualified and certified for permeable pavement installation
- Generally limited to soils with high infiltration rates unless underdrains are provided

3.1.3 Major Design Elements

- Permeable pavement layers should be a minimum of 6 inches in depth. That includes the bedding layer for permeable pavers.
- Completed permeable pavement installation must have a slope less than 0.5 percent
- Soils must have infiltration capacity of at least 0.5 in/hr (City's *Storm Water Standards*)
- Surface and stone bed suitable for design traffic loads consisting of an open-graded subbase with minimum 40 percent void space at least 6 inches in depth
- Limit runoff from adjacent areas with exposed or disturbed areas
- Do not place bed bottom on compacted fill

3.1.4 Characteristics and Function

Permeable pavement systems are designed to allow rainfall and runoff to percolate into the subsurface. They are designed to reduce the amount of runoff, therefore reducing pollutant loadings by reducing the impervious area and providing temporary storage in the gravel media. Many permeable pavement surfaces are available, including pervious concrete, porous asphalt, and permeable interlocking concrete pavers. While the specific design can vary, all permeable pavements have a similar structure, consisting of a surface pavement layer, an underlying stone aggregate reservoir layer, and a filter layer or fabric installed on the bottom. Descriptions of the types of permeable pavement are below.

Permeable concrete is a mixture of Portland cement, fly ash, washed gravel, and water. The water to cementitious material ratio is typically 0.35–0.45 to 1 (NRMCA 2004). Unlike traditional installations of concrete, permeable concrete usually contains a void content of 15 to 25 percent, which allows water to infiltrate directly through the pavement surface to the subsurface. A fine, washed gravel, less than 13 mm in size (No. 8 or 89 stone), is added to the concrete mixture to increase the void space (GCPA 2006). An admixture improves the bonding and strength of the pavements. The pavements are typically laid with a 4- to 8-inch (10 to 20 cm) thickness and at least a 6-inch gravel base course, typically a washed no. 57 stone, for additional storage or infiltration. Compressive strength can range from 2.8 to 28 megapascals (MPa) (400 to 4,000 pounds per square inch [psi]) (NRMCA 2004).

Porous asphalt pavement consists of fine- and course-aggregate stone bound by a bituminous-based binder. The amount of fine aggregate is reduced to allow for a larger void space of typically 15 to 20 percent. Thickness of the asphalt depends on the traffic load but usually ranges from 3 to 7 inches. A required underlying base course, typically a washed no. 57 stone, increases storage, and adds strength (Ferguson 2005).

Permeable interlocking concrete pavements (PICPs) are available in many different shapes and sizes. When lain, the blocks form patterns that create openings through which rainfall can infiltrate. The openings, generally 8 to 20 percent of the surface area, are typically filled with pea gravel aggregate but can also contain top soil and grass. ASTM C936 specifications (200 1b) state that the pavers be at least 2.36 inches (60 mm) thick with a compressive strength of 55 MPa (8,000 psi) or greater. Typical installations consist of the pavers and gravel fill, a 1.5- to 3.0-inch (38 to 76 mm) fine-gravel bedding layer, and a gravel base-course, typically a washed no. 57 stone, storage layer (ICPI 2004).

Plastic grid systems, also called geocells or turf pavers, consist of flexible-plastic, interlocking units that allow for infiltration through large gaps filled with gravel or topsoil planted with turf grass. A sand bedding layer and gravel base course are often added to increase infiltration and storage. The empty grids are typically 90 to 98 percent open space, so void space depends on the fill media (Ferguson 2005). To date, no uniform standards exist; however, one product specification defines the typical load-bearing capacity of empty grids at approximately 13.8 MPa (2,000 psi). That value increases up to 38 MPa (5,500 psi) when filled with various materials (Invisible Structures 2001).

Concrete pavers conform to ASTM C 1319, Standard Specification for Concrete Grid Paving Units (2001a), which describes paver properties and specifications. Concrete Grid Paving units are typically 3.5 inches (90 mm) thick with a maximum 24 × 24 inch (60 × 60 cm) dimension. The percentage of open area ranges from 20 to 50 percent and can contain topsoil and grass, sand, or aggregate in the void space. The minimum average compressive strength of Concrete Grid Paving units can be no less than 35 MPa (5,000 psi). A typical installation consists of grid pavers with fill media, 1–1.5 inches (25 to 38 mm) of bedding sand, gravel base course typically consisting of washed no. 57 stone, and a loosely compacted soil subgrade (ICPI 2004).

3.1.5 Applicability and Performance

Chapter 2 describes the process for selecting BMPs according to the pollutants of concern. Permeable pavement systems primarily reduce the annual runoff volume and, as a result, reduce the pollutant load to receiving waterbodies. Volume reduction is dependent primarily on the design and subsurface soil infiltration capacities. Permeable pavement drainage has also been shown to have decreased concentrations of several storm water pollutants, including heavy metals, motor oil, sediment, and some nutrients (Pratt et al. 1989, 1995; James and Shahin 1998; Brattebo and Booth 2003; Bean et al. 2007). The aggregate subbase provides water quality improvements through filtering and chemical and biological processes.

Pollutant-removal efficiencies for permeable pavements have been well studied. Total nitrogen removal has been shown to range from 25 to 88 percent (CWP 2007; MWCOG 1983; Schueler 1987). As with total nitrogen, total phosphorous removal has been shown to have a wide range of removal efficiencies, ranging from 25 to 65 percent (CWP 2007; MWCOG 1983; Schueler 1987). Permeable pavements are very good at removing oil and metals from the runoff, where the pollutants are stored in the top portion of the pavement system. Metal-removal efficiencies range from 66 to 99 percent (CWP 2007; MWCOG 1983; Schueler 1987). Permeable pavement systems are also very good at removing sediment; however, high loadings of TSS significantly reduce the service life of permeable pavement systems because of clogging of the filter media. TSS reductions have been shown to range from 82 to 95 percent (CWP 2007; MWCOG 1983; Schueler 1987).

3.2 Design

Off-site drainage must be limited to runoff from stabilized areas with little sediment running onto the permeable pavement. Permeable pavement is typically designed to treat storm water that falls on the actual pavement surface area and has been used at commercial, institutional, and residential sites in spaces that are traditionally impervious. Areas proposed for permeable pavement should have a low traffic frequency. The primary factors that should direct permeable pavement design include the following:

1. Providing adequate infiltration and temporary storage
2. Preventing sediment, oils, and greases from reaching the permeable pavement surface where they have the potential to clog
3. Using construction techniques that minimize the compaction of subsurface soils

A typical section used in the construction of permeable pavement systems is shown in Figure 20. This section provides the typical components of the system: permeable pavement (pervious concrete or asphalt or paver blocks), the bedding and base course, the reservoir, and optional geotextile.

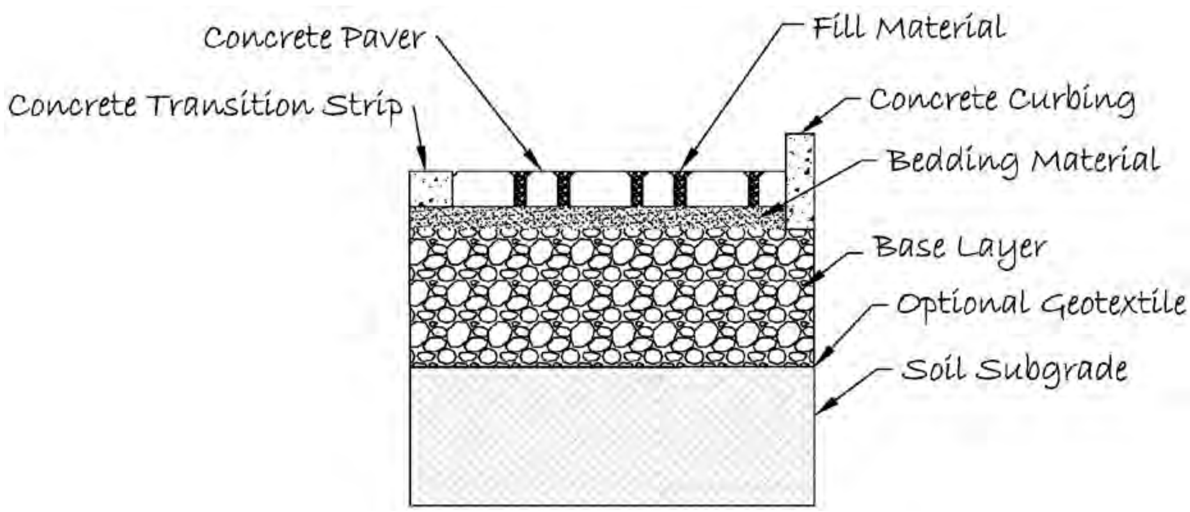


Figure 20. Typical cross section and components of a permeable pavement system.

The design of a permeable pavement system follows an eight-step process.

1. Determine BMP configuration
2. Determine permeable pavement type

3. Structural design requirements
4. Determine appropriate bedding
5. Determine the volume of water to treat (see Appendix A)
    a. Calculate reservoir media depth
6. Determine if an underdrain pipe is necessary
7. Provide a geotextile
8. Additional considerations

Specific design information for installing pervious pavement systems is provided below.

Note: Construction of permeable pavement systems should be performed only by a contractor with experience in permeable pavement installation and that is certified by the Interlocking Concrete Pavement Institute or the National Ready Mix Concrete Association. Lists of certified contactors are at http://www.icpi.org or http://www.nrmca.org.

3.2.1 Determine BMP Configuration

Permeable pavement is a highly versatile storm water BMP because it can effectively reduce pollutants and can be integrated into site plans with various configurations and components. Storm water treatment should be considered as an integral component and incorporated in the site design and layout from conception. Many times, determining how permeable pavement will be included in the site design is a critical and required first step. How the water is routed to the permeable pavement and the available space will be key components in determining how the permeable pavement is configured. Site assessment, planning, and site design are discussed in detail in chapter 2. Following is a list of settings in which permeable pavement can be incorporated to meet more than one project-level or watershed-scale objective:

- Parking lots
- Within rights-of-way along roads

Pretreatment at some level is always required to remove gross solids, where possible, and reduce flows to a non-erosive rate when run on is allowed to flow onto the permeable pavement. Permeable pavement can serve the dual purpose of storm water management and provide the structural support for parking or other purposes that would typically have to be impervious. Permeable pavement generally has multiple components consisting of the following:

- Filter strip or grass buffer for pretreatment if required
- Paving or paver surface
- Bedding layer if required
- Gravel storage layer

In addition, permeable pavement areas can be combined with other basic and storm water runoff BMPs to form a treatment train that provides enhanced water quality treatment and reductions in runoff volume and rate. For example, runoff can flow from a roadway to the permeable pavement section and overflow to a bioretention area as shown in Figure 21. Both facilities can be reduced in size according to demonstrated performance for meeting the storm water runoff requirements as outlined in Chapter 2 and addressing targeted pollutants of concern.

Figure 21. Permeable pavement and bioretention treatment train.

3.2.1.1 Pretreatment

1. Permeable pavement areas require a filter strip to pretreat incoming flows from adjacent areas.

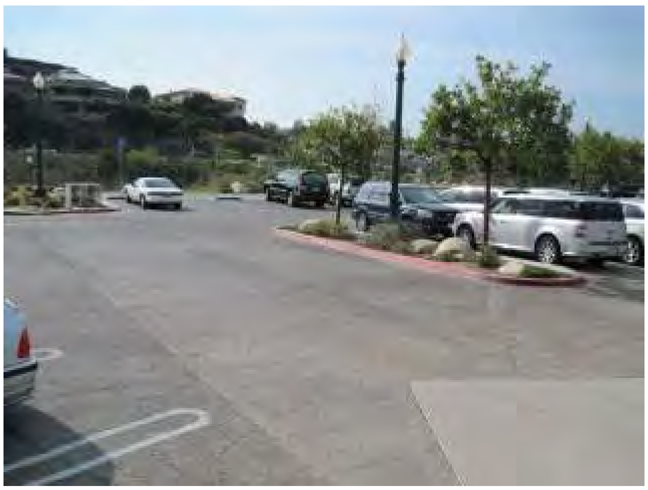
2. If sheet flow is conveyed to the treatment area over stabilized grassed areas, the site must be graded in such a way that minimizes erosive conditions. Sheet flow velocities should not exceed 3 ft/sec.

3.2.1.2 Parking Lots

Permeable pavement is typically used in a parking lot to provide a pervious alternative to a typically impervious area. Permeable pavement provides the structural support required for the traffic loading while being pervious to allow rainfall and runoff to infiltrate through the surface and be stored in the gravel storage layer or infiltrate into the subsurface soils. Two options are available for permeable pavement parking lots—either the entire lot can be paved or only the parking stall with the driving lane standard paving. If a high level of traffic is anticipated regularly, such as in a drive through, or heavy vehicles must pass through, such as garbage trucks, it is best to design the travel lane with standard paving materials and slope them toward the permeable parking stalls. Figure 22 shows an example of the entire parking lot being permeable pavement, and Figure 23 shows only the parking stalls being permeable.

3.2.1.3 Rights-of-way

Permeable pavement can also be integrated into the right-of-way along roads where parking is permitted. Figure 24 shows an example of permeable pavement in the right-of-way, Figure 25 shows an example of angled parking constructed with permeable pavement within the right-of-way, and Figure 26 shows an example of permeable pavement implemented in the parking lanes in a residential area. The parking areas can be constructed from permeable paving materials, and the travel lanes can be sloped to drain toward the edges of the roadway. Hydraulic restriction layers should be considered in the design to limit the effect of infiltration on the adjacent impervious surfaces. For details on hydraulic restriction layers, see section 10.4 of this Appendix B.



Location: Cotton Wood Creek Park, Encinitas, CA

Figure 22. Permeable parking lot.

Location: Silver Strand Boulevard and Avenida Del Sol, Coronado, CA

Figure 23. Permeable parking stalls.

Figure 24. Permeable pavement in the right-of-way.

Location: South Coast Highway 101 and West D Street, Encinitas, CA (rendering)

Figure 25. Permeable pavement parking area in the right-of-way.

Location: Upas Street and Texas Street, San Diego, CA (rendering)

Figure 26. Permeable pavement parking lanes.

3.2.1.4 Sidewalks

Permeable pavement can also be effective for pedestrian uses. Sidewalks can be constructed of pervious pavement materials to reduce runoff in highly impervious areas.

Figure 27. Permeable pavement sidewalk.

3.2.1.5 Additional Configurations

Permeable pavement can also be used in areas that receive little traffic but must be structurally sound, such as fire lanes, shown in Figure 28, or vegetated shoulders for temporary parking. Most pavers are rated for infrequent loading of vehicles such as fire trucks.

Figure 28. Permeable pavement fire access lane.

3.2.2 Determine Permeable Paver Type

As mentioned above, several types of permeable pavement are available: pervious concrete, porous asphalt, permeable interlocking concrete pavers, and plastic grid systems, among others. Each type of pavement has advantages and disadvantages, so factors such as cost, pavement use (parking area, driveway, sidewalk, fire lane, and such) and maintenance requirements should be considered when selecting the type of pavement to use. When applicable, follow manufacturers' instructions to ensure a successful implementation.

Pervious concrete and porous asphalt are best suited for large parking areas, and the advantage to those systems is that the same mixing and application equipment is used as for traditional asphalt and concrete. PICPs, grid pavers, and plastic grid systems are better suited to smaller areas because of the labor involved with installation. PICP and block pavers are most often used for driveways, entryways, walkways, or terraces to achieve a more traditional, formal appearance.

More detailed information for the various types of permeable pavement follow.

3.2.2.1 Porous Asphalt

The properties of porous asphalt depend on the materials used and the compaction procedures. General guidelines are provided below.

Permeability. Typical flow rates for water through porous asphalt range from 150 in/hr to 300 in/hr (Roseen and Ballestero 2008). Those values exceed the typical permeability of subsurface soils, so the soils would be the limiting factor.

Aggregates. A typical aggregate size distribution for porous asphalt is

Aggregate gradation size	Percent passing
0.75”	100%
0.50”	85%–100%
0.375”	55%–75%
No. 4	10%–25%
No. 8	5%–10%
No. 200	2%–4%

Durability. As with all BMPs, the longevity of porous asphalt (Figure 29) is highly dependent on proper maintenance. Many porous asphalt parking lots have been in service for more than 20 years.

Figure 29. Example of porous asphalt.

3.2.2.2 Pervious Concrete

The properties of pervious concrete (Figure 30) vary with design and depend on the materials used and the compaction procedures. General guidelines for specifications are provided below.

Permeability. Typical flow rates for water through pervious concrete average around 9.9 in/hr (Wanielista et al. 2007) but can be double that amount if desired.

Compressive Strength. Pervious concretes can develop compressive strengths in the range of 500 to 4,000 psi—suitable for a wide range of applications.

Flexural Strength. Flexural strength of pervious concrete ranges between 150 and 550 psi.

Shrinkage. Drying shrinkage of pervious concrete is faster but much less than that experienced with conventional concrete. Many pervious concretes are made without control joints and are allowed to crack randomly.

Abrasion resistance. Because of the rougher surface texture and open structure of pervious concrete, abrasion and raveling of aggregate particles can be a problem. Surface raveling in new pervious concrete can occur when rocks loosely bound to the surface break free under traffic loads. Such raveling is considerably reduced after the first few weeks.

Figure 30. Example of permeable concrete.

3.2.2.3 Permeable Interlocking Concrete Pavement

Unlike permeable concrete and porous asphalt, PICP (Figure 31) is not subject to time and temperature limitations in installation.

Permeability. Lifetime infiltration rates on maintained PICP surfaces range from 14 to 4,000 in/hr depending on the joint filling material (Borgwardt 2006).

Compressive Strength. PICP has an average compressive strength of 8,000 psi (55 MPa).

Durability. Permeable pavement systems can last more than 20 years while providing an initial high level of surface infiltration even as the surface takes in moderate amounts of sediment.

Figure 31. Example of PICPs.

3.2.2.4 Plastic Grid Systems

Plastic grids (Figure 32) provide structural support and prevent erosion and are typically filled with gravel or soil. They are usually planted with grass. Several companies manufacture plastic grid systems.

Load bearing capacity. Plastic grid systems have a load-bearing capacity up to 6,700 psi when filled.

Durability. Because plastic grid systems are typically manufactured from high-density polyethylene (HDPE), long service lives, up to 50 years, can be expected with proper maintenance.

Figure 32. Example of plastic grid systems.

3.2.3 Structural Design Requirements

If permeable pavement will be used in a parking lot or other setting that involves vehicles, the pavement surface must be able to support the maximum anticipated traffic load. The structural design process will vary according to the type of pavement selected, and the manufacturer's specific recommendations should be followed. The thickness of the permeable pavement and reservoir layer must be sized to support structural loads and to temporarily store the design storm volume (e.g., the water quality, channel protection, and flood-control volumes). On most new development and redevelopment sites, the structural support requirements will dictate the depth of the underlying stone reservoir.

The structural design of permeable pavements involves consideration of four main site elements:

- Total traffic
- In situ soil strength
- Environmental elements
- Bedding and reservoir layer design

The resulting structural requirements can include the thickness of the pavement, filter, and reservoir layer. Designers should note that if the underlying soils have a low California Bearing Ratio (less than 4 percent), they might need to be compacted to at least 95 percent of the Standard Proctor Density, which generally rules out their use for infiltration.

Designers should determine structural design requirements by consulting transportation design guidance sources, such as the following:

- AASHTO Guide for Design of Pavement Structures (1993)
- AASHTO Supplement to the Guide for Design of Pavement Structures (1998)
- AASHTO Flexible Pavement Method

3.2.4 Determine Appropriate Bedding

Once the type of permeable pavement has been selected and the structural requirements have been identified, determine the appropriate bedding (Figure 33 through Figure 36). Porous asphalt requires a 2- to 4-inch layer of asphalt and a 1- to 2-inch layer of choker course (single-sized crushed aggregate, one-half inch) to stabilize the surface. Pervious concrete also requires an aggregate course of clean gravel or crushed stone with a minimum amount of fines. PICP requires 1 or 2 inches of sand or No. 8 aggregate to allow for leveling of the paver blocks. Similar to PICP, plastic grid systems also require a 1- to 2-inch bedding course of either gravel or sand.

For PICP and plastic grid systems, if sand is used, a geotextile should be used between the sand course and the reservoir media to prevent the sand from migrating into the stone media.

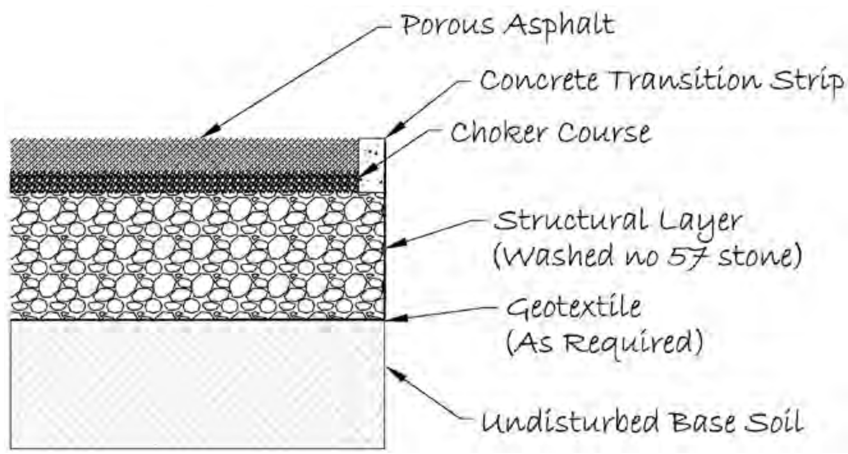


Figure 33. Typical porous asphalt section

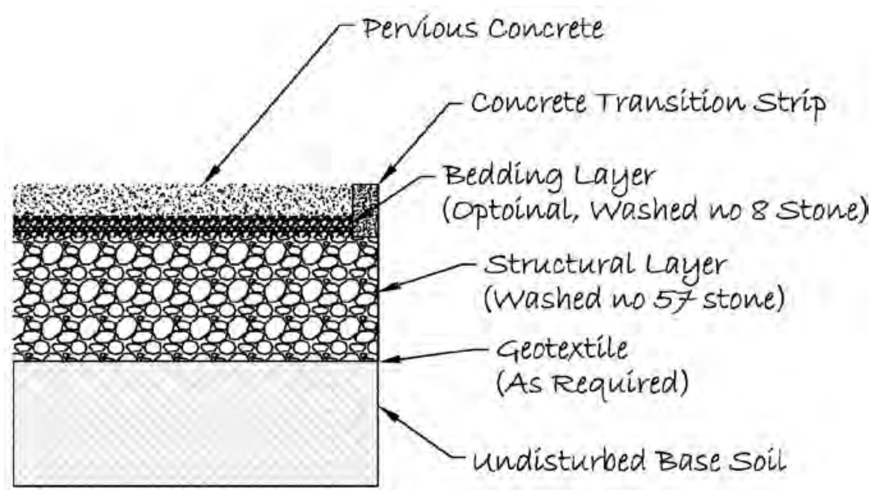


Figure 34. Typical pervious concrete section.

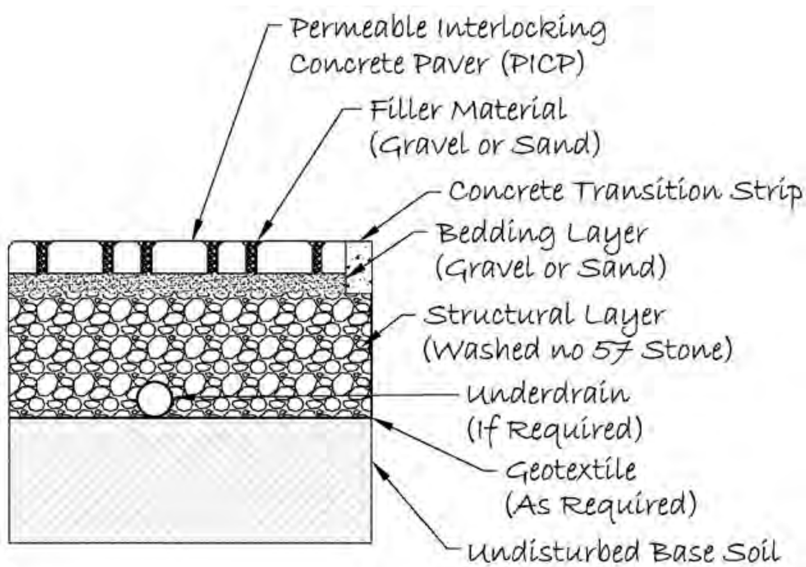


Figure 35. Typical PICP section.

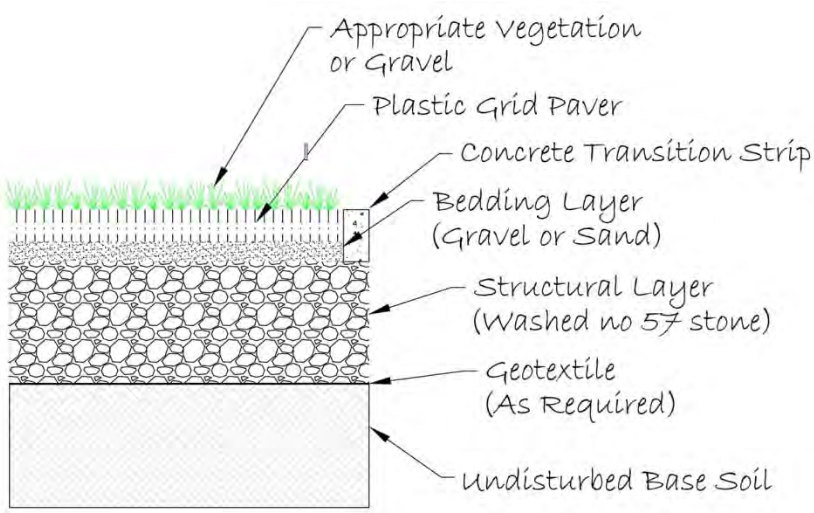


Figure 36. Typical plastic grid system section.

3.2.5 Determine Required Storage Volume

The volume of water that must be treated is equal to the volume produced by the design storm. The methods for calculating the volume required for treatment are outlined in the City's *Storm Water Standards*, and the *San Diego County Hydrology Manual*, Appendix A.

3.2.5.1 Calculate Reservoir Media Depth

The gravel base course should be designed to store at a minimum the volume determined in the previous step that cannot be stored in the pavement layer. The stone aggregate used should be washed, bank-run gravel, 0.75 to 2.5 inches in diameter with a void space of about 40 percent (no. 57 stone). Aggregate contaminated with soil and typical *crusher run* stone should not be used because those materials will clog the pores at the bottom of the pavement. A washed no. 57 stone is considered appropriate for such a purpose.

The gravel base course must have a minimum depth of 6 inches. The following equation can be used to determine if the depth of the storage layer (gravel base course) needs to be greater than the minimum depth:

$$d = V / A \times n$$

where

d = Gravel Layer Depth (ft)

V = Water Quality Volume

A = Surface Area (square ft)

n = Porosity (use n = 0.32)

3.2.6 Determine if an Underdrain Pipe is Necessary

A geotechnical investigation should be performed by a licensed soil scientist or geotechnical engineer, and a report should be prepared in accordance with the City's *Guidelines for Geotechnical Reports*. The investigation should determine the infiltration rate of the soils and the depth to the seasonally high groundwater table. If the infiltration rate of the soils on which the permeable pavement area will be installed is less than 0.5 in/hr, underdrains will be required. For information on designing an underdrain system, see section 10.2 of this Appendix B.

3.2.7 Provide Geotextile

A geotextile should be placed beneath the reservoir media. Use a needled, non-woven, polypropylene geotextile with Grab Tensile Strength equal to or greater than 120 lbs (ASTM D4632), with a Mullen Burst Strength equal to or greater than 225 lbs/sq. in. (ASTM D3786), with a Flow Rate greater than 125 gpm/sq ft (ASTM D4491), and an Apparent Opening Size (AOS) equivalent to a US # 70 or # 80 sieve (ASTM D4751). The geotextile AOS selection is based on the percent passing the No. 200 sieve in *A* Soil subgrade, using FHWA or AASHTO selection criteria.

It is important to line the entire trench area, including the sides, with a geotextile before placing the aggregate. The geotextile serves an important function by inhibiting soil from migrating into the reservoir layer and reducing storage capacity.

3.2.8 Additional Considerations

In addition to the information provided above, follow these guidelines when designing permeable pavement systems.

1. Permeable pavement systems should not be placed on compacted fill.
2. Completed permeable pavement installation must have a slope of less than 0.5 percent.
3. Pavement systems should not be constructed in areas with high traffic volumes.

4. A minimum vertical distance of 2 feet must be provided between the bottom of the permeable pavement installation (i.e., the bottom invert of the reservoir layer) and the seasonal high water table.

5. Avoid overhanging trees above the permeable pavement installation or other areas where detritus from vegetation can clog the permeable pavement.

6. Permeable pavement should not be designed to receive concentrated flow from roofs or other surfaces. Diffuse run on from stabilized areas is permissible.

7. Runoff in the form of sheet flow onto the permeable pavement is acceptable, although pretreatment with a vegetated filter strip or other means is preferred. Concentrated flows should bypass the permeable pavement.

8. Permeable pavement should not be hydraulically connected to structure foundations, to avoid harmful seepage. For information on designing hydraulic restriction layers, see section 10.4 of this Appendix B.

9. Porous paver system designs must use some method to convey larger storm event flows to the conveyance system. One option is to use storm drain inlets set slightly above the elevation of the pavement. Doing so would allow for some ponding above the surface but would accept bypass flows that are too large to be infiltrated by the permeable pavement system.

10. Pervious pavements should not be used on sites with a likelihood of high oil and grease concentrations. Such sites include vehicle wrecking or impound yards, fast food establishments, automotive repair and sales, and parking lots that receive a high number of average daily trips (more than 1,000).

11. Studies have shown that PICP pavement systems reduce nitrogen concentrations better than other permeable pavement systems (Collins et al. 2009). That is because the sand layer acts similarly to a sand filter.

12. Sand retains a greater water volume than stone. As a result, pavement systems that contain a sand layer will produce less runoff than those with just a gravel layer.

13. Time to peak can be delayed by creating an internal water storage zone in the media layer.

14. Permeable pavement should always be installed by experience contractors that have been certified by a reputable organization such as the Interlocking Concrete Pavement Institute or the Concrete Ready Mix Association. A list of certified contractors is at http://www.icpi.org/ and http://www.nrmca.org/.

3.3 Operation and Maintenance

Maintenance of permeable pavement systems is critical to the overall and continued success of the system. Key maintenance procedures consist of the following:

1. Adjacent areas that drain to the permeable pavement area should be permanently stabilized and maintained to limit the sediment load to the system.

2. Vacuum sweeping should be performed a minimum of twice a year. Adjust the frequency according to the intensity of use and deposition rate on the permeable pavement surface.

3. Any weeds that grow in the permeable pavement should be sprayed with pesticide immediately. Weeds should not be pulled, because doing so can damage the fill media.

4. Mowing and trimming of turf grass used with permeable pavers and plastic grid systems must be performed regularly according to site conditions. Grass should be mowed at least once a month during the growing season. All vegetated areas must be inspected at least annually for erosion and scour.

Task	Frequency	Maintenance notes
Inlet inspection	Once after first rain of the season, then monthly during the rainy season	Check for sediment accumulation to ensure that flow onto the permeable pavement is not restricted. Remove any accumulated sediment. Stabilize any exposed soil.
Vacuum street sweeper	Twice a year as needed	Pavement should be swept with a vacuum power street sweeper at least twice per year or as needed to maintain infiltration rates.
Mowing	2–12 times/year	Pavers filled with turf will require mowing. Frequency depends on location and desired aesthetic appeal.
Replace fill materials	4 times/year	Fill materials will need to be replaced after each sweeping and as need to keep voids level with the paver surface.
Watering	1 time/2–3 days for first 1–2 months; sporadically after establishment	If droughty, watering after the initial year might be required.
Fertilization	1 time initially	One-time spot fertilization for first year vegetation.
Miscellaneous upkeep	4 times/year or as needed for aesthetics	Tasks include trash collection, sweeping, and spot weeding.

3.4 References

Bean, E.Z., W.F. Hunt, and D.A. Bidelspach. 2007. Field survey of permeable pavement surface infiltration rates. *Journal of Irrigation and Drainage Engineering* 133(3):247–255.

Borgwardt, S. 2006. Long-term in situ infiltration performance of permeable concrete block pavement, In *Proceedings of the 8th International Conference on Concrete Block Paving*, Interlocking Concrete Pavement Institute, Washington, DC.

Brattebo, B.O., and D.B. Booth. 2003. Long-term stormwater quantity and quality performance of permeable pavement systems. *Water Research* 37(18):4369–4376.

CWP (Center for Watershed Protection). 2007. National Pollutant Removal Performance Database. Center for Watershed Protection, Ellicott City, MD.

Collins, K.A., W.F. Hunt, and J.M. Hathaway. 2009. Side-by-side comparison of nitrogen species removal for four types of permeable pavement and standard asphalt in eastern North Carolina. *Journal of Hydrologic Engineering*. in press - June 2010.

Ferguson, B.K. 2005. *Porous Pavements*. CRC Press, Boca Raton, FL.

GCPA (Georgia Concrete and Products Association). 2006. *Guide for Construction of Portland Cement Concrete Pervious Pavement*. Georgia Concrete and Products Association, Tucker, GA.

Invisible Structures. 2001. *Grasspave2TM Technical Specifications*. Invisible Structures, Inc., Golden, CO.

ICPI (Interlocking Concrete Pavement Institute). 2004. *Tech Spec 8, Concrete Grid Pavements*. Interlocking Concrete Pavement Institute, Washington, DC.

James, W., and R. Shahin. 1998. Pollutants leached from pavements by acid rain. In W. James (ed.), *Advances in Modeling the Management of Stormwater Impacts*. 6:321–349. Computational Hydraulics International, Guelph, Canada.

MWCOG (Metropolitan Washington Council of Governments). 1983. *Urban Runoff in the Washington Metropolitan Area: Final Report, Urban Runoff Project, EPA Nationwide Urban Runoff Program*. Metropolitan Washington Council of Governments, Washington, DC.

NRMCA (National Ready Mixed Concrete Association). 2004. *CIP 38 – Pervious Concrete. Concrete in Practice*. National Ready Mixed Concrete Association, Silver Spring, MD.

Pratt, C. J., J.D.G. Mantle, and P.A. Schofield. 1989 Urban stormwater reduction and quality improvement through the use of permeable pavements. *Water Science and Technology* 21(8):769–778.

Pratt, C.J., J.D.G. Mantle, and P.A. Schofield. 1995. UK research into the performance of permeable pavement, reservoir structures in controlling stormwater discharge quantity and quality. *Water Science Technology* 32(1):63–69

Roseen, R.M., and T.P. Ballestero. 2008. Porous asphalt pavements for stormwater technology. *Hot Mix Asphalt Technology* pp. 26–34.

Schueler, T.R. 1987. *Controlling Urban Runoff: A Practical Manual for Planning and Designing Urban BMPs*. Metropolitan Washington Council of Governments, Washington, DC.

Wanielista, M., M. Chopra, J. Spence J., and C. Ballock. 2007. *Hydraulic Performance Assessment of Pervious Concrete Pavements for Stormwater Management Credit*. University of Central Florida, Stormwater Management Academy, Orlando, FL.

4 Infiltration Trench

Location: Cottonwood Creek Park, Encinitas, CA

4.1 Description

Infiltration trenches are narrow, linear BMPs that have similar functions as bioretention areas with variable surface materials, including rock or decorative stone, designed to allow storm water to infiltrate into subsurface soils. Runoff infiltrates into the soils and is stored in the void space between the stones. Infiltration trenches can reduce runoff volume and remove fine sediment and associated pollutants. Pretreatment using vegetated buffer strips or vegetated swales and bioswales is important for limiting the amount of coarse sediment entering the trench that can clog and render the trench ineffective. Infiltration trenches are designed to reduce the volume of runoff while enhancing water quality through pollutant-removal mechanisms such as filtration and sorption.

4.1.1 Advantages

- Efficient removal of suspended solids, heavy metals, adsorbed pollutants, nitrogen, phosphorus, and pathogens
- Can effectively reduce peak runoff rates for relatively frequent storms, reduce runoff volumes, and recharge groundwater if soil conditions allow
- Useful for space limited applications

- Can be integrated into transportation rights-of-way
- Can be integrated naturally into landscaping to enhance aesthetics

4.1.2 Disadvantages

- Surface soil layer can clog over time (though it can be restored)
- Need appropriate pretreatment for optimal effectiveness
- Vigilance in protecting native soils from compaction during construction is essential
- Single units can serve only small drainage areas
- Requires maintenance of surface materials

4.1.3 Major Design Elements

- Sizing must take into account all runoff at ultimate build-out including off-site drainage. (For volume calculations, see Appendix A and the City's *Storm Water Standards*.)
- Drainage areas should be less than 2 acres.
- Side slopes stabilized with vegetation must be no steeper than 3:1.
- Unlined infiltration trenches must not be used where the seasonally high water table or confining layer is less than 10 feet below bottom of the BMP (City's *Storm Water Standards*).
- Media permeability must be at least 0.5 in/hr (City's *Storm Water Standards*).
- Inflow must be non-erosive sheet flow (3 ft/sec for grass cells) or use energy-dissipating devices.
- Must be a minimum of 100 feet from water supply wells and septic system drain fields (City's *Storm Water Standards*) and 10 feet from any structures.
- Media depth must be a minimum of 2 feet.
- Media should meet the specifications listed in Design Step 5: Decide the depth and type of soil media.
- Ponded water must completely drain into the soil within 24 hours; 12 hours is preferred as a safety factor. It must drain to a level below the soil media (2 to 3 feet) within 48 hours.
- An underdrain must be installed if in situ soil drainage is less than 0.5 in/hr. The underdrain pipe should be at least 4 inches in diameter and installed at a 0.5 percent minimum slope.
- An underdrain must be installed if the infiltration trench is within 50 feet of a sensitive, steep slope.
- Cleanout pipes must be provided if underdrains are required.
- Surface must be gravel or decorative stone that covers all exposed earth.
- Longitudinal slope should be less than 2 percent. Slope can exceed 2 percent, but check dams should be used such that one continuous section does not exceed 2 percent. Overall slope should not exceed 5 percent.

4.1.4 Characteristics and Function

Infiltration trenches function similarly to bioretention areas in that they are shallow, often narrow, depressions that capture and temporarily store storm water runoff. The captured runoff percolates through the bottom of the depression and a layer of soil media, approximately 2 to 4 feet deep, that has an infiltration rate capable of draining the infiltration trench (to the bottom of the media) within a specified design drawdown time (usually 10 to 48 hours). The soil media provides treatment through filtration and adsorption.

After the storm water infiltrates through the soil media, it percolates into the subsoil, if site conditions allow for adequate infiltration and slope protection. If site conditions do not allow for adequate infiltration or slope protection, filtered water is directed toward a storm water conveyance system or other storm water runoff BMP via underdrain pipes.

Infiltration trenches are designed to capture a specified design volume and can be configured as online or offline systems. Online BMPs require an overflow system for passing larger storms. Offline BMPs do not require an overflow system but do require some freeboard (the distance from the overflow device and the point where storm water would overflow the system) and a diversion structure.

If an underdrain is not needed because infiltration rates are adequate and slope is not a concern, the remaining storm water passes through the soil media and infiltrates into the subsoil. Partial infiltration (approximately 20 to 50 percent, depending on soil conditions) can still occur when underdrains are present as long as an impermeable barrier is not between the soil media and subsoil. Partial infiltration occurs in such cases because some of the storm water bypasses the underdrain and percolates into the subsoil (Strecker et al. 2004; Hunt et al. 2006).

Infiltration trenches are typically planted with grasses that can withstand short periods of saturation (i.e., 10 to 48 hours) followed by longer periods of drought. Infiltration trenches can have a wide variety of surface materials including stone and turf as long as the materials are suitable for the site conditions.

4.1.5 Applicability and Performance

Chapter 2 describes the process for selecting BMPs according to the pollutants of concern. Infiltration trenches are volume-based BMPs intended primarily for water quality treatment and, depending on site slope and soil conditions, can provide high-volume reduction. Where site conditions allow, the volume-reduction capability of an infiltration trench can be enhanced for achieving additional credit toward meeting the volume-reduction requirement by omitting underdrains and providing a gravel drainage layer beneath the soil media. Infiltration trenches can be used to help meet the peak runoff discharge requirement.

Infiltration trenches use similar functions as a bioretention area for pollutant reduction including sedimentation, filtration, and sorption, but they are typically designed to be narrow and linear to fit within specific site constraints.

4.2 Design

The design of an infiltration trench can be broken down to a nine-step process:

1. Determine BMP configuration
    a. Determine how to incorporate an infiltration trench into the layout of the site
    b. Determine and incorporate the necessary BMP components
2. Determine the volume of water to treat (see the City's *Storm Water Standards* and the *San Diego County Hydrology Manual*)
3. Determine the surface area required
4. Determine the depth and type of soil media
5. Inlet configuration
6. Determine if an underdrain pipe is necessary
7. Select the appropriate overflow or bypass method
8. Surface materials
9. Additional considerations

4.2.1 Determine BMP Configuration

An infiltration trench is a highly versatile storm water BMP in that it can effectively reduce pollutants while providing some flexibility in integrating storm water treatment into the site plan with various configurations and components. Many times, determining how an infiltration trench will be included in the site design is a critical and required first step. How the water is routed to the infiltration trench and the available space will be key components in determining how the infiltration trench will be configured. Site assessment, planning, and site design are discussed in detail in Chapter 2. The following is a list of settings where infiltration trenches can be incorporated to meet more than one project-level or watershed-scale objective:

- Edges of parking lots
- In parks and along open space edges
- Within rights-of-way along roads

How the infiltration trench is configured determines the required components. Pretreatment at some level is always recommended to remove gross solids and sediment where possible and reduce flows to a non-erosive rate. Curb cuts could be required to allow storm water to enter the infiltration trench while providing some delineation in high traffic areas. Infiltration trenches can serve the dual purpose of storm water management and landscape design and can significantly enhance the aesthetics of a site. Figure 37 shows an example of the components of a typical infiltration trench. Infiltration trenches typically have multiple components including the following:

- Filter strip or grass buffer for pretreatment
- Gravel surface for filtration
- Sand bed for filtration
- Ponding area for storage

In addition, infiltration trenches can be combined with other BMPs to form a treatment train that can provide enhanced water quality treatment and reductions in runoff volume and rate. For example, runoff can be collected from a parking lot in an infiltration trench that then overflows to a bioretention area. Both facilities can be reduced in size according to demonstrated performance for meeting the storm water runoff requirements as outlined in Chapter 2 and addressing targeted pollutants of concern.

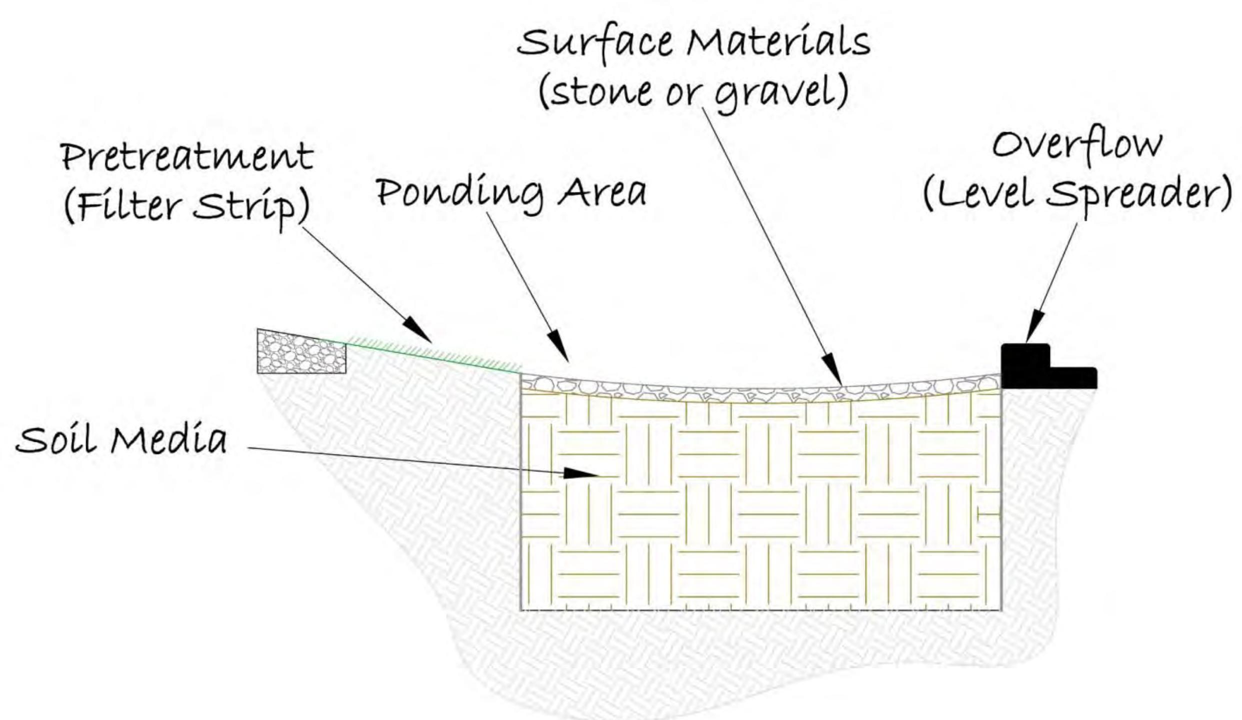


Figure 37. Typical infiltration trench components.

4.2.1.1 Pretreatment

1. Infiltration trenches should have a filter strip to pretreat incoming flows from impervious surfaces, where space is available. Infiltration trenches that treat runoff from residential roofs or other cleaner surfaces will not require pretreatment for trash or sediment but should include flow reduction as much as possible.

2. If sheet flow is conveyed to the treatment area over stabilized grassed areas, the site must be graded in such a way that minimizes erosive conditions. Sheet flow velocities must not exceed 3 ft/sec.

4.2.1.2 Curb Cuts

When an infiltration trench is incorporated into highly impervious areas, such as parking lots and in road rights-of-way, curb cuts could be required to allow surface runoff to enter the infiltration trench. Curb cuts are designed such that the design storm can pass through the curbing without causing water to pond in the travel lanes. Further detail for curb cuts is in section 10.1 of this Appendix B.

Some pretreatment flow reduction can be provided by providing multiple, smaller curb cuts to minimize the flow at each opening and by armoring the curb opening from the back of the curb to the base elevation of the infiltration trench.

4.2.1.3 Parking Lots

Infiltration trenches can be used along the edge of a parking lot or in the median areas between the parking spaces. Pretreatment is important for parking lot areas to remove large sediments and to slow the runoff to non-erosive flow rates (3 ft/sec for sod). Pretreatment typically consist of a gravel verge followed by turf as shown in Figure 37.

4.2.1.4 Roads

Infiltration trenches can also be integrated into the right-of-way of roads. Similar concepts apply to roads as for parking lots. Some pretreatment could be required to remove large particles and slow the runoff to non-erosive flows.

Infiltration trench designs can be incorporated into the edge of road ways using the open space in the right-of-way. Figure 38 shows an example of an infiltration trench incorporated into the right-of-way along a road.

For standard right-of-way specifications, see the City's *Street Design Manual*. The maximum width right-of-way and curb-to-curb spacing should be used to most effectively implement infiltration trenches within the right-of-way.

4.2.2 Determine the Volume of Water or Flow to Treat

The volume of water that must be treated is equal to the design storm volume. The methods for calculating the volume required for treatment are outlined in the City's *Storm Water Standards* and the *San Diego County Hydrology Manual* as well as *Appendix A*.

4.2.3 Determine the Surface Area Required

4.2.3.1 Geometry and Size

1. Infiltration trenches are narrow with a linear configuration and are intended to fit along the edges of parking lots and roads. They can vary from 2 to 8 feet in width.

2. Infiltration trenches have a maximum ponding depth of 12 inches, with 9 inches preferred.

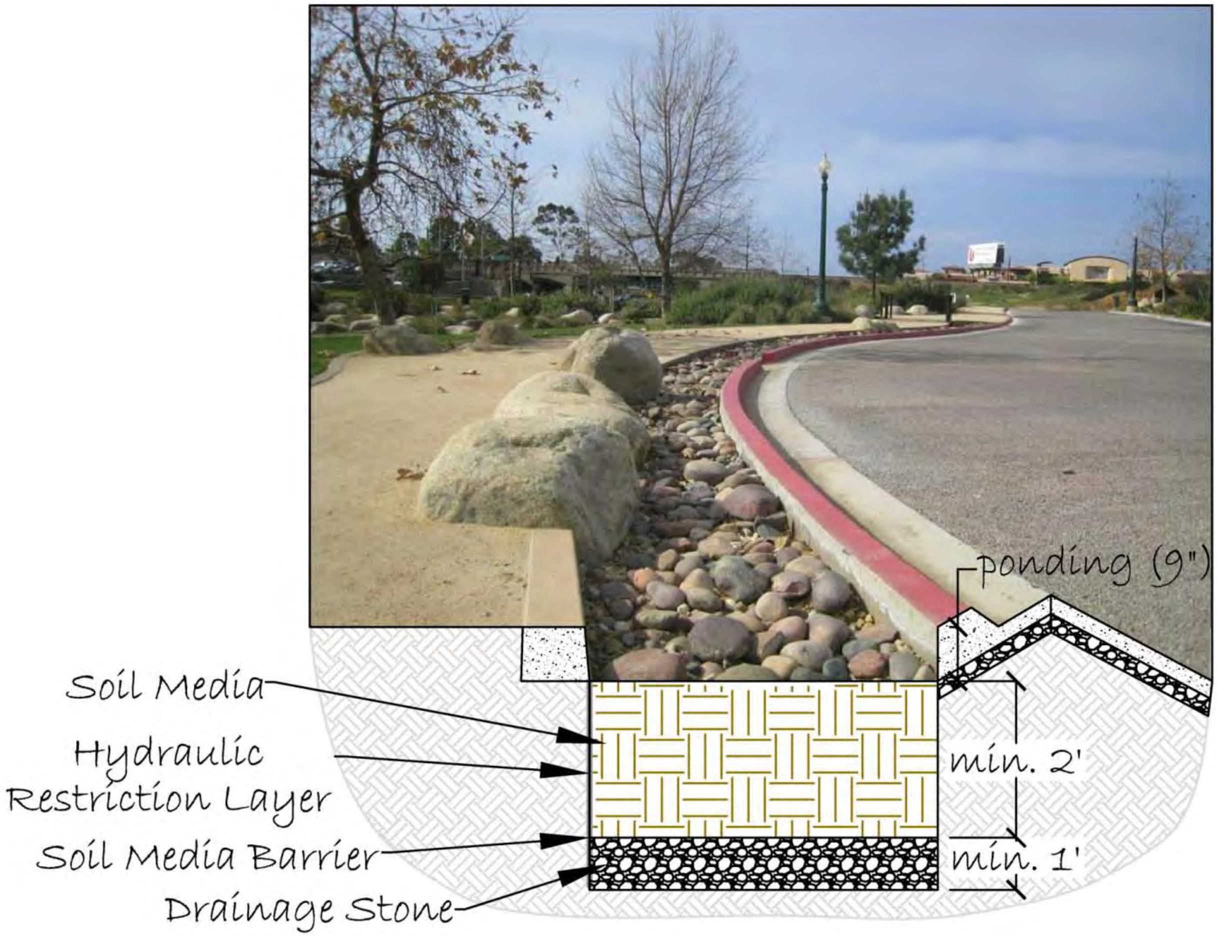


Figure 38. Infiltration trench in the right-of-way.

3. Soil media depth, if it is required, is a minimum of 2 feet, although 3 feet is preferred. The soil media depth provides a beneficial root zone for grasses in the infiltration trench and provides adequate water storage for the water quality design volume. A deeper soil media depth will allow for a smaller surface area footprint.

4. Infiltration trenches are intended to drain to below the surface in less than 24 hours, 12 hours is preferred as a safety factor, and below the soil media depth in less than 48 hours. If a gravel drainage layer is included beneath the infiltration trench, stored runoff in the drainage layer should drain in less than 72 hours. The soils must be allowed to dry out periodically to restore hydraulic capacity to receive flows from subsequent storms, maintain infiltration rates, maintain adequate soil oxygen levels for healthy soil biota and vegetation, and to provide proper soil conditions for biodegradation and retention of pollutants.

4.2.3.2 Sizing Methodology

Infiltration trenches are to be sized to capture and treat the volume produced by the design storm and, where site conditions allow, should also be sized to infiltrate the volume reduction requirement. For the storm water runoff requirements and calculations, see Appendix A. Procedures for sizing infiltration

BMPs will be in accordance with the sizing methodology developed for the City's *Storm Water Standards* manual.

4.2.4 Determine the Depth and Type of Soil Media

4.2.4.1 Depth of Soil Medium

Different pollutants are removed in various zones using several mechanisms. TSS is removed both in pretreatment and on the surface of the infiltration trench itself. For that reason, TSS removal is not a major factor in depth of the infiltration trench design. Depth, however, is an issue for other pollutants. Metals are removed within the first 18 inches of media because they are often bound to sediment (Davis et al. 2003; Li and Davis 2008). Bacterial, viral, and protozoan pathogens can be killed on the surface and removed throughout the soil media by several mechanisms: sun exposure, drying, sedimentation, and filtration (Hathaway et al. 2009). Media depth should be 30 inches to optimize nitrogen removal and 24 inches for phosphorus (Hunt and Lord 2006). Considering the target pollutant, the depth of the media should be between 2 and 4 feet. That range reflects the fact that most of the pollutant removal occurs within the first 2 feet of soil, and excavations deeper than 4 feet become more expensive.

4.2.4.2 Type

The soil media in the infiltration trench should meet the requirements as set by the City's *Storm Water Standards*. Soils at infiltration sites must have the following properties: OC > 5 percent, pH between 6–8, CEC > 5 meq/100 g soil, and infiltration rates of 0.5 in/hr or greater. The soil media within the infiltration trench should be highly permeable (at least 0.5 in/hr) and have an appropriate amount of organic material to support plant growth (e.g., loamy sand mixed thoroughly with an organic material). If the existing soils meet those criteria, it can be used as the soil media. If the existing soils do not meet the criteria, a substitute media must be used. Soil media that is brought to the site must meet the following criteria:

1. Soil media consists of 90 percent washed course sand, 10 percent fines (range: 8–12 percent. 8 percent = 2 in/hr infiltration rate, 12 percent = 1 in/hr infiltration rate), and 5 percent organic matter.

2. The sand portion should consist of concrete sand (passing a one-quarter-inch sieve). Mortar sand (passing a one-eighth-inch sieve) is acceptable as long as it is thoroughly washed to remove the fines.

3. Fines should pass a # 270 sieve.

4. All media should be analyzed for background levels of nutrients. Total phosphorus should not exceed 15 ppm.

4.2.5 Inlet Configuration

Inlets must be designed to convey the design storm volume, while limiting ponding or flooding at the entrance to the infiltration trench. Several options are available. Ideally, runoff will pass over a filter strip where flow can be dispersed and gross solids removed before entering the infiltration trench as shown in Figure 38. That is not always possible, especially in retrofit situations were space might not be available.

In those situations, flow should be dispersed as much as possible. Several options are available and are detailed in section 10.1 of this Appendix B.

4.2.6 Determine if an Underdrain Pipe is Necessary

A geotechnical investigation should be performed by a licensed soil scientist or geotechnical engineer, and a report should be prepared in accordance with the City's *Guidelines for Geotechnical Reports*. The investigation should determine the infiltration rate of the in situ soils and the depth to the seasonally high groundwater table. If the infiltration rate of the soils on which the infiltration trench will be installed is less than 0.5 in/hr or the depth of the seasonally high groundwater table is less than 10 feet but greater than 2 feet, underdrains should be installed. Section 10.2 of this Appendix B provides guidance on underdrain design.

4.2.7 Select the Appropriate Outlet or Bypass Method

Two design configurations can be used for treating storms that are larger than the infiltration trench is designed to store:

1. Offline: Design a structure that diverts only the volume of storm water that the infiltration trench is designed to treat. For details on diversion structures, see section 10.3 of this Appendix B.
2. Online: All runoff enters the infiltration trench with an outlet or overflow for volumes exceeding the design storm. Outlet systems for online infiltration trenches can be designed to provide some peak flow mitigation in addition to storing the design volume.

Most infiltration trenches will be designed to accept surface flows and, therefore, will be online systems; however, when flows through an infiltration trench could exceed the recommended maximum flow rates, regardless of whether a system is designed to be online or offline, a bypass structure is recommended to prevent erosion in the infiltration trench. The flow velocity in a grassed system should not exceed 3 ft/sec. Flows can be greater (up to 14 ft/sec) with the use of reinforced turf matting and will depend on the matting selected. A bypass structure should be used to ensure that flows through the system do not exceed the recommended design flow.

If the infiltration trench is online, an outlet or overflow device is required at the 12-inch maximum ponding depth. Two options are provided:

Option 1: Vertical riser

1. A vertical PVC pipe that is connected to the underdrain or directly to the drainage system.
2. The outlet riser(s) is 4 inches or greater in diameter, so it can be cleaned without damage to the pipe. The vertical pipe provides access to cleaning the underdrains.
3. The inlet to the riser should be a maximum of 12 inches above the soil media and be capped with a spider cap. Figure 39 shows a schematic of an online infiltration area with a vertical riser overflow design.

Option 2: Flow spreader

1. A flow spreader can be used to diffuse overflows from the infiltration trench and should be installed along the exit edge or outflow section of the trench. The flow spreader can be earthen, covered with sod or any stable material.
2. The top surface of the flow spreader should be installed at a height equal to the ponding depth, or slightly greater if in conjunction with a vertical riser, to allow runoff exceeding the capacity of the infiltration trench to safely pass.
3. The flow spreader can be designed as a weir to allow for varied outlet flows providing some peak flow mitigation.

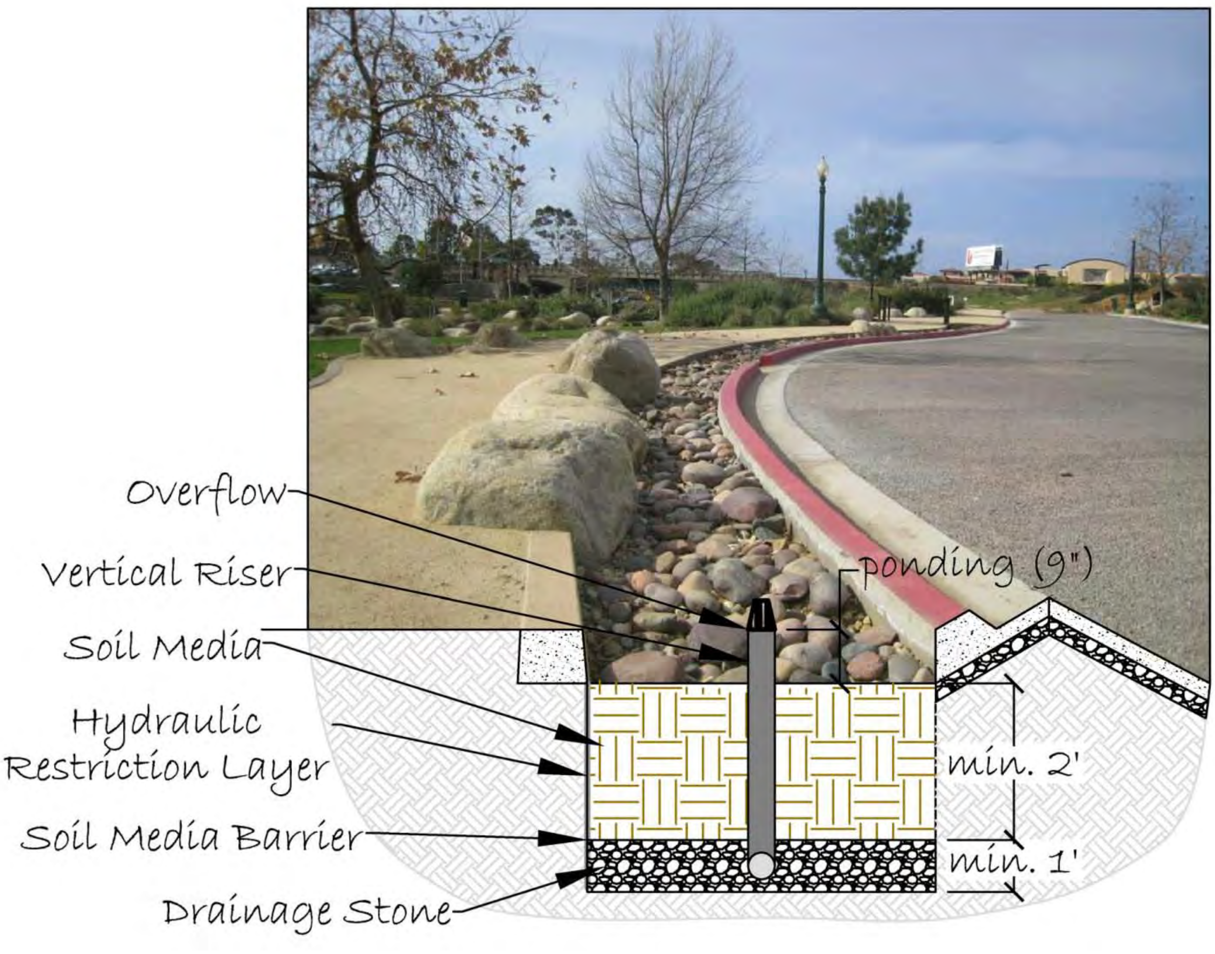


Figure 39. Online infiltration trench with a vertical riser overflow.

If an infiltration trench constructed in the right-of-way requires underdrains, a vertical riser overflow system can also be incorporated as the primary overflow method in addition to the bypass.

4.2.8 Surface Materials

The main difference between an infiltration trench and a bioretention area is the surface materials. Infiltration trenches are intended to be installed in areas where vegetation might not be feasible, such as the edge of parking lots or in rights-of-way where vegetation could prevent appropriate site distances or where survival rates would be minimal. In such cases, the surface of the infiltration trench should be stabilized with gravel or a decorative stone.

4.2.9 Additional Considerations

4.2.9.1 Hydraulic Restriction Layers

Infiltration pathways might need to be restricted because of the close proximity of roads, foundations, other infrastructure, or hotspot locations. In some conditions, lateral seepage could cause damage to surrounding structures depending on the type of soils in the area. Areas that have a potential for settling under saturated conditions should be protected from lateral flows. Types of clay that have a high potential for expansion when saturated should be protected from moisture in load-bearing conditions. Section 10.4 of this Appendix B provides details on hydraulic restriction layers.

4.2.9.2 Check Dams

Infiltration trenches can be used as conveyance systems, especially when used in a treatment train system. The longitudinal slope should be minimized to prevent erosion within the infiltration trench and to minimize velocities. The longitudinal slope should not exceed 2 percent. Infiltration trenches can be used effectively in areas with slopes from 2 to 5 percent by installing check dams to prevent erosive flow velocities. Check dams should be constructed as required such that each section between check dams does not exceed 2 percent. Overall slope should not exceed 5 percent.

4.2.9.3 Utilities

Utilities should be avoided where possible when implementing an infiltration trench. In many cases, infiltration trenches can be shifted in the landscape to prevent implementation over utilities. In cases where utilities cannot be avoided, take care to prevent impact from infiltration or saturation by using hydraulic restricting layers to direct infiltration away from the utility. For further details, see section 10.4 of this Appendix B.

4.3 Operation and Maintenance

Infiltration areas require regular maintenance of the surface layers to ensure optimum infiltration, storage, and pollutant-removal capabilities. In general, infiltration trench maintenance requirements are typical landscape care procedures and consist of the following:

1. Erosion control: Inspect flow entrances, ponding area, and surface overflow areas periodically during the rainy season, and replace gravel and soil in areas if erosion has occurred and stabilize (for an infiltration trench inspection and maintenance checklist, see Appendix F). Properly designed facilities with appropriate flow velocities will not have erosion problems except perhaps in extreme events. If erosion problems occur, the following should be reassessed: (1) flow velocities and gradients within the infiltration trench and (2) flow dissipation and erosion protection strategies in the pretreatment area and flow entrance. If sediment is deposited in the

infiltration trench, immediately determine the source in the contributing area, stabilize, and remove excess surface deposits.

2. Inlet: The inlet to the infiltration trench should be inspected after the first storm of the season and then monthly during the rainy season to check for sediment accumulation and erosion. Sediment can accumulate, especially at inlets where curb cuts or bypass structures are used, and inlets should be inspected regularly. Any accumulated sediment that impedes flow into the infiltration trench should be removed and properly disposed of.

3. Overflow and underdrains: Sediment accumulation in the overflow device or underdrain system can cause prolonged ponding and potential flooding. Excess ponding can have adverse effects on vegetation and vector control. Overflow and underdrain systems should be inspected after the first storm of the season, then monthly during the rainy season to remove sediment and prevent mulch accumulation around the overflow. The underdrain systems should be designed so that it can be flushed and cleaned as needed. If water is ponded in the infiltration trench for more than 72 hours, the underdrain system should be flushed with clean water until proper infiltration is restored.

4. Soil: Soil mixes for infiltration trenches are designed to maintain long-term fertility and pollutant processing capability. Estimates from metal attenuation research suggest that metal accumulation should not present an environmental concern for at least 20 years in the systems.

Task	Frequency	Maintenance notes
Inlet inspection	Once after first rain of the season, then monthly during the rainy season	Check for sediment accumulation to ensure that flow into the system is as designed. Remove any accumulated sediment.
Outlet inspection	Once after first rain of the season, then monthly during the rainy season	Check for erosion at the outlet and remove any accumulated sediment.
Miscellaneous upkeep	12 times/year	Tasks include trash collection, spot weeding, and removing mulch from overflow device.

4.4 References

Davis, A.P., M. Shokouhian, H. Sharma, C. Minami, and D. Winogradoff. 2003. Water quality improvement through bioretention: Lead, copper, and zinc. *Water Environment Research* 75(1):73–82.

Hathaway, J.M., W.F. Hunt, and S.J. Jadlocki. 2009. Indicator bacteria removal in stormwater best management practices in Charlotte, North Carolina. *Journal of Environmental Engineering*, 135(12):1275-1285.

Hunt, W.F., and W.G. Lord. 2006. *Bioretention performance, design, construction, and maintenance*, North Carolina Cooperative Extension, Raleigh, NC.

Hunt, W.F., A.R. Jarrett, J.T. Smith, and L.J. Sharkey. 2006. Evaluating bioretention hydrology and nutrient removal at three field sites in North Carolina. *Journal of Irrigation and Drainage Engineering* 132(6):600–608.

Li, H., and A.P. Davis. 2008. Urban particle capture in bioretention media. I: Laboratory and field studies. *Journal of Environmental Engineering* 143(6):409–418.

Strecker, E.W., M.M. Quigley, B. Urbonas, and J. Jones. 2004. Analyses of the Expanded EPA/ASCE International BMP Database and Potential Implications for BMP Design. In *Proceedings of the World Water and Environmental Resources Congress*, American Society of Civil Engineers, Salt Lake City, UT, June 27–July 1, 2004.

5 Planter Boxes

5.1 Description

A planter box is a precast concrete box containing soil media and vegetation that functions similarly to a small biofiltration BMP but is completely lined and must have an underdrain. Planter boxes have been implemented around paved streets, parking lots, and buildings to provide initial storm water treatment to runoff from the impervious areas. Roof downspouts are directed to planter boxes, which then attenuate and filter the runoff. Planter boxes provide on-site storm water treatment options, green space, and natural aesthetics in tightly confined urban environments.

Planter boxes are usually implemented around buildings and along sidewalks. Planter boxes intercept and filter runoff from adjacent impervious areas before it enters the storm water conveyance system. Such an application offers an ideal opportunity to minimize directly connected impervious areas in highly urbanized areas. The vegetation and soil media in the planter box provide similar functionalities of bioretention BMPs.

5.1.1 Advantages

- Efficient removal of suspended solids, heavy metals, adsorbed pollutants, nitrogen, phosphorus, and pathogens
- Can effectively reduce peak runoff rates for relatively frequent storms and reduce runoff volumes

- Flexible to adapt to urban retrofits and are well suited for small, highly impervious, areas
- Can be integrated naturally into landscaping to enhance aesthetics
- Does not require a setback from structural foundations
- No geotechnical limitations

5.1.2 Disadvantages

- Surface soil layer could clog over time (though it can be restored)
- Frequent trash removal could be required, especially in high-traffic areas
- Vigilance in protecting native soils from compaction during construction is essential
- Single units can serve only small drainage areas
- Requires maintenance of plant material and mulch layer
- Does not promote deep infiltration to supplement groundwater recharge

5.1.3 Major Design Elements

- Sizing must take into account all runoff at ultimate build-out including off-site drainage.
- Drainage areas should be less than 0.35 acre (15,000 square feet).
- A bypass and internal overflow is required for bypassing storms in excess of the design storm.
- Soil media permeability must be at least 1 in/hr.
- Inflow must be non-erosive sheet flow (1 ft/sec) for mulch cells, 3 ft/sec for grass cells) or use energy-dissipating devices.
- Bioretention facilities must not be used in areas that are not permanently stabilized drainage areas.
- Ponding depth must be 12 inches or less, 9 inches is preferred.
- Media depth must be 2 feet minimum, with 3 feet preferred.
- Media should meet the specifications listed in Design Step 4: Decide the depth and type of soil media for bioretention areas.
- Ponded water must completely drain into the soil within 12 hours. It must drain to a level below the soil media (2 to 3 feet) within 48 hours.
- An underdrain must be installed. The underdrain pipe should be at least 4 inches in diameter and installed at a 0.5 percent minimum slope.
- Cleanout pipes, equal to the diameter of the underdrain, must be provided.
- Grassed BMPs can be used; however, grassed BMPs must be sodded, and the sod must not be grown in soil with an impermeable (clay) layer.

- Finely shredded hardwood mulch 2 to 4 inches deep (3 inches preferred) must be used in all mulched bioretention areas (for details, see section 1.2.8).
- Soil media must be completely contained using an appropriate geotextile or impervious liner as described in Design Step 9: Additional Considerations.

5.1.4 Characteristics and Function

Planter boxes are vegetated and mulched or grassed (i.e., landscaped), shallow depressions that capture, temporarily store, and filter storm water runoff before directing the filtered storm water toward a storm water conveyance system or other storm water runoff BMP via underdrain pipes. The captured runoff infiltrates through the bottom of the depression and a soil media layer approximately 2 to 4 feet deep that has an infiltration rate capable of draining the planter box (to the bottom of the soil media) within a specified design drawdown time (usually 10 to 48 hours). The soil media provides treatment through filtration, adsorption, and biological uptake. Some volume reduction is possible through evapotranspiration and storage in the soil media. Planter boxes are typically planted with grasses, shrubs, and trees that can withstand short periods of saturation (10 to 24 hours) followed by longer periods of drought.

5.1.5 Applicability and Performance

Chapter 2 describes the process for selecting BMPs on the basis of pollutants of concern. Planter boxes are volume-based BMPs intended, primarily, for water quality treatment that can provide peak-flow reduction and volume reduction. Planter boxes should be used only in place of bioretention areas where geotechnical conditions do not allow for infiltration. Although planter boxes do not allow for infiltration into the subsoils, they still provide functions considered fundamental for low impact development (LID) practices. Research has shown that runoff volume can be reduced by as much as 15 to 20 percent by systems that are lined or completely contained (Hunt et al. 2006) through evapotranspiration. They are considered only as a last resort to provide some water quality treatment in areas where infiltration is not recommended.

Planter boxes remove pollutants through physical, chemical, and biological mechanisms. Specifically, they use absorption, microbial activity, plant uptake, sedimentation, and filtration, similar to bioretention areas. Planter boxes are capable of consistent and high pollutant removal for sediment, metals, and organic pollutants (e.g., hydrocarbons). Current research shows that pollutant removal is possible with underdrains through the function provided at the surface and by the soil media. Most of the sediment removal occurs in the top mulch layer, while metals removal commonly occurs within the first 18 inches of the soil media (Hseih and Davis 2005; Hunt and Lord 2006).

Removal of nitrogen and phosphorus species is less consistent. Total phosphorus percent removal has been found to vary between a 240 percent increase (production) and a 99 percent decrease (removal) (Davis 2007; Hunt et al. 2006; Hseih and Davis 2005). Greater total phosphorus removal can be achieved by using soil media with total phosphorus concentrations below 15 ppm (Hunt and Lord 2006). Nitrate removal has been found to vary between a 1 and 80 percent decrease (Kim et al. 2003; Hunt et al. 2006). TKN has been found to vary between a 5 percent increase and 65 percent decrease (Kim et al. 2003; Hunt and Lord 2006). Greater nitrate and TKN removal can be achieved by reducing the infiltration rate within the soil media to 1–2 in/hr and ensuring that the soil media is at least 3 feet deep (Hunt and Lord 2006).

Greater nitrate removal can also be achieved by incorporating a saturated layer within the soil media to promote anaerobic conditions for denitrification (Kim et al. 2003; Hunt and Lord 2006; Passeport et al. 2009).

Limited data exist for bacteria removal in bioretention areas; although, most scientists and engineers agree that bacteria die-off occurs at the surface where storm water is exposed to sunlight and the soil can dry out; dense vegetation within the bioretention area can limit the penetration of sunlight and removal of bacteria (Hunt et al. 2008; Hunt and Lord 2006).

5.2 Design

Planter boxes provide similar function to a bioretention area but can be used to provide treatment where infiltration is not possible because of geotechnical limitations. The design process is similar to the nine-step design process for bioretention areas with a few noted exceptions.

The design of a bioretention area can be broken down to a nine-step process:

1. Determine BMP configuration
   a. Determine how to incorporate planter boxes into the layout of the site
   b. Determine and incorporate the necessary BMP components
2. Determine the volume of water to treat (see the City's *Storm Water Standards* and the *San Diego County Hydrology Manual*)
3. Determine the surface area required
4. Determine the depth and type of soil media
5. Inlet configuration
6. Determine if an underdrain pipe is necessary
7. Select the appropriate overflow or bypass method
8. Select mulch and vegetation
9. Additional considerations

5.2.1 Determine BMP Configuration

Planter boxes, like bioretention areas, can be incorporated into the site design with various configurations and components. Unlike bioretention areas, planter boxes, because they are completely contained, can be included in close proximity to buildings and other structural foundations without affecting structural stability. Figure 40 shows how a planter box can be incorporated adjacent to a building, and Figure 41 shows a planter box in a highly urban area.

Source: Low Impact Development Center, Inc.

Figure 40. Building planter boxes.

Source: Low Impact Development Center, Inc.

Figure 41. Planter box in a highly urban setting.

Planter boxes require the same pretreatment as bioretention areas with one key addition—rooftop downspouts must be armored to prevent erosion. For more detail, see Design Step 5: Inlet Configuration.

5.2.2 Determine the Volume of Water or Flow to Treat

The volume of water that must be treated is equal to the volume produced by the design storm. The methods for calculating the volume required for treatment are outlined in the City's *Storm Water Standards*, the *San Diego County Hydrology Manual*, and Appendix A.

5.2.3 Determine the Surface Area Required

Planter boxes have the same ponding depth standards as a bioretention area.

5.2.4 Determine the Depth and Type of Soil Media

Planter boxes must meet same soil media standards as a bioretention area.

5.2.5 Inlet Configuration

Inlets for a planter box must meet the same standards as inlets for bioretention area. Planter boxes can incorporate filter strips, forebays, and curb cuts for the inlet. Because of the ability to install planter boxes adjacent to structural foundations. A planter box inlet can also incorporate a downspout from an adjacent building. Pipe flow and downspouts can be stabilized using similar strategies for a curb cut using sod, if the flow rate is less than 3 cubic feet per second (cfs), stone, splash block, or other erosion protection material for higher flows. A potential inlet configuration is shown in Figure 42 and Figure 43.

5.2.6 Determine if an Underdrain Pipe is Necessary

Because planter boxes are lined on all sides, an underdrain will always be necessary. Underdrains must meet the requirements specified in section 10.2 of this Appendix B.

5.2.7 Select the Appropriate Bypass Method

Planter boxes can be designed as offline or online systems. Planter boxes designed in the right-of-way should be designed as offline systems. Because underdrains will be required for planter boxes, the overflow system will include a vertical riser regardless of the system being an online or offline system. The vertical riser should be designed as described in section 1.2.7. Figure 44 shows an example of a planter box with a vertical riser.

Source: Low Impact Development Center, Inc.

Figure 42. Downspout configuration.

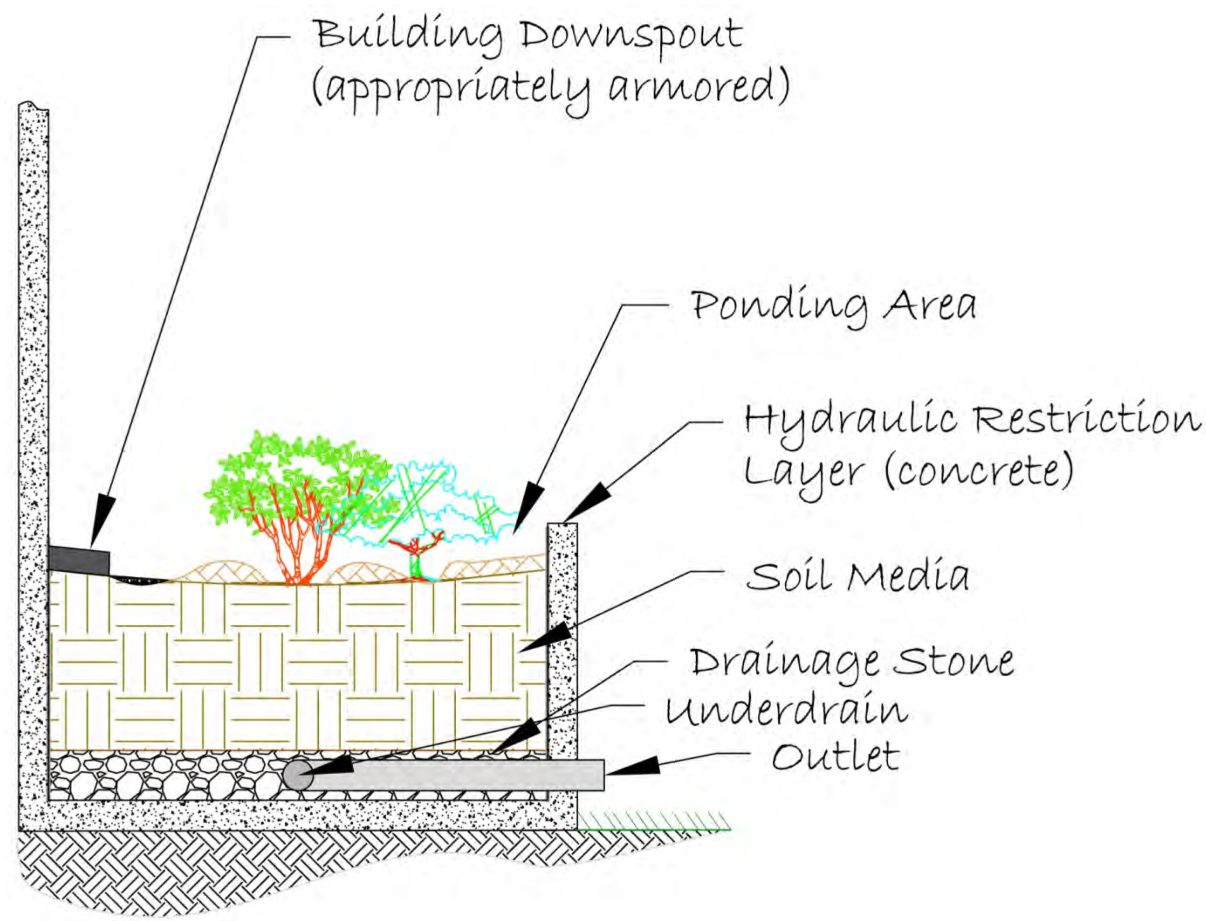


Figure 43. Planter box inlet configuration.

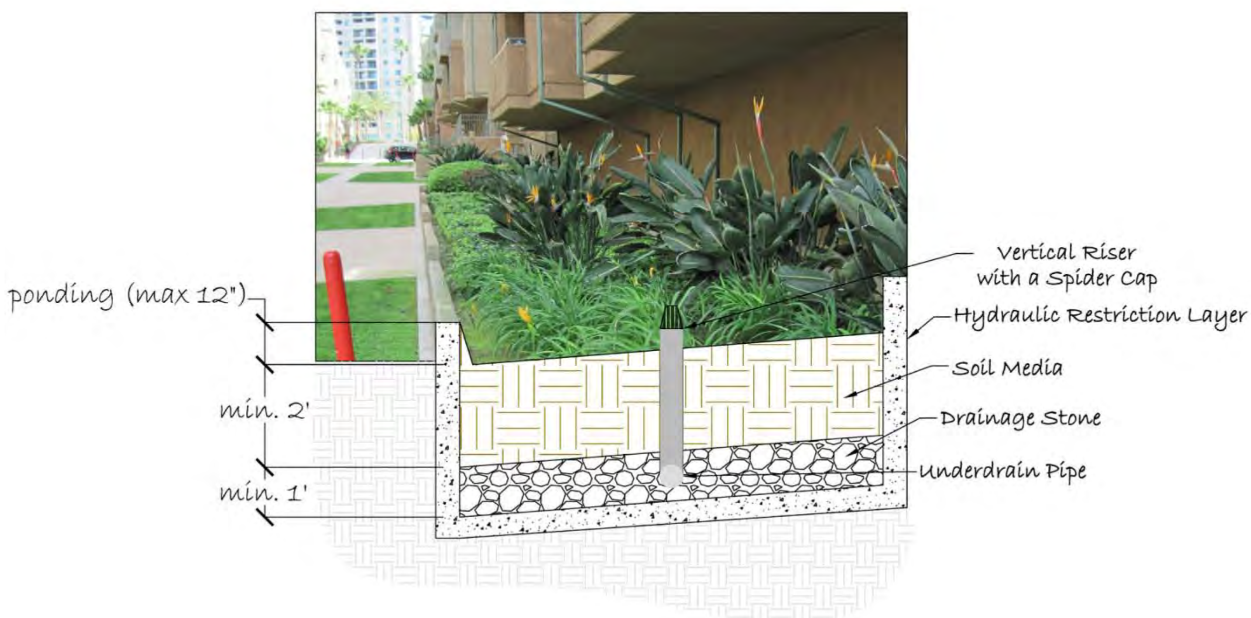


Figure 44. Planter box with a vertical riser.

5.2.8 Select Mulch and Vegetation

The mulch and vegetation will be the same for a planter box as a bioretention area. Some consideration should be taken as to the location of the planter box when selecting the vegetation. Shade-tolerant plants should be selected if the planter box will be shaded by surrounding structures. Planter boxes in the right-of-way should be vegetated with low shrubs to comply with sight distance requirements specified in the City's *Street Design Manual*. Only native non-invasive species will be selected for areas in the MHPA or in areas designated as natural open space.

5.2.9 Additional Considerations

5.2.9.1 Hydraulic restriction layers

Four types of restricting layers can be incorporated into planter box designs:

1. Filter fabric can be placed along vertical walls to reduce lateral flows.

2. Clay (bentonite) liners can be used. If a clay liner is used to prevent infiltration into in situ soils, an underdrain system is also required.

3. Geomembrane liners can be used to prevent lateral flow and should have a minimum thickness of 0.03 inch (30 mils).

4. Concrete barriers can be used in the furnishing zone and along roadways to prevent lateral seepage to adjacent utilities or areas of concern. Concrete could withstand impacts from maintenance performed in the right-of-way but can increase the overall cost of the project significantly.

In planter boxes, the entire perimeter of the soil media must be lined to prevent infiltration into the existing soils while gaining some pollutant removal from the soil media. Underdrains are required in planter boxes as shown in Figure 43 and Figure 44.

For planter boxes constructed in the right-of-way or where maintaining utilities is a concern, concrete barriers might be the most appropriate. Concrete barriers can be constructed as extensions of the surrounding curb installed vertically to the depth where saturation will not affect the stability of the load-bearing soils. Concrete barriers will prevent damage that can occur from maintenance required for utilities in the right-of-way. For details of the hydraulic restriction layers, see section 10.4 of this Appendix B.

5.3 Operation and Maintenance

Planter boxes require the same operation and maintenance as a bioretention area. For appropriate operation and maintenance, see section 1.3 in this Appendix B.

5.4 References

Davis, A.P. 2007. Field performance of bioretention: Water quality. *Environmental Engineering Science* 24(8):1048–1063.

Hsieh, C.H., and A. Davis. P. 2005. Evaluation and optimization of bioretention media for treatment of urban storm water runoff. *Journal of Environmental Engineering* 131(11):1521–1531.

Hunt, W.F., and W.G. Lord. 2006. *Bioretention performance, design, construction, and maintenance*, North Carolina Cooperative Extension, Raleigh, NC.

Hunt, W.F., A.R. Jarrett, J.T. Smith, and L.J. Sharkey. 2006. Evaluating bioretention hydrology and nutrient removal at three field sites in North Carolina. *Journal of Irrigation and Drainage Engineering* 132(6):600–608.

Hunt, W. F., J.T. Smith, S.J. Jadlocki, J.M. Hathaway, and P.R. Eubanks. 2008. Pollutant removal and peak flow mitigation by a bioretention cell in urban Charlotte, NC. *Journal of Environmental Engineering* 134(5):403–408.

Kim, H., E.A. Seagren, and A.P. Davis. 2003. Engineered bioretention for removal of nitrate from stormwater runoff. *Water Environment Research* 75(4):355–367.

Passeport, E., W.F. Hunt, D.E. Line, R.A. Smith, and R.A. Brown. 2009. Field study of the ability of two grassed bioretention cells to reduce storm-water runoff pollution. *Journal of Irrigation and Drainage Engineering* 135(4):505–510.

6 Sand Filters

6.1 Description

A sand filter is a treatment system that is used to remove particulates and solids from storm water runoff by facilitating physical filtration. It is a flow-through system designed to improve water quality from impervious drainage areas by slowly filtering runoff through sedimentation and filtration chambers. With increased detention time, the sedimentation chamber allows larger particles to settle to the bottom of the chamber. The filtration chamber removes pollutants and enhances water quality as the storm water is strained through a layer of sand. The treated effluent is collected by underdrain piping and discharged to the existing storm water collection system or another BMP.

6.1.1 Advantages

- Efficient removal of suspended solids, heavy metals, oil and grease, particle-bound nutrients, and pathogens
- Can effectively reduce peak runoff rates for relatively frequent storms, reduce runoff volumes, and recharge groundwater if soil conditions allow
- Flexible to adapt to urban retrofits
- Can require less space and be placed underground in areas where space is limited
- Can have high infiltration rates

6.1.2 Disadvantages

- Surface soil layer can clog over time (though it can be restored)
- Frequent trash removal might be required, especially in high-traffic areas
- Vigilance in protecting native soils from compaction during construction might be necessary
- Single units can serve only small drainage areas

- Can be unattractive in some areas
- Higher cost for implementation

6.1.3 Major Design Elements

- When sizing, take into account all runoff at ultimate build-out including off-site drainage. (For volume calculations, see the City's *Storm Water Standards*.)
- Drainage areas should be less than 5 acres.
- A bypass and an internal overflow are required for bypassing storms in excess of the design storm.
- Sand filters allowing for infiltration must not be used where the seasonally high water table or confining layer is less than 10 feet below bottom of the BMP (City of San Diego *Storm Water Standards*).
- Media permeability must be at least 1 in/hr.
- Inflow must be non-erosive sheet flow unless an energy-dissipation device or forebay is installed.
- Infiltration BMPs must be a minimum of 100 feet from water supply wells and septic drain fields and 10 feet from any structural foundations.
- Ponding depth must be 12 inches or less; 9 inches is preferred.
- Media depth must be 1.5 feet minimum
- Media should meet the specifications listed in Design Step 4: Determine Depth and Type of Media.
- The sand filter must drain completely within 48 hours.
- An underdrain must be installed if in situ soil drainage is less than 0.5 in/hr. The underdrain pipe should be at least 4 inches in diameter and installed at a 0.5 percent minimum slope.
- An underdrain must be installed if the BMP is within 50 feet of a sensitive, steep slope.
- Cleanout pipes must be provided if underdrains are required.

6.1.4 Characteristics and Function

Sand filters are pure filtering BMPs that remove trash and pollutants by passing storm water vertically through a sand media. Sand filters are capable of removing a wide variety of pollutant concentrations in storm water via settling, filtering, and adsorption processes. Sand filters have been a proven technology for drinking water treatment for many years and now have been demonstrated to be effective in removing urban storm water pollutants including TSS, biochemical oxygen demand, fecal coliform, hydrocarbons, and metals. Because sand filters can be underground, they can also be used in areas with limited surface space.

Sand filters are designed primarily for water quality enhancement; flow-volume control is typically a secondary consideration. They are generally applied to land uses with a large fraction of impervious surfaces and ultra-urban locations. Although an individual sand filter can handle only a small contributing drainage area, multiple units can be dispersed throughout a large site.

Two strategies are available for incorporating sand filters into the site design. One option is the open basin design that allows sunlight penetration to enhance pathogen removal. The second option is a closed basin that requires very little space in a site but has reduced pollutant-removal capabilities. Sand filters typically employ underdrain systems to collect and discharge treated storm water but can also be designed as infiltration-type systems when in soils with sufficient permeability or infiltration rates.

6.1.5 Applicability and Performance

Sand filters are volume-based BMPs intended primarily for treating the water quality design volume. In most cases, sand filters are enclosed concrete or block structures with underdrains; therefore, only minimal volume reduction occurs via evaporation as storm water percolates through the filter to the underdrain. Because sand filters rely on filtration as the primary function for pollutant reduction, infiltration rates could be higher than what is recommended for a bioretention area allowing a greater volume to pass through the media in a short amount of time. That requires less surface area of the BMP to treat the same volume with a lower performance for some pollutants. Sand filters have high removal rates for sediment, biochemical oxygen demand, and fecal coliform bacteria (USEPA 1999). TSS removal rates can be as high as 80 percent (Bell et al. 1995; Horner and Horner 1995)

6.2 Design

The design of a sand filter can be broken down to an eight-step process:

1. Determine BMP configuration
    a. Determine how to incorporate the BMP into the layout of the site
    b. Determine and incorporate the necessary BMP components
2. Determine the volume of water to treat (see the City's *Storm Water Standards* and the *San Diego County Hydrology Manual*)
3. Determine the surface area required
4. Determine the depth of media
5. Inlet configuration
6. Determine if an underdrain pipe is necessary
7. Select the appropriate overflow or bypass method
8. Additional considerations

6.2.1 Determine BMP Configuration

Sand filters require less space than many BMPs and are typically used in parking lots or other highly impervious areas. Two basic configurations are available for sand filters: aboveground with a vegetated filter strip as a pretreatment element, or belowground with a forebay sediment chamber. The aboveground option requires more space to incorporate the pretreatment filter, while providing a greater pathogen reduction to the exposure of the surface to sunlight.

Aboveground: Aboveground sand filters require some method of pretreatment, such as a filter strip or flow reduction, to remove large solids and reduce the velocity of storm water entering the BMP. Aboveground sand filters can be integrated into the site plan as recreation facilities or open space as shown in Figure 45.

Source: Portland BES

Figure 45. Aboveground sand filter.

Belowground: Belowground sand filters require very little space and are easily incorporated into the edge of parking lots and roadways. Belowground sand filters require a pretreatment sedimentation chamber that is a minimum of 1.5 feet wide to allow for settling of large solids. An example of a belowground sand filter with a sedimentation chamber is shown in Figure 46.

Source: NCSU–BAE

Figure 46. Belowground sand filter.

6.2.2 Determine the Volume of Water or Flow to Treat

The volume of water that must be treated is equal to the volume produced by the design storm. The methods for calculating the volume required for treatment are outlined in the City's *Storm Water Standards,* the *San Diego County Hydrology Manual,* and Appendix A.

6.2.3 Determine the Surface Area Required

6.2.3.1 Geometry and Size

1. The ponding depth of sand filters is not limited as with some BMPs because the effect on vegetation is not a concern. Depth is determined by the ability of the sand filter to completely drain within 48 hours and, therefore, is a function of the surface area and infiltration rate of the sand media. Ponding depth should not exceed 3 feet as a safety precaution (Figure 47).

2. Sand media depth should be a minimum of 1.5 feet.

Figure 47. Sand filter geometry and profile.

6.2.3.2 Sizing Methodology

Sand filters are to be sized to treat the volume produced by the design storm and, where site conditions allow, should also be sized to infiltrate the volume reduction requirement. For storm water runoff requirements and calculations, see Appendix A. Procedures for sizing infiltration BMPs should be in accordance with the sizing methodology developed for the City's *Storm Water Standards,* the *San Diego County Hydrology Manual,* and Appendix A.

6.2.4 Determine the Depth and Type of Soil Media

6.2.4.1 Depth of Soil Media

Different pollutants are removed in various zones of soil media using several mechanisms. TSS is removed both in pretreatment and on the surface of the media itself. For that reason, TSS removal is not a major factor in depth of the filter design. Depth, however, is an issue for other pollutants. Metals are removed in the top layer of media and within 18 inches of media as they are often bound to sediment (Davis et al. 2003; Li and Davis 2008). Bacterial, viral, and protozoan pathogens can be killed on the surface and removed throughout the cell by several mechanisms: sun exposure, drying, sedimentation, and filtration (Hathaway et al. 2009). The depth of the media should be a minimum of 18 inches.

6.2.4.2 Type

The soil media in the sand filter should be highly permeable; free of fines, stones, and other debris; and must meet the following criteria:

1. Media in the sand filter should consist of clean washed concrete or masonry sand (passing a one-quarter-inch sieve) or sand similar to the ASTM C33 gradation.

2. High levels of phosphorus in the media have been identified as the main cause of BMPs exporting nutrients. All media should be analyzed for background levels of nutrients. Total phosphorus should not exceed 15 ppm.

6.2.5 Inlet Configuration

Erosive velocities and high sediment loads can be detrimental to sand filters. Both aboveground and belowground sand filters require some type of pretreatment before storm water contacts the filter media. Aboveground sand filters should be constructed with a flow diversion, where possible, to divert volumes that exceed the water quality volume away from the sand filter to prevent excessive loads and erosive flow from affecting the filter media. For more detail on diversion structures, see section 10.3 of this Appendix B. Vegetated filters can also be used with aboveground sand filters where space is available. Flows entering sand filters should be diffused by passing over a level spreader before contacting the filter media to reduce flows, minimize erosion of the filter media, and distribute the flow over a larger surface area. Flows entering a belowground sand filter should enter the sedimentation chamber and can be either concentrated or diffuse, depending on the inlet type. Concentrated flow, such as the flow for the end of a storm water pipe, should enter the sedimentation chamber and flow into the media chamber over a level spreader to diffuse the flow before contacting the filter media as shown in Figure 48. Diffuse flow passing into the sediment chamber over a level lip, such as the edge of a parking lot, should still flow over a level spreader before contacting the filter media. Figure 48 shows a belowground sand filter with a diffuse flow inlet in a parking lot. It is important to distribute the flow across the surface area of the sand filter as much as possible to prevent the inflow from concentrating into one area, causing increased maintenance.

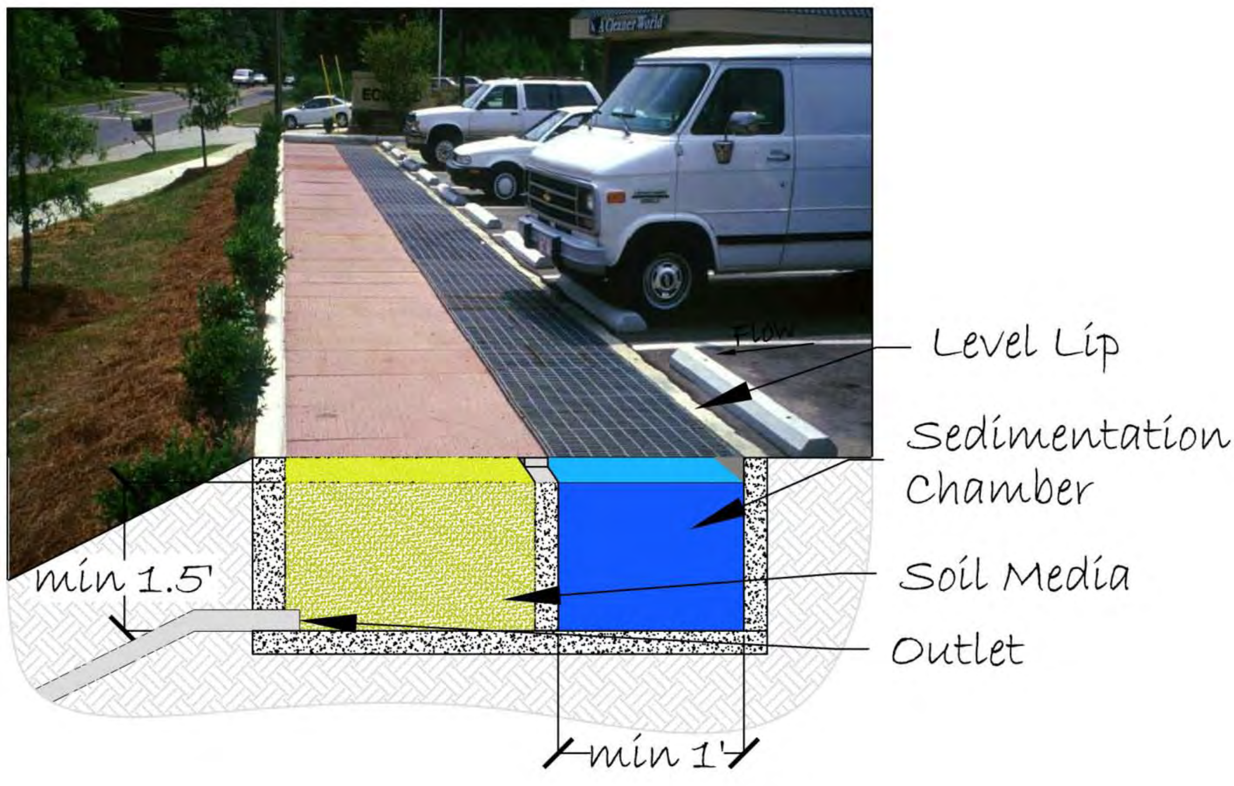


Figure 48. Belowground sand filter with diffuse flow inlet.

6.2.6 Determine if an Underdrain Pipe is Necessary

Soil testing should be performed at the site by a licensed soil scientist or geological engineer to determine the infiltration rate of the soils and the depth to the seasonally high groundwater table. If the infiltration rate of the soils where the sand filter will be installed is not of sufficient capacity to allow for the filter media to drain within 48 hours, underdrains will be required.

Sizing the Underdrain Pipes: If underdrains are required, they must meet the criteria described in section 10.2 of this Appendix B.

6.2.7 Select the Appropriate Outlet or Bypass Method

All flows entering the sand filter should pass through the filter media for treatment. An alternative overflow should be designed for cases when the filter media clogs; doing so will prevent damage to the BMP and surrounding areas. Two options are available for the overflow system. Option 1 would be appropriate only for systems with underdrains.

Option 1: Vertical riser

1. A vertical PVC pipe that is connected to the underdrain or directly to the drainage system.
2. The outlet riser(s) should be 4 inches or greater in diameter so it can be cleaned without damage to the pipe. The vertical pipe will provide access for cleaning the underdrains.

3. The inlet to the riser should be a sufficient height above the filter media to allow for the design head but to also allow for bypass if the filter media clogs. The vertical riser should be capped with a spider cap or other means appropriate to prevent debris from clogging the overflow system.

Option 2: Flow spreader

A flow spreader can be installed along a section of the exit edge or outflow section of the sand filter to protect the surrounding areas if the sand filter clogs or overflows. The flow spreader can be earthen covered with sod or any stable material.

6.2.8 Additional Considerations

6.2.8.1 Hydraulic Restriction Layers

Sand filters are typically completely contained with no infiltration into the subsoils. It is possible to achieve some infiltration by not lining the bottom of the media chamber if the subsoils will allow. The sides of the sand filter will need to be lined with an impervious material to prevent the filter media from integrating with less permeable soils. Aboveground sand filters can be lined with a geomembrane liner with a minimum thickness of 0.03 inch (30 mils). Belowground sand filters must be more rigid and should be constructed with concrete.

A geotechnical investigation should be performed by a licensed soil scientist or geotechnical engineer, and a report should be prepared in accordance with the City's *Guidelines for Geotechnical Reports*. The investigation should determine the effect of infiltration from a sand filter including the appropriate depth of the hydraulic restriction layer. Hydraulic restriction layers are discussed in greater detail in section 10.4 of this Appendix B.

6.2.8.2 Utilities

Avoid utilities where possible. In many cases, sand filters can be shifted in the landscape to prevent implementation over utilities. In cases where utilities cannot be avoided, take care to prevent impact from infiltration or saturation by using hydraulic restricting layers to direct infiltration away from the utility. Sand filters should not block or prevent access to the utility. For further details, see section 10.4 of this Appendix B.

6.3 Operation and Maintenance

Sand filters require regular, frequent maintenance of the media layer and pretreatment devices to ensure optimum infiltration, storage, and pollutant removal capabilities.

1. Erosion control: Inspect flow entrances, ponding area, and surface overflow areas periodically during the rainy season, and replace vegetation or erosion control materials if erosion has occurred (for a sand filter inspection and maintenance checklist, see Appendix F). Properly designed facilities with appropriate flow velocities will not have erosion problems except perhaps in extreme events. If erosion problems occur, the following must be reassessed: (1) flow velocities and gradients within the filter, and (2) flow dissipation and erosion protection strategies in the pretreatment area and flow entrance. If sediment other than the designed soil media is

deposited in the media chamber, immediately determine the source in the contributing area, stabilize, and remove excess surface deposits.

2. Inlet: The inlet should be inspected after the first storm of the season, then monthly during the rainy season to check for sediment accumulation and erosion. Sediment can accumulate, especially at inlets where bypass structures are used, and should be inspected regularly. Any accumulated sediment that impedes flow into the sand filter should be removed and properly disposed of. Flow spreaders should be cleaned and reset as needed to maintain diffuse flows.

3. Overflow and underdrains: Sediment accumulation in the overflow device or underdrain system can cause prolonged ponding and potential flooding. Overflow and underdrain systems should be inspected after the first storm of the season, then monthly during the rainy season to remove sediment accumulation around the overflow. The underdrain system should be designed so that it can be flushed and cleaned as needed. If water is ponding over the filter media for more than 72 hours, the underdrain system should be flushed with clean water until proper infiltration is restored. Flow spreaders should be checked to maintain diffuse flow.

4. Soil: Filter media is designed to maintain long-term pollutant processing capability. Estimates from metal attenuation research suggest that metal accumulation should not present an environmental concern for at least 20 years. If in question, have the soil analyzed for pollutant levels.

5. General maintenance: Trash and debris should be removed from the sand filter as needed. Any visual evidence of contamination from pollutants such as oil and grease should be removed as needed.

Task	Frequency	Maintenance notes
Inlet inspection	Once after first rain of the season, then monthly during the rainy season	Check for sediment accumulation to ensure that flow into the sand filter is as designed. Remove any accumulated sediment.
Outlet inspection	Once after first rain of the season, then monthly during the rainy season	Check for erosion at the outlet and remove any accumulated sediment.
Miscellaneous upkeep	12 times/year	Tasks include trash collection, spot weeding, soil media replacement, and removal of visual contamination.

6.4 References

Bell, W., L. Stokes, L.J. Gavan, and T. Nguyen. 1995. *Assessment of the Pollutant Removal Efficiencies of Delaware Sand Filter BMPs*. City of Alexandria, Department of Transportation and Environmental Services, Alexandria, VA.

Davis, A.P., M. Shokouhian, H. Sharma, C. Minami, and D. Winogradoff. 2003. Water quality improvement through bioretention: Lead, copper, and zinc. *Water Environment Research* 75(1):73–82.

Hathaway, J.M., W.F. Hunt, and S.J. Jadlocki. 2009. Indicator bacteria removal in storm water best management practices in Charlotte, North Carolina. *Journal of Environmental Engineering* 135(12):1275–1285.

Horner, R.R., and C.R. Horner. 1995. *Design, Construction, and Evaluation of a Sand Filter Stormwater Treatment System*. Part II: Performance Monitoring. Prepared for Alaska Marine Lines, Seattle, WA.

Li, H., and A.P. Davis. 2008. Urban particle capture in bioretention media. I: Laboratory and field studies. *Journal of Environmental Engineering* 143(6):409–418.

USEPA (U.S. Environmental Protection Agency). 1999. *Stormwater Management Fact Sheet Sand Filters.* EPA-832-F-99-007. U.S. Environmental Protection Agency. Washington, DC.

7 Vegetated Filter Strips

Source: CASQA

7.1 Description

Vegetated filter strips are bands of dense, permanent vegetation with a uniform slope, designed to provide pretreatment of runoff generated from impervious areas before flowing into another BMP as part of a treatment train. When on soils with high percolation rates, vegetated filter strips can also provide infiltration, improving volume reduction. Increased infiltration can decrease the necessary horizontal length. Such characteristics make it ideal to use vegetated filter strips as storm water BMPs around roadside shoulders or safety zones.

Vegetated filter strips are implemented for improving storm water quality and reducing runoff flow velocity. As water flows in a sheet across the vegetated filter strip, the vegetation filters out and settles the particulates and constituents, especially in the initial flow of storm water. Removal efficiency is often dependent on the slope, length, gradient, and biophysical condition of the vegetation in the system.

7.1.1 Advantages

- Good pretreatment BMP
- Simple to install (often requiring only minimal earthwork and planting)
- Simple, aesthetically pleasing landscaping
- Low cost/maintenance

7.1.2 Disadvantages

- Must be sited adjacent to impervious surfaces
- Might not be suitable for industrial sites or large drainage areas
- Requires sheet flow across vegetated area

- Application in arid areas is limited because of the need for thick vegetation
- Does not provide attenuation of peak flows

7.1.3 Major Design Elements

- The length of flow of the filter strip cannot exceed the length at which sheet flow concentrates.
- Length of flow minimum 15 feet (25 feet preferred). If used as pretreatment, minimum can be 2 ft.
- Maximum length is 150 feet.
- Minimum width (perpendicular to flow direction) is equal to the width of the contributing area.
- Separate from groundwater by at least 10 feet.
- The filter strip must be constructed on a level contour to encourage sheet flow across the filter. The slope of the filter strip should be no less than 1.5 percent to prevent ponding and no greater than 5 percent.
- Selected grasses or vegetation should be able to withstand storm water flows and sustain through wet and dry periods.
- The toe and top of the slope should be as flat as possible to encourage sheet flow and prevent erosion.
- The contributing area may not exceed twice the filter strip area.
- Should not be placed in areas of high automobile or foot traffic.

7.1.4 Characteristics and Function

Filter strips are often used as pretreatment devices for other, larger-capacity BMPs such as bioretention areas and assist by filtering sediment and associated pollutants before it enters the larger-capacity BMP, preventing clogging and reducing the maintenance requirements for larger-capacity BMPs. Filter strips provide an attractive and inexpensive vegetative storm water runoff BMP that can be easily incorporated into the landscape design of a site. Filter strips are commonly used in the landscape designs of residential, commercial, industrial, institutional, and roadway applications. They must be adjacent to the impervious areas that they are intended to treat.

7.1.5 Applicability and Performance

Vegetated filter strips are well suited for treating runoff from roads, highways, driveways, roof downspouts, small parking lots and other impervious surface. They can also be used along streams or open vegetated waterways to treat runoff from adjacent riparian areas. In such applications, they are commonly referred to as buffer strips. Because of their limited ability to provide peak attenuation and their ability to decrease sediment loads, vegetated filter strips are often used as a pretreatment for other BMPs such as bioretention or permeable pavement. They have not been widely accepted as primary BMPs because of the wide range of pollutant removal efficiencies (Schueler et al. 1992; Young et al. 1996).

Vegetated filter strips are flow-based BMPs intended for achieving water quality treatment and, depending on site slope and soil conditions, can provide some volume reduction. Vegetated filter strips are not intended, however, to be a primary BMP for meeting the volume-reduction objectives; although, they do help increase a site's time of concentration (T_c) and reducing storm water runoff volumes and runoff discharge rates. Because runoff passes through filter strip vegetation in shallow, uniform flow, some volume reduction occurs, although filter strips are not designed specifically for volume reduction. While some assimilation of dissolved constituents can occur, filter strips are generally more effective in trapping sediment and particulate-bound metals, nutrients, and pesticides. Nutrients that bind to sediment include phosphorus and ammonium; soluble nutrients include nitrate. Biological and chemical processes could help break down pesticides, uptake metals, and use nutrients that are trapped in the filter.

Vegetated filter strips also exhibit good removal of litter and other debris because the water depth flowing across the strip is typically below the vegetation height.

7.2 Design

The primary function of vegetated filter strips is to maintain sheet flow of runoff. That function is critical to the performance of the BMP. The primary mechanism of failure for filter strips is the development of concentrated flow, which results in erosion and the formation of rills. Hydraulically, filter strips should be designed according to two primary criteria: maximum depth of flow and maximum flow velocity.

Depth of runoff flow generated, by the design storm, within the filter strip should be limited to less than or equal to 1 inch. Maximum design storm flow velocity should be limited to 1 ft/sec. The design configuration having the greatest effect on those design standards are the contributing watershed area, longitudinal slope (along the direction of flow), the resistance to flow (Mannings n), and the width and slope of the filter strip.

Vegetated filter strip design and sizing guidelines are as follows:

7.2.1 Step 1. Determine the Design Flow Rate.

Identify the contributing watershed and calculate the design storm flow rate. (For more information on water quality design flow rate, see Appendix A.)

7.2.2 Step 2. Determine Available Filter Strip Width and Slope.

In some design cases, the filter strip width and slope are predetermined on the basis of existing conditions. However, in many cases, determining the final width and slope are part of the design process.

7.2.3 Step 3. Determine Vegetative Cover

Select vegetative cover for the filter strip that is appropriate for local soil and climate conditions. Considerations should include requirements for maintenance, irrigation, and fertilization. Only native non-invasive species will be selected for areas in the MHPA or in areas designated as natural open space.

7.2.4 Step 4. Calculate the Flow Depth of the Design Flow

The design flow depth (d) is calculated on the basis of the width and the slope (parallel to the flow path) using a modified Manning's equation as follows:

$$d = \left[Q_{wq} \times n_{wq} / 1.49 \times w \times s^{0.5} \right]^{0.6}$$

where

d = design flow depth (ft)

Q_{wq} = water quality design flow rate (cfs)

w = width of strip perpendicular to flow that equals the width of impervious surface contributing to the filter strip (ft)

s = slope (ft/ft) of strip parallel to flow, average over the whole width

n_{wq} = Manning's roughness coefficient (0.025–0.03)

If d is greater than 1 inch, a smaller slope is required, or a filter strip cannot be used.

7.2.5 Step 5 Calculate the Design Velocity

The design flow velocity is based on the design flow, design flow depth, and width of the strip as follows:

$$v_{wq} = Q_{wq} / dw$$

where

v_{wq} = water quality design flow velocity (ft/sec)

Q_{wq} = water quality design flow rate (cfs)

d = design flow depth (ft)

w = width of strip perpendicular to flow that equals the width of impervious surface contributing to the filter strip (ft)

7.2.6 Step 6: Calculate the Desired Length of the Filter Strip.

Determine the required length (L) to achieve a desired residence time of 10 minutes using this equation:

$$L = 600 v_{wq}$$

where

L = swale length (ft)

v_{wq} = design water quality flow velocity (ft/sec)

If the design parameters as computed in steps 1 through 6 above are not within the recommended standards, an alternate BMP, such as a grassed swale should be considered to treat storm water runoff.

7.2.7 Level Spreader/Energy Dissipater

The transition of storm water runoff from upslope, impervious areas to the gently sloping, vegetated surface of a filter strip is critical to the proper function of the BMP. Flow should not be concentrated and should not transition to flow over the filter strip such that it causes concentration or erosive flows. Where flow originates on roadways and parking lots, the designer can elect to incorporate an energy-dissipation device at the interface between the hardened pavement surface and the filter strip. Energy dissipaters typically take the form of a gravel flow spreader consisting of a gravel filled trench that is perpendicular to the direction of flow. The gravel flow spreader should have the following characteristics:

- The gravel flow spreader must be a minimum of 6 inches deep and 12 inches wide.
- The gravel surface should be a minimum of 1 inch below the surface of the adjacent pavement.
- Vegetated filter strips are often used in combination with concrete level spreaders to provide energy dissipation. Runoff is distributed through a channel along the upslope side of the vegetated filter strip and evenly dispersed onto the vegetated filter strip along the level spreader as shown in Figure 49.

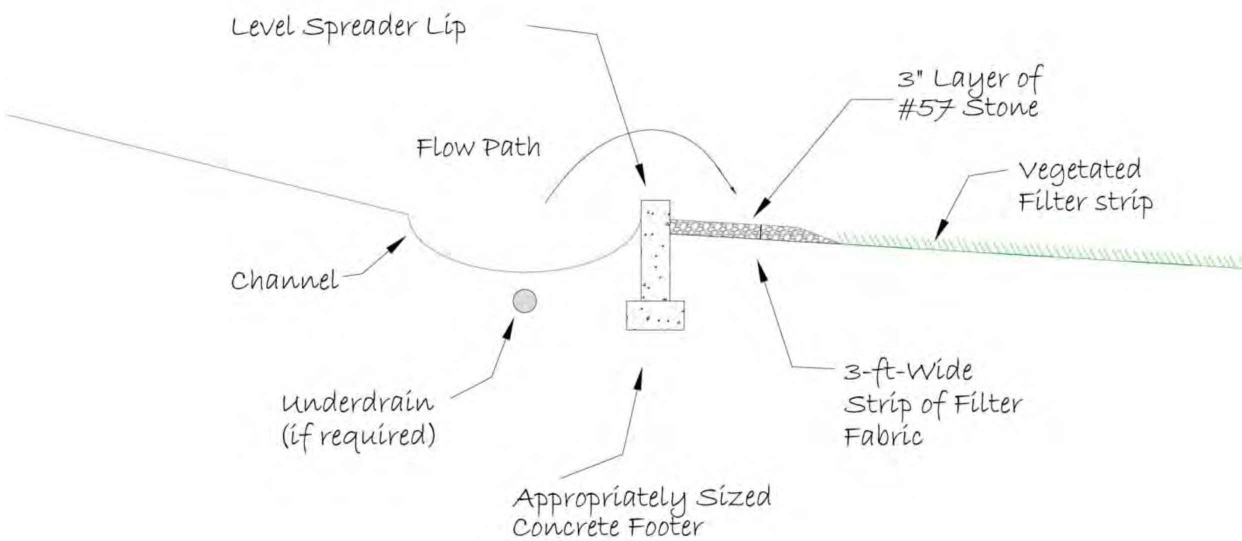


Figure 49. Vegetated filter strip with a level spreader.

7.3 Operation and Maintenance

The primary maintenance requirement of a vegetated filter strip is managing vegetation in the filter strip. As a result, specialized equipment and training of maintenance crews is typically not necessary. Maintenance activities for vegetated filter strips include:

1. Regular mowing to maintain visual aesthetics. Grass height should be maintained at a minimum height of 2 inches. Clippings should be removed so flow is not impeded.

2. Remove accumulated sediment from the inlet lip of the vegetated filter strip before the rainy season and monthly during the rainy season.

3. Weeds and other vegetation should be removed as needed being careful not to cause pits or exposed soil that could lead to increased erosion.

Task	Frequency	Maintenance notes
Mowing	2–12 times/year	As needed to maintain aesthetics. Grass height should be a minimum of 2 inches.
Inlet inspection	Once after first rain of the season, then monthly during the rainy season	Check for sediment accumulation to ensure that flow into the system is as designed. Remove any accumulated sediment.
Miscellaneous upkeep	12 times/year	Tasks include trash collection and spot weeding.

7.4 References

Schueler, T.R., P.A. Kumble, and M.A. Heraty. 1992. A Current Assessment of Urban Best Management Practices, Techniques for Reduction Non-Point Source Pollution in the Coastal Zone. Metropolitan Washington Council of Governments, Anacostia Restoration Team, Department of Environmental Programs, Washington D.C.

Young, G.K., S. Stein, P. Cole, T. Kammer, F. Graziano, and F. Bank. 1996. *Evaluation and Management of Highway Runoff Water Quality*. Rep. No. FHWA-PD-96-032, Federal Highway Administration, Washington, DC.

8 Vegetated Swales

Source: CASQA Stormwater BMP Handbook: Municipal

8.1 Description

Vegetated swales are shallow, open channels that are designed to remove pollutants by physically straining/filtering water through vegetation in the channel. Swales can also serve as conveyance for storm water and can be used in place of traditional curbs and gutters. When compared to traditional conveyance systems, the primary objective of vegetated swales is filtration and water quality enhancement rather than conveyance. An effective vegetated swale achieves uniform sheet flow through densely vegetated areas. When soil conditions allow, infiltration and volume reduction are enhanced by adding a gravel drainage layer underneath the swale.

Vegetated swales are well suited for use in the right-of-way of linear transportation corridors and provide a conveyance system with the added benefits of filtration and infiltration of runoff, depending on the design. Vegetated swales with subsurface bioretention media provide enhanced infiltration, water retention, and pollutant-removal capabilities.

8.1.1 Advantages

- Combines storm water treatment with runoff conveyance
- Often less expensive than curb and gutter
- Provides peak flow reduction
- Can be installed almost anywhere

8.1.2 Disadvantages

- Higher maintenance than curb and gutter
- Impractical in areas with very flat grades or steep topography
- They are not effective and can even erode when flow volumes or velocities are high
- Not effective for volume reduction

8.1.3 Major Design Elements

- Vegetated swales should be designed to accommodate the peak flow from the water quality design storm with a depth of no more than two-thirds of the length of the grass and with a maximum depth above the grass of no more than 6 inches. Remaining depth will be used to convey runoff from larger storm events.
- Design storm velocity should not exceed 1.0 ft/sec. Velocity within vegetated swales should not exceed 3 ft/sec. Swales lined with turf mats can withstand velocities up to 14 ft/sec depending on the manufacturer.
- For flow calculations in vegetated swales, a Manning's n value for well maintained grass channels (i.e., grass maintained at 4 inches) should be 0.025 and as high as 0.035 for poorly maintained channels.
- Vegetated swales should be designed to provide at least 10 minutes of residence time for the peak discharge rate generated by the target water quality event (Claytor and Schueler 1996). Residence times can be increased by adjusting channel dimensions, slopes, and vegetative covers or by including check dams in the channel design.
- The bottom of a vegetated swale should be between 2 and 8 feet wide (Figure 50). Channel bottoms greater than 8 feet wide encourage channel braiding, while channel bottoms less than 2 feet wide encourage soil erosion. If a channel bottom needs to be more than 8 feet wide to accommodate the peak discharge rate generated by the target runoff reduction rainfall event, the use of a compound channel cross section (e.g., two smaller channels separated by a permeable berm) is recommended.
- Vegetated swales should be designed with trapezoidal or parabolic cross sections and should be designed with side slopes of 3:1 (H:V) or flatter.
- The depth from the bottom of a vegetated swale to the top of the seasonally high groundwater table should be at least 2 feet to help prevent ponding and to ensure proper operation of the swale.
- Consider the storm water runoff rates and volumes generated by larger storm events to help ensure that the larger storm events do not cause localized flooding or significant damage to the vegetated swale. Vegetated swales should be designed to safely convey the 10-year storm event. Provisions should be made to bypass larger storm events.

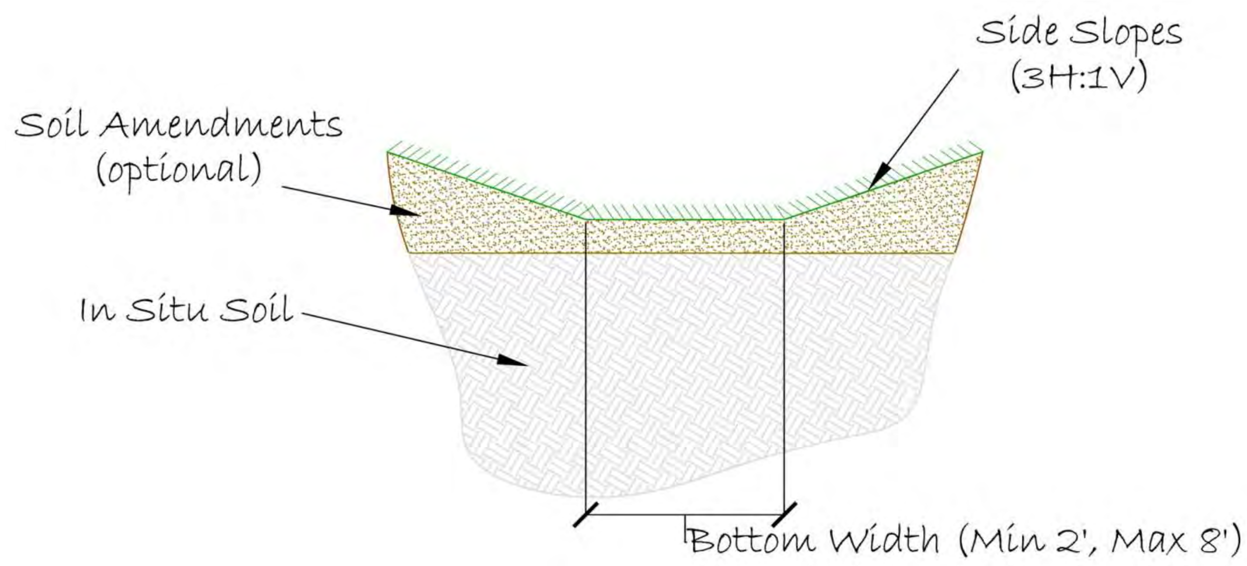


Figure 50. Vegetated swale components.

8.1.4 Characteristics and Function

Although it might be difficult to use vegetated swales to receive storm water runoff in urban areas because of space constraints, they can be used to receive storm water management on a wide variety of development sites in rural and suburban areas, including residential, commercial, industrial, and institutional development sites. Compared with other LID practices, vegetated swales have a relatively low construction cost, a moderate maintenance burden, and require only a moderate amount of surface area.

The following are additional site suitability recommendations and limitations for vegetated swales:

- Limit the contributing drainage area to 5 acres or less.
- The maximum longitudinal slope over the length of the swale should not exceed 2.5 percent. Check dams must be provided for slopes that exceed 2.5 percent.
- The minimum longitudinal slope is 1.5 percent to prevent ponding in the vegetated swale.
- Vegetated swales should not be applied in areas with highly erodible soils unless a permanent turf reinforcement mat is used.
- Vegetated swales should not be located in areas with excessive shade to avoid poor vegetative growth. For moderately shaded areas, shade-tolerant plants should be used.
- Avoid large trees that could drop leaves or needles. Excessive tree debris could smother the grass or impede the flow through the swale.

8.1.5 Applicability and Performance

Vegetated swales are flow-based BMPs intended primarily for water quality treatment and, depending on site slope and soil conditions, can provide minimal volume reduction. Vegetated swales are not intended to be a primary BMP for meeting peak runoff discharge goals, although they do help reduce the peak runoff discharge rate by increasing the site's T_C and decreasing runoff volumes and velocities.

Vegetated swales remove sediment and particulate-bound pollutants by filtration through the vegetation. The effectiveness of vegetated swales can be enhanced by adding check dams or appropriate trees at approximately 50-foot increments along their length. The dams maximize the retention time in the swale, decrease flow velocities, and promote particulate settling. Incorporating vegetated filter strips parallel to the top of the channel banks can help to treat sheet flows entering the swale.

8.2 Design

The flow capacity of a vegetated swale is a function of the longitudinal slope (parallel to flow), the resistance to flow (e.g., Manning's roughness), and the cross-sectional area. The cross section is normally approximately trapezoidal, and the area is a function of the bottom width and side slopes. The flow capacity of vegetated swales should be such that the design water quality flow rate will not exceed a flow depth of two-thirds the height of the vegetation in the swale or 4 inches at the peak of the water quality design storm intensity. Once design criteria have been selected, the resulting flow depth for the design water quality flow rate should be checked. If the depth restriction is exceeded, swale parameters (e.g., longitudinal slope, width) should be adjusted to reduce the flow depth.

The design of vegetated swales follows a 10-step procedure as follows:

1. Determine BMP configuration
2. Determine the volume of water to treat
3. Calculate the swale cross-sectional dimensions
4. Determine design flow velocity
5. Calculate swale length
6. Adjust swale layout to fit the site
7. Provide conveyance capacity for flows higher than Q_{wq}
8. Determine if a gravel drainage layer is needed
9. Determine if soils need to be amended
10. Select vegetation

8.2.1 Determine BMP Configuration

Vegetated swales can be in many different areas, particularly road sides, around parking lots, medians, and open areas. The linear structure of swales favors their use in the treatment of runoff from highways, residential roadways and common areas in residential subdivisions, along property boundaries and in and around parking lots. If permitted, vegetated swales are an excellent alternative to curb and gutter, providing water quality and quantity benefits as well as adding an aesthetic appeal. Vegetated swales are more appropriate along residential, low-traffic roads. Generally, a vegetated filter strip or buffer should be placed between the roadway and the vegetated swale to limit the amount of sediment entering the swale.

Around parking lots is a good location to place vegetated swales. A vegetated filter strip should pretreat the incoming storm water runoff before it enters the vegetated swale. Vegetated swales can also be incorporated into common or open areas in parking lots and in medians. Placing swales around parking lots eliminates the need for curb and gutter, potentially reducing construction costs while meeting water quality and quantity criteria.

8.2.2 Determine the Volume of Water to Treat

The volume of water that must be treated is equal to the design storm. The methods for calculating the volume required for treatment are outlined in the City's *Storm Water Standards*, the *San Diego County Hydrology Manual,* and Appendix A. In addition to the volume requirement, the vegetated swale should be designed to safely convey the 10-year storm event unless a flow splitter is installed to allow only the water quality volume into the swale. For details on diversion structures, see section 10.3 of this Appendix B.

8.2.3 Calculate the Swale Dimensions

The design procedure detailed below uses a trial-and-error method for solving Manning's equation for a trapezoidal, open channel when the longitudinal channel slope, Manning's roughness, and design flow rate are known. The general Manning's equation is as follows, assuming the design flow rate is Q_{wq}:

$$Q_{wq} = \left(\frac{1.49}{n}\right) AR^{\frac{2}{3}} s^{\frac{1}{2}}$$

where

Q_{wq} = design storm flow rate (cfs)

n = Manning's roughness coefficient (no units)

A = cross-sectional area of flow (ft^2)

R = hydraulic radius (ft) = area (A) divided by wetted perimeter (P)

s = longitudinal channel slope (along direction of flow) (ft/ft)

For the purposes of the trial and error process presented below, Manning's equation can be rearranged as follows:

$$AR = \frac{Q_{wq}^{\frac{3}{2}} n^{\frac{3}{2}}}{1.82 s^{\frac{3}{4}}}$$

An iterative trial and error process is best used to determine the depth of flow, d, bottom width, b, and side slope, z (side slope horizontal per unit vertical, minimum value is 3). Trial values of bottom width, flow depth, and side slope should be used to determine A, P, and R for the configuration of the swale cross section until the equations are equal and the flow depth, bottom width, and channel side slope are within the guidelines established in the previous sections. The equations for A and R for a trapezoidal channel are provided below:

$$R = \frac{A}{P}$$

$$A = (b + zd)d$$

$$P = b + 2d(1 + z^2)^{0.5}$$

Given the complex nature of the trial and error process, it is recommended that a computer spreadsheet be used for this analysis.

8.2.4 Determine Design Flow Velocity

The flow continuity equation should be used to calculate the design flow velocity through the swale:

$$V_{wq} = \frac{Q_{wq}}{A_{wq}}$$

where

Q_{wq} = design flow (ft^3/sec)

V_{wq} = design flow velocity (ft/sec)

$A = (b + zd)d$ = cross sectional area (ft^2) of flow at the design depth, where z = side slope length per unit height

The swale should convey the design storm without the threat of erosion. If the design flow velocity exceeds 1 ft/sec, one or more of the design parameters (longitudinal slope, bottom width, or flow depth) must be altered to reduce the design flow velocity to 1 ft/sec or less. It is important to verify that the velocity produced by the 10-year storm will not cause erosion and will be safely conveyed within the vegetated swale. It is desirable to have the design velocity as low as possible, both to improve treatment effectiveness and to reduce swale length requirements.

8.2.5 Calculate Swale Length

Use the following equation to determine the necessary swale length to achieve a hydraulic residence time of at least 10 minutes (600 seconds):

$$L = 600V_{wq}$$

where

L = Swale length (ft)

V_{wq} = design flow velocity (ft/sec)

If the length of the swale is too long to be accommodated within the site, the design parameters can be adjusted to provide the flow velocity required to meet the recommended residence time.

8.2.6 Conveyance Capacity for Flows Higher than the Design Storm

Vegetated swales are often designed as online systems that convey flows higher than the design storm flow but can be designed as offline systems incorporating a high-flow bypass or diversion structure upstream of the swale inlet. A high-flow bypass usually results in a smaller swale size. If a high-flow bypass is required, see details on designing diversion structures in section 10.3 of this Appendix B.

If the swale will be designed as an online system, confirm that the swale can convey the post-development peak storm water discharge rate for the 10-year, 24-hour storm event. The post-development peak storm water runoff velocity for the 10-year, 24-hour storm should be less than 3.0 ft/sec. If the 10-year, 24-hour peak flow velocity exceeds 3.0 ft/sec, increase the bottom width or reduce the longitudinal slope as necessary to reduce the peak flow velocity to 3.0 ft/sec or less. If the longitudinal slope is reduced, the swale bottom width must be recalculated and must meet all guidelines established in the previous section.

8.2.7 Determine if a Gravel Drainage Layer is Needed

To increase volume reduction and if soil conditions allow (infiltration rate > 0.5 in/hr), install an appropriately sized gravel drainage layer (typically a washed no. 57 stone) beneath the swale to increase the volume reduction capacity. Where slopes are greater than 1 percent, the gravel drainage layer should be installed in combination with check dams to slow the flow in the swale and allow for infiltration into the gravel drainage layer and percolation into the subsurface soils. The base of the drainage layer should be level, and the drawdown time in the gravel drainage layer should not exceed 72 hours. The soil and gravel layers should be separated with a geotextile filter fabric or a thin, 2- to 4-inch layer of pure sand and a thin layer (nominally 2 inches) of choking stone (such as #8).

8.2.8 Determine if Soils Need to be Amended

Vegetated swale soils should be amended with 2 inches of soil media (for soil media specifications, see section 1.2.4.2 of the main document) unless the organic content is already greater than 5 percent. The soil media should be mixed into the native soils to a depth of 6 inches to prevent soil layering.

8.2.9 Select Vegetation

Swales must be vegetated to provide adequate treatment of runoff via filtration. Vegetation, when chosen and maintained appropriately, also improves the aesthetics of a site. It is important to maximize water contact with vegetation and the soil surface. The following criteria should be used for selecting appropriate vegetation:

1. The swale area must be appropriately vegetated with a mix of erosion-resistant plant species that effectively bind the soil. A diverse selection of low-growing plants that thrive under the specific site, climatic, and watering conditions should be specified. A mixture of dry-area and wet-area grass species that can continue to grow through silt deposits is most effective. Native or adapted grasses are preferred because they generally require less fertilizer, limited maintenance, and are more drought resistant than exotic plants. When appropriate, swales that are integrated within a

project can use turf or other more intensive landscaping, while swales that are on the project perimeter, in a park, or close to an open space area should be planted with a more naturalistic plant palette. Only native non-invasive species will be selected for areas in the MHPA or in areas designated as natural open space. Vegetation in the swale must be rooted before the wet season. If vegetation cannot be rooted in time, turf should be installed and properly stabilized.

2. Trees or shrubs can be used in the landscape as long as they do not over-shade the turf.

3. Above the design treatment elevation, a typical lawn mix or landscape plants can be used, provided they do not shade the swale vegetation.

4. Irrigation is required if the seed is planted in spring or summer. Use of a permanent irrigation system can help provide maximal water quality performance. Drought-tolerant grasses should be specified to minimize irrigation requirements.

5. Vegetative cover should be at least 4 inches in height, ideally 6 inches. Swale water depth will ideally be 2 inches below the height of the shortest plant species.

For a local plant list, see Appendix E.

8.3 Operation and Maintenance

1. Inspect vegetated swales for erosion or damage to vegetation at least twice annually for offline swales, preferably at the beginning and end of the wet season. Additional inspection during the wet season and after periods of heavy runoff is recommended. Each swale should be checked for debris and litter and areas of sediment accumulation (for a vegetated swale inspection and maintenance checklist, see Appendix F).

2. Inspect inlets for erosion and sediment accumulation twice annually. Remove sediment if it is blocking the entry of storm water. After sediment-removal activities, vegetation replanting or reseeding might be required. Repair erosion immediately and stabilize.

3. Side slopes should be maintained to prevent erosion. Slopes should be stabilized and planted using appropriate vegetation when native soil is exposed or erosion is observed.

4. Swales should drain within 48 hours. If a gravel drainage layer is incorporated underneath the swale to promote infiltration, the layer should drain within 72 hours of the end of the storm. Till the swale if compaction or clogging occurs. The perforated underdrain pipe, if present, should be cleaned if necessary.

5. Vegetation should be healthy and dense enough for filtration while protecting underlying soils from erosion. Specific maintenance items for vegetation consist of the following:

   - Vegetation, large shrubs, or trees that interfere with landscape swale operation should be pruned.
   - Fallen leaves and debris from deciduous plant foliage should be removed.

- Grassy swales should be mowed to keep grass 4 to 6 inches in height. Grass clippings should be removed.
- Invasive vegetation must be removed and replaced with non-invasive species.
- Dead vegetation should be removed if it composes more than 10 percent of the area covered or when swale function is impaired. Vegetation should be replaced and established before the wet season to maintain cover density and control erosion where soils are exposed.

6. Check dams (if present) should control and distribute flow across the swale. Causes for altered water flow and channelization should be identified and obstructions cleared. Check dams and swale should be repaired if damaged.

7. The vegetated swale should be well maintained; trash and debris, sediment, visual contamination (e.g., oils), and noxious or nuisance weeds should be removed.

Task	Frequency	Maintenance notes
Inlet inspection	Twice annually	Check for sediment accumulation and erosion in the swale.
Mowing	2–12 times / year	Frequency depends on location and desired aesthetic appeal.
Watering	1 time/2–3 days for first 1–2 months. Sporadically after establishment	If droughty, watering after the initial year may be required.
Fertilization	1 time initially	One-time spot fertilization for first year vegetation.
Remove and replace dead plants	1 time/year	Within the first year 10 percent of plants can die. Survival rates increase with time.
Check dams	1 time before the wet season and monthly during the wet season.	Check for sediment accumulation and erosion around or underneath the dam materials.
Miscellaneous upkeep	12 times/year	Tasks include trash collection, spot weeding, and removing mulch from overflow device.

8.4 References

Claytor, R.A., and T.R. Schueler. 1996. *Design of Stormwater Filtering Systems*. The Center for Watershed Protection, Silver Spring, MD.

9 Cisterns

Location: Mira Mesa Library, San Diego, CA

9.1 Description

Cisterns or their smaller counterpart, rain barrels, are containers that can capture rooftop runoff and store it for future use. With control of the timing and the volume released, the captured rainwater can be more effectively released for irrigation or alternative grey water uses between storm events. Rain barrels tend to be smaller systems, less than 100 gallons. Cisterns are larger systems that can be self-contained aboveground or belowground systems generally larger than 100 gallons. Belowground systems frequently require a pump for water removal. For San Diego and surrounding areas, cisterns and rain barrels primarily provide control of storm water runoff. Treatment can be successful when cisterns and rain barrels are used in a treatment train along with BMPs such as bioretention. Rain water in cisterns or rain barrels can be controlled by permanently open outlets or operable valves depending on project specifications. Cisterns and rain barrels can be a useful method of reducing storm water runoff volumes in urban areas where site constraints limit the use of other BMPs.

9.1.1 Advantages

- Provides peak flow mitigation
- Aids in infiltration by delaying runoff

- Variable configurations
- Can reduce the size of infiltration BMPs

9.1.2 Disadvantages

- Requires regular maintenance of inlet filters
- Can require structural support
- Small storage capacities

9.1.3 Major Design Elements

- Rooftop runoff should be filtered at the downspout or inlet of the cistern.
- Cistern size can vary depending on the drainage area, available space, and size of associated BMPs.
- Cisterns require necessary structural support for the weight of the storage volume.

9.1.4 Characteristics and Function

Cisterns are typically located near roof downspouts such that flows from existing downspouts can be easily diverted into the cistern. Runoff enters the cistern near the top and is filtered to remove large sediment and debris. Collected water exits the cistern from the bottom by gravity or can be pumped to areas more conducive for infiltration. Cisterns can be used as a reservoir for temporary storage or as a flow-through system for peak flow control.

Cisterns are fitted with a valve that can hold the storm water for reuse, or they release the storm water from the cistern at a rate below the design storm rate. Regardless of the intent of the storage, an overflow must be provided if the capacity of the cistern is exceeded. The overflow system should route the runoff to a storm water BMP for treatment or safely pass the flow into the storm water drainage system. The overflow should be conveyed away from structures. The volume of the cistern should be allowed to slowly release, preferably into a storm water BMP for treatment or into a landscaped area where infiltration has been enhanced.

9.1.5 Applicability and Performance

Cisterns provide no direct pollutant-removal capacity. They should be designed as part of a treatment train with BMPs that provide the required pollutant reduction.

9.2 Design

The design of a cistern or rain barrel can be broken down into a five-step process:

1. Determine BMP configuration
   a. Determine how to incorporate cisterns into the layout of the site
   b. Determine and incorporate the necessary components

2. Determine the volume of water to treat (see the City's *Storm Water Standards* and the *San Diego County Hydrology Manual*.
3. Inlet configuration
4. Select the appropriate overflow or bypass method
5. Additional considerations

9.2.1 Determine BMP Configuration

Cisterns are available commercially in numerous sizes, shapes, and materials. Many are made to custom fit the available space and can be short and fat, tall and skinny, round, rectangular, and almost any size imaginable. They can be made from multiple materials but are primarily constructed of plastic or metal. Plastic cisterns can be covered in wood to provide a more finished appearance or can be painted with any image desired. Some examples of possible cistern configurations and materials are presented in Figure 51 through Figure 56.

Figure 51. Tall, narrow, plastic cistern.

Figure 52. Short, wide, plastic cistern.

Figure 53. Metal cistern.

Figure 54. Wood-wrapped cisterns in series.

Figure 55. Small, painted, plastic cistern.

Source: Sante Fe, NM, Children's Museum

Figure 56. Painted metal cistern.

Cisterns are intended to capture runoff from elevated surfaces, such as rooftops, and, therefore, must be next to structures where runoff can be collected. Cisterns are typically designed to capture runoff from concentrated sources or collection systems such as a downspout. The conditions or layout of the site could determine if the foundation can be excavated and what materials will be used to support the cistern. Cisterns, especially large systems, must have a proper foundation to support the weight when they are at capacity. Two options exist, with three suggested criteria for foundations:

- **Cisterns holding less than 3,000 gallons:** The area where the cistern will be installed should be cleared and leveled. The foundation can be excavated as long as gravity flow can be maintained. Four to six inches of no. 57 stone, or acceptable equivalent, should be placed and leveled to serve as the base for the cistern.
- **Cisterns holding between 3,000 and 5,000 gallons:** The foundation of the cistern should be cleared and leveled. The foundation should be no. 57 gravel or concrete depending on the stability of the underlying soils.
- **Cisterns holding more than 5,000 gallons:** The area beneath the cistern should be cleared and leveled. Concrete should be poured such that gravity flow can be maintained and the cistern can be drained to the level of the outlet valve.

If the structural capacity of the site to support a full cistern is in doubt, a geotechnical evaluation should be performed to determine the structural capacity of the soils. Figure 57 shows the foundation options.

Figure 57. Cistern foundations.

9.2.2 Determine the Volume of Water or Flow to Treat

The volume of water that must be treated is equal to the design storm. The methods for calculating the volume required for treatment are outlined in the City's *Storm Water Standards*, the *San Diego County Hydrology Manual,* and Appendix A. The treatment volume must be treated on-site and can be treated by multiple BMPs. Cisterns will typically be part of a treatment system that would include cisterns and other BMPs including bioretention or pervious pavement. The cistern could be included to reduce the size of another BMP.

9.2.3 Inlet Configuration

Inlet connections can either be made through the top of the cistern as shown in Figure 58 or through the sides of the vertical portion formed for the opening of the cistern, often referred to as the man way, as shown in Figure 59. Inlet connections made through the top of the cisterns can also include a basket filter as an inlet filter option. Inlet connects through the sides with the proper gaskets are recommended for ease of maintenance and access to the cistern.

Figure 58. Inlet in the top of the cistern.

Figure 59. Inlet in the sides of the man way.

Storm water runoff must be filtered before it enters the cistern to remove debris and particles that could clog the outlet. Two types of systems can be used: first-flush diverters and inlet filters. A first-flush diverter will not always be required and will be up to the designer depending on site conditions. A first-flush diverter is recommended for sites where pollen or other fine particles that might not be removed by an inlet filter.

9.2.3.1 Inlet Filters

Inlet filters are designed to remove particles as runoff passes through the filters before entering the cistern; many filter options are available. The size and type of filter will be determined by the size of the area draining to the downspout. The filters can be installed at the gutter as shown in Figure 60 or at the end of the downspout as shown in Figure 61 depending on the configuration of the downspouts. Flow through filters that force all the runoff through the filter can be used for smaller drainage areas (less than 1,500 square feet). Filters capable of bypassing larger events could be required for larger drainage areas (1,500 to 3,000 square feet). Examples of two types of filters are shown in Figure 62 and Figure 63.

Figure 60. Inlet filters at the gutter.

Figure 61. Inlet filters at the downspout.

Figure 62. Flow-through inlet filter.

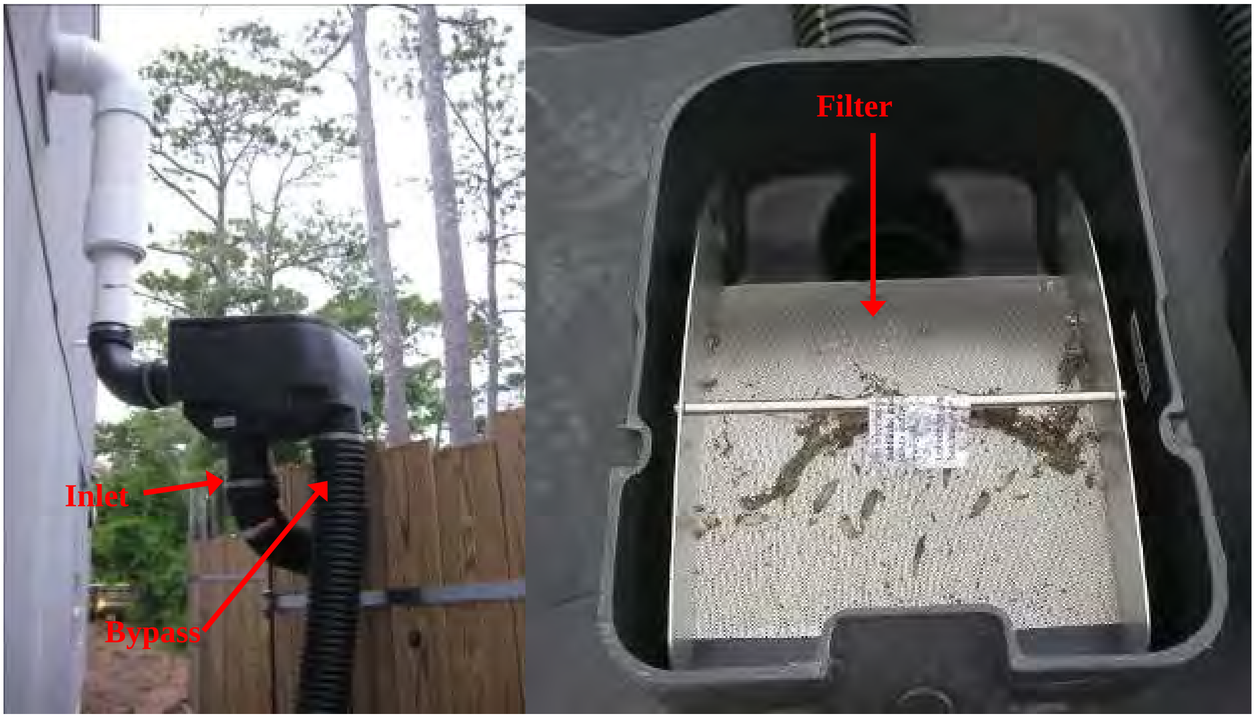


Figure 63. Self-flushing filter with a bypass.

9.2.3.2 First-Flush Diverter

First-flush diverters can be installed after the inlet filter and are designed to divert an initial volume of water away from the cistern to prevent small particles that might initially be washed off of the roof from clogging the outlet. First-flush diverters are typically attached to the inlet or, in some cases, the inlet filter with a 4- to 6-inch diameter pipe with a small relief valve from which water can be diverted. The volume of water diverted away from the cistern depends on the length of the pipe. Once the diverter is full, a valve closes and water flows into the cistern.

Figure 64. Valve for a first-flush diverter.

Figure 65. First-flush diverter configuration.

9.2.4 Select the Appropriate Outlet or Bypass Method

The outlet of the cistern should be designed to release the volume of captured runoff at a rate below the design storm rate at its maximum capacity. The outlet of the cistern should be directed to a bioretention area or other pervious surface with enhanced infiltration capacity as demonstrated in Figure 66.

Location: Mira Mesa Library, San Diego, CA

Figure 66. Cistern outlet.

All cisterns should have an overflow for runoff volumes that exceed the capacity of the cistern. The overflow should be set slightly below the inlet. Overflow connections should be connected to the tank using appropriate watertight gaskets as shown in Figure 59 in the inlet section. An additional bypass can be incorporated using an appropriate inlet filter. An example of a filter with a built-in bypass is shown in Figure 63.

Figure 67. Cistern outlet to a bioretention area (bioretention area not shown).

All overflow and outlet volumes should be directed safely away from all structural foundations and any areas where infiltration could have an adverse effect.

9.2.5 Additional Considerations

Smaller cisterns (less than 100 gallons), commonly referred to as rain barrels, can be used on a residential scale. Rain barrels are much less complicated to install, because of their size, and have similar components as cisterns. Rain barrels require an inlet connection to the downspout, an outlet, and an overflow. The inlet for most rain barrels can be through the top of the barrel with a simple piece of filter material to filter the runoff, such as a screen or wire mesh. Water that is collected can be used to supplement municipal water for non-potable uses, primarily irrigation.

Figure 68. Residential rain barrel.

9.3 Operation and Maintenance

Cisterns require regular maintenance during the rainy season to ensure proper function. Typical maintenance consists of the following:

1. The main source of debris in the cistern is leaf litter and other detritus collected in the gutter system. The gutter systems should be inspected and cleaned. Any leaks discovered should be immediately repaired.

2. Check inlet filters to prevent clogging and debris accumulation to allow for proper flow into the cisterns. Clean as needed to ensure proper operation.

3. Outlet pipes and fittings should be inspected to verify proper flows from the cistern. Cisterns should empty within 24 to 48 hours.

4. Overflow systems should direct water away from any structural foundations.
5. Cisterns should be checked for structural stability and secured as necessary.
6. It is possible for some sediment and debris to accumulate in the bottom of the cistern. Access to the cistern should be maintained, and it is necessary to conduct a visual inspection to verify debris in the cistern.

Task	Frequency	Maintenance notes
Inlet inspection	Annually before the rainy season	Clean gutters of debris that have accumulated, check for leaks
Remove accumulated debris	Monthly (during the rainy season)	Clean debris screen to allow unobstructed storm water flow into the cistern
Structure inspection	Biannually (before and after the rainy season)	Check cistern for stability, anchor system if necessary
Structure inspection	Annually	Check pipe and valve connection for leaks
Miscellaneous upkeep	Annually	Make sure cistern manhole is accessible, operational, and secure
Miscellaneous upkeep	Before any major wind-related storms	Add water to half full (if the tank is less than half full)

10 Common Design Elements

Many BMPs have similar elements or standards. Those common elements and associated design standards are outlined in this section.

10.1 Curb Cuts

When BMPs are incorporated into highly impervious areas, such as parking lots and in road rights-of-way, curb cuts can be required to allow surface runoff to enter the BMP. Curb cuts are designed such that the design storm can pass through the curbing without causing water to pond in the travel lanes with the following recommendations:

- The opening should be at least 18 inches wide at the base to prevent clogging and to provide dispersed flow.
- The curb cut can have vertical sides or have chamfered sides at 45 degrees (as shown in Figure 69 through Figure 72).
- Slope the bottom of the concrete curb cut toward the storm water facility.
- Provide a minimum 2-inch drop in grade between the curb cut entry point and the finish grade of the storm water facility.
- The curb cut must pass the design storm flow without causing backup that would disrupt normal travel in the lane.
- The curb cut opening should be armored to prevent erosion. Concrete, stone, or sod can be used to armor the flow path to the base of the bioretention area.

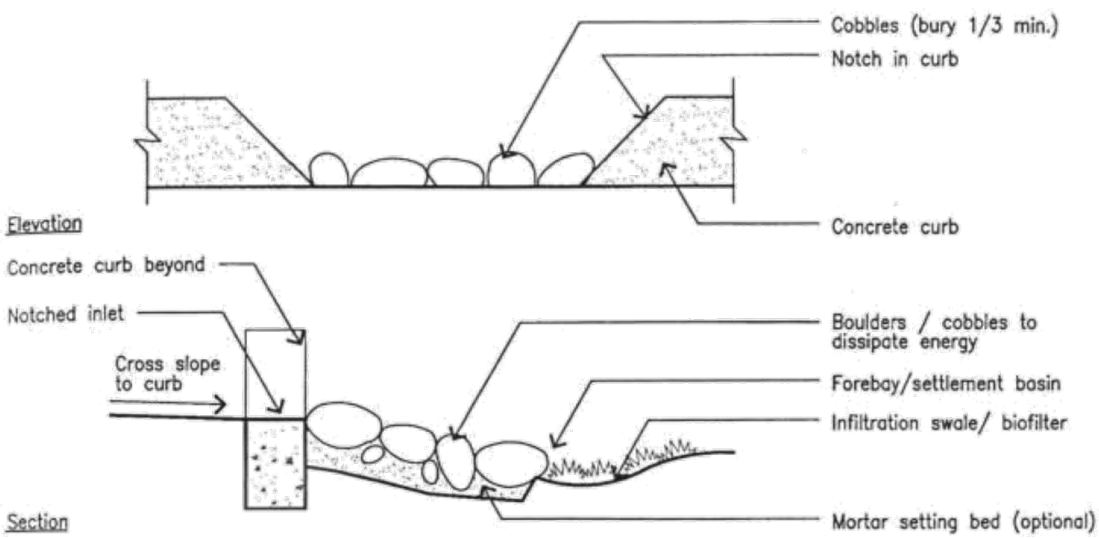


Figure 69. Typical curb cut diagram.

Figure 70. A typical curb cut.

In high traffic areas, multiple, smaller curb cuts are preferred over fewer, large curb cuts. Figure 71 through Figure 73 show examples of potential curb cut configurations. Figure 71 shows a covered curb cut that would be appropriate in areas experiencing high pedestrian traffic. Inlets can be covered or protected for pedestrians or other traffic using a covered curb cut. Covered curb cuts, such as the one shown in Figure 74, are preferred over other curb inlet methods including the use of pipes or linear cuts in the curbing for ease of maintenance. Covering the inlet with a removable grate allows for easy visual inspection of the inlet and can reduce the effort required for maintenance. Such curb cuts can also be modified with a small sump or lip to capture coarse sediments and trash. Some pretreatment flow reduction can be provided using multiple, smaller curb cuts, as shown in Figure 72, to minimize the flow at each opening. Armoring the curb opening from the back of the curb to the base elevation of the bioretention as indicated in Figure 73 will reduce inlet velocities, preventing scour and erosion in the BMP.

Figure 71. Pedestrian-friendly planter curb cut.

Figure 72. Curb cuts for a parking lot bioretention area.

Figure 73. Armored curb cuts.

Figure 74. Covered curb cut with a sump.

10.1.1 Inlet Pipe Stabilization

In some cases, the inlet can be a pipe with concentrated flow. Flow dissipation is difficult yet critical in such situations. Several options can be used for dissipating flow from a pipe. The flow can be discharged into a shallow forebay. Energy dissipation can be implemented at the outlet of the pipe, such as by using sod or stones, to slow the flow as shown in Figure 75. Another option would be to install an elbow at the end of the pipe, with stable materials around the elbow, to slow the flow and allow the water to cascade into the bioretention area. A small weep hole should be used to prevent water from permanently ponding in the elbow. An example of a constructed energy dissipater is shown in Figure 76, and an upturned elbow used for energy dissipation is shown in Figure 77.

Figure 75. Stone flow dissipater.

Figure 76. Constructed energy dissipater.

Figure 77. Energy dissipater.

10.2 Determine if an Underdrain Pipe is Necessary

Soil testing should be performed at the site by a licensed soil scientist or geological engineer to determine the infiltration rate of the soils and the depth to the seasonally high groundwater table. If the infiltration rate of the soils where the bioretention area will be installed is less than 0.5 in/hr, underdrains will be required.

10.2.1 Sizing the Underdrain Pipes

If underdrains are required, they must meet the following criteria:

1. They must be 4 inches in diameter minimum.
2. Underdrains should be made of slotted, PVC pipe conforming to ASTM D 3034 or equivalent or corrugated, HDPE pipe conforming to AASHTO 252M or equivalent. As compared to round-hole perforated pipe, slotted underdrains provide greater intake capacity, clog resistant drainage, and reduced entrance velocity into the pipe, thereby reducing the chances of solids migration.
3. The type of perforated pipe is not critical to the function of the BMP as long as the total opening area exceeds the expected flow capacity of the underdrain and does not limit infiltration through the soil media. The perforations can be placed closest to the invert of the pipe to achieve maximum potential for draining the facility. If an anaerobic zone is intended, the perforation can be placed at the top of the pipe.
4. Underdrains should be sloped at a minimum of 0.5 percent.
5. Rigid, unperforated observation pipes with a diameter equal to the underdrain diameter should be connected to the underdrain every 250 to 300 feet to provide a cleanout port and an observation well to monitor dewatering rates. The wells/cleanouts are to be connected to the perforated underdrain with the appropriate manufactured connections. The wells/cleanouts must extend 6 inches above the mulch or sod layer and be capped with a lockable screw cap to avoid damage from maintenance and vandalism. The ends of upgradient, lateral underdrain pipes not terminating in an observation well/cleanout must also be capped.
6. A barrier to separate the soil media from the drainage layer should be installed. Two options can be used for providing the separation from the soil media and the drainage layer. Option 1 is the most widely accepted method; however, some concern exists over the potential for the geotextile to clog. Option 2 might be the preferred method, but some sediment could leave the system through the underdrains. In situations where there is concern of clogging around the geotextile, option 2 is recommended.
   - Option 1: The drainage stone should be a washed no. 57 stone, or similar alternative that has been washed to remove all fines. The drainage stone should be used to provide a gravel blanket and bedding for the underdrain pipe. Place the underdrain on a 3-foot-wide bed of the drainage stone 6 inches deep and cover with the same drainage stone to provide a 16-inch minimum depth around the bottom, sides, and top of the slotted pipe.

A geotextile fabric should be placed between the soil media and the drainage layer as shown in Figure 78. If a geotextile fabric is used, it must meet the following minimum materials requirements.

Geotextile property	Value	Test method
Trapezoidal tear (lbs)	40 (min)	ASTM D4533
Permeability (cm/sec)	0.2 (min)	ASTM D4491
AOS (sieve size)	#60–#70 (min)	ASTM D4751
Ultraviolet resistance	70% or greater	ASTM D4355

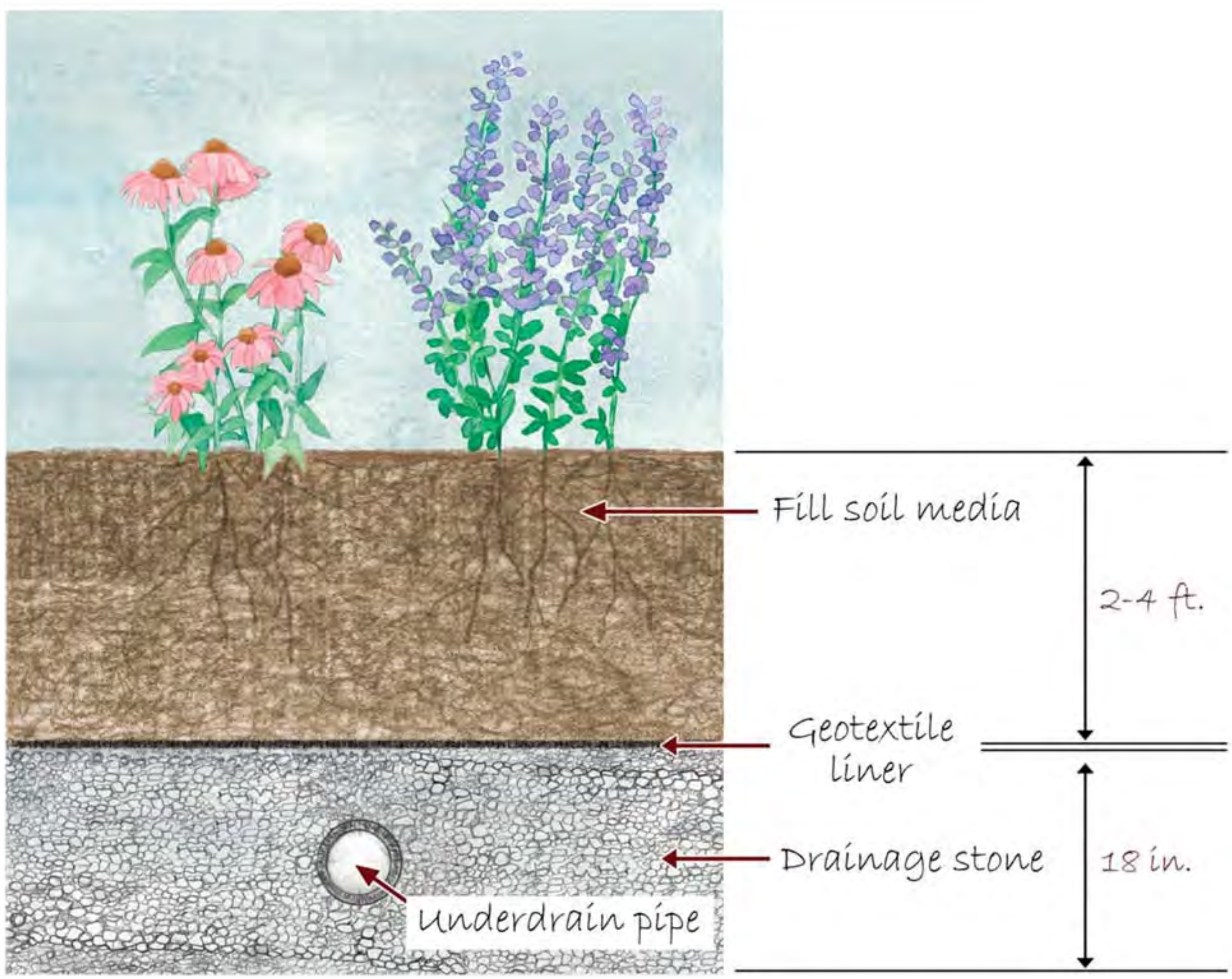


Figure 78. Underdrain barrier option 1: geotextile layer.

- Option 2: Place a thin, 2- to 4-inch layer of pure sand and a thin layer (nominally 2 inches) of choking stone (such as no. 8) between the soil media and the drainage stone as shown in Figure 79.

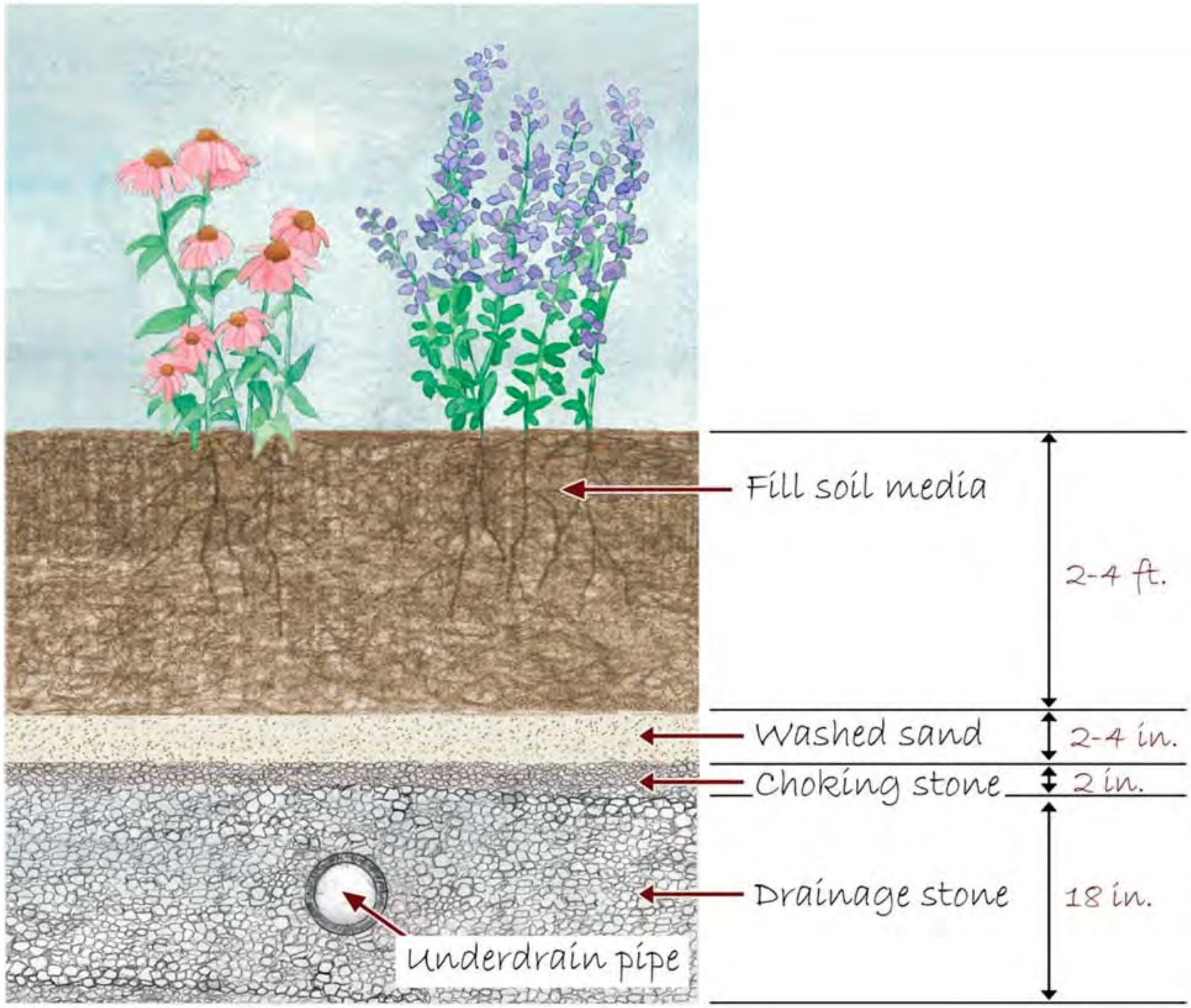


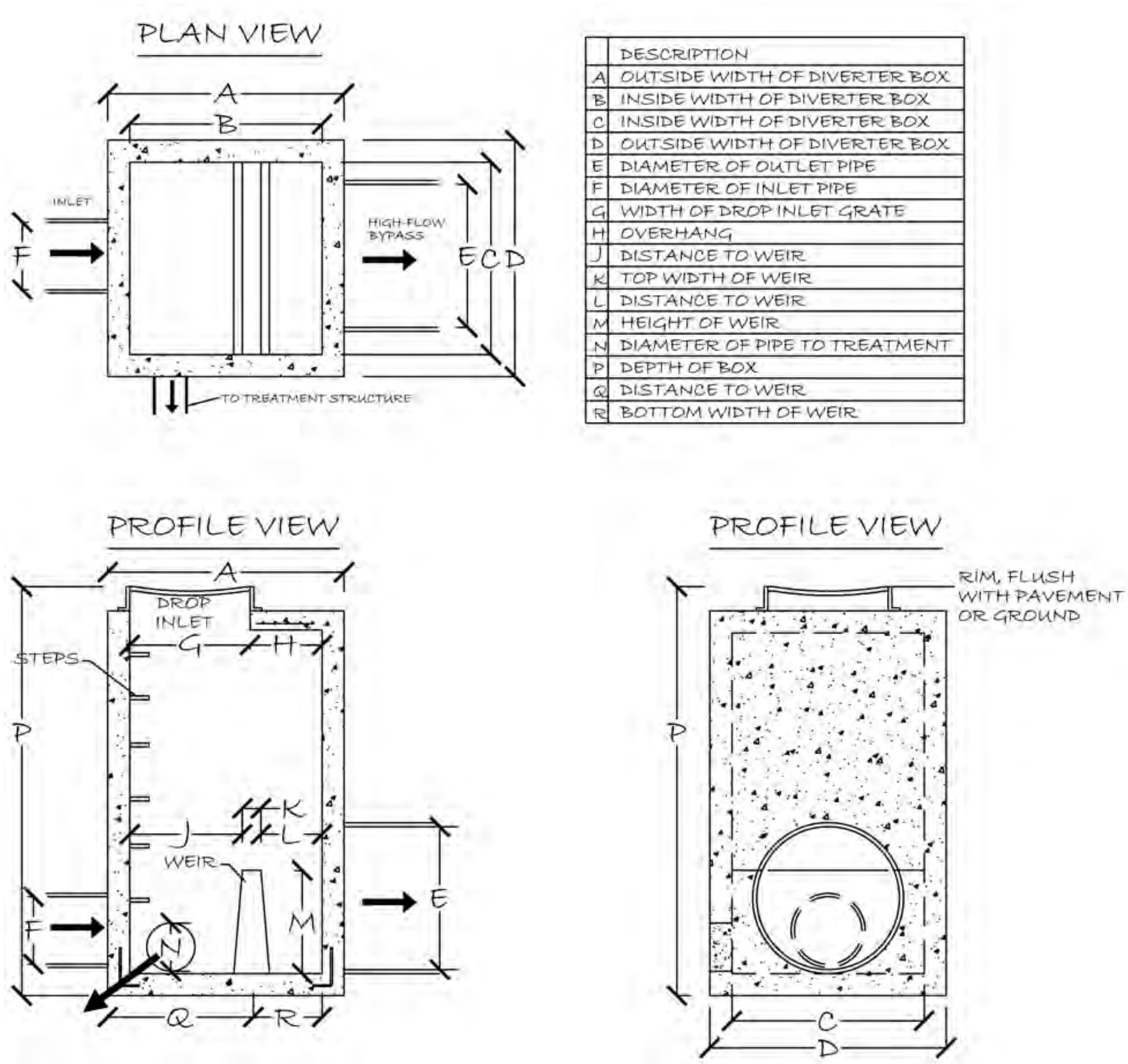
Figure 79. Underdrain barrier option 2: choking layer.

7. The underdrain should be elevated from the bottom of the bioretention facility by 4 to 6 inches within the gravel blanket to create a fluctuating anaerobic/aerobic zone below the drain pipe. Denitrification within the anaerobic/anoxic zone is facilitated by microbes using forms of nitrogen (NO_2 and NO_3) instead of oxygen for respiration.

8. The underdrain must drain freely to an acceptable discharge point. The underdrain can be connected to a vegetated swale, to another bioretention cell as part of a connected treatment system, daylight to a vegetated dispersion area using an effective flow dispersion device, stored for reuse, or to a storm water drainage system.

10.3 Diversion Structures

If a BMP is designed to be an offline system, a structure will be required to divert the design volume into the BMP. Figure 80 shows an example of a typical bypass structure. When the capacity of the BMP is exceeded or the flow exceeds the capacity of the diversion pipe, the flow passes over the weir and enters or continues into the storm water drainage system and does not enter the BMP. The bypass pipe should be sized to limit the flow into the BMPs to non-erosive flows. When flows through a BMP could exceed the recommended maximum flow rates, regardless of whether a system is designed to be online or offline, a bypass structure is recommended to prevent erosion in the BMP. The flow velocity in a mulched system should not exceed 1 ft/sec. Flow in a grassed system should not exceed 3 ft/sec. Flows can be greater (up to 14 ft/sec) with the use of reinforced turf matting and will depend on the matting selected. A bypass structure should be used to ensure that flows through the system do not exceed the recommended design flow.



	DESCRIPTION
A	OUTSIDE WIDTH OF DIVERTER BOX
B	INSIDE WIDTH OF DIVERTER BOX
C	INSIDE WIDTH OF DIVERTER BOX
D	OUTSIDE WIDTH OF DIVERTER BOX
E	DIAMETER OF OUTLET PIPE
F	DIAMETER OF INLET PIPE
G	WIDTH OF DROP INLET GRATE
H	OVERHANG
J	DISTANCE TO WEIR
K	TOP WIDTH OF WEIR
L	DISTANCE TO WEIR
M	HEIGHT OF WEIR
N	DIAMETER OF PIPE TO TREATMENT
P	DEPTH OF BOX
Q	DISTANCE TO WEIR
R	BOTTOM WIDTH OF WEIR

Figure 80. Typical diversion structure.

Is situations where storm water is collected in a pipe and routed to a BMP, a bypass structure should be designed at the inlet of the BMP to divert flows that exceed the volume or flow capacity of the BMP.

10.4 Hydraulic Restriction Layers

Infiltration pathways might need to be restricted because of the close proximity of roads, foundations, other infrastructure, or hotspot locations. In some conditions, lateral seepage could cause damage to surrounding structures depending on the type of soils in the area. Areas that have a potential for settling in saturated conditions should be protected from lateral flows. Types of clay that have a high potential for expansion when saturated should be protected from moisture in load-bearing conditions. Four types of restricting layers can be incorporated into BMP designs:

1. Filter fabric can be placed along vertical walls to reduce lateral flows.
2. Clay (bentonite) liners can be used. If a clay liner is used to prevent infiltration into in situ soils, an underdrain system is also required.
3. Liners can be used to prevent lateral flow and should have a minimum thickness of 0.03 inch (30 mils).
4. Concrete barriers can be used in the furnishing zone and along roadways to prevent lateral seepage to adjacent utilities or areas of concern. Concrete could withstand impacts from maintenance performed in the right-of-way but could significantly increase the overall cost of the project.

The most ideal configuration, from a storm water pollutant-removal perspective, is to infiltrate as much runoff as possible. In situations where conditions require limiting infiltration, two basic options can be used for hydraulic restriction layers.

Option 1: The preferred option is to restrict lateral flow while allowing for deep percolation infiltration of storm water. To allow infiltration, the bottom of the bioretention area should remain unlined. The hydraulic restriction layer should extend the full depth of the media to the base of the drainage layer in situations where underdrains are required. In situations where underdrains are not required, the hydraulic restriction layer should extend to a depth where saturation will not affect any adjacent load-bearing soils. An example is shown in Figure 81.

Option 2: In situations where infiltration is not possible, because of limiting soil capacity or existing conditions, the entire perimeter of the soil media can be lined to prevent infiltration into the existing soils while gaining some pollutant removal from the soil media. For more details on such a design configuration, see section 5 of this appendix for details on Planter Boxes. An example is shown in Figure 82.

A full geotechnical investigation should be performed by a licensed soil scientist or geotechnical engineer, and a report should be prepared in accordance with the City's *Guidelines for Geotechnical Reports*. That should be done for all sites to determine the effect of infiltration, including the appropriate depth of the hydraulic restriction layer.

For BMPs constructed in the right-of-way or where maintaining a utility is a concern, concrete barriers might be the most appropriate. Concrete barriers can be constructed as extensions of the surrounding curb installed vertically to the depth where saturation will not affect the stability of the load-bearing soils. Concrete barriers will prevent damage that can occur from maintenance required for utilities in the right-of-way. For details of the hydraulic restricting layers, see the BMP Design Templates in Appendix C.

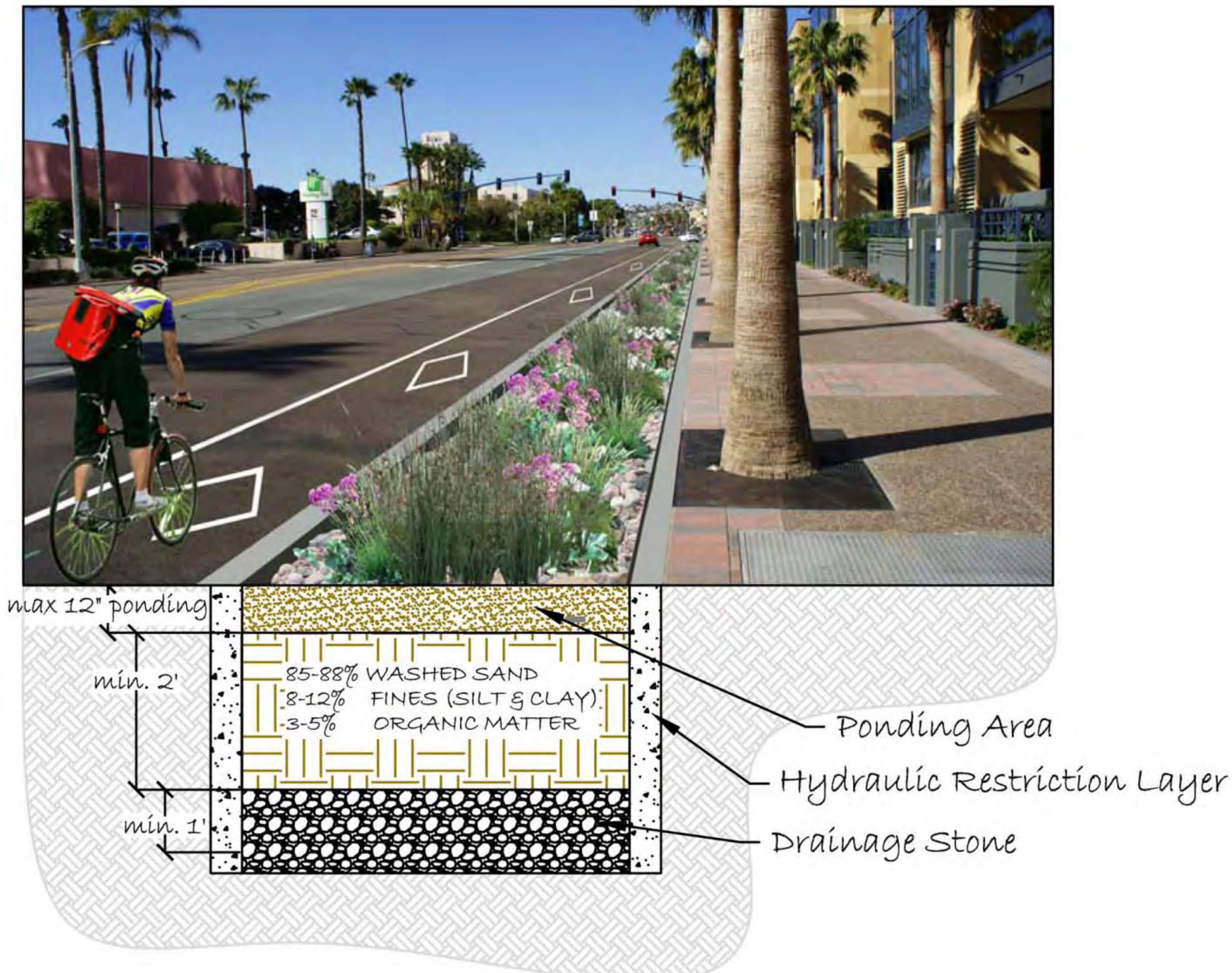


Figure 81. Vertical hydraulic restriction layer.

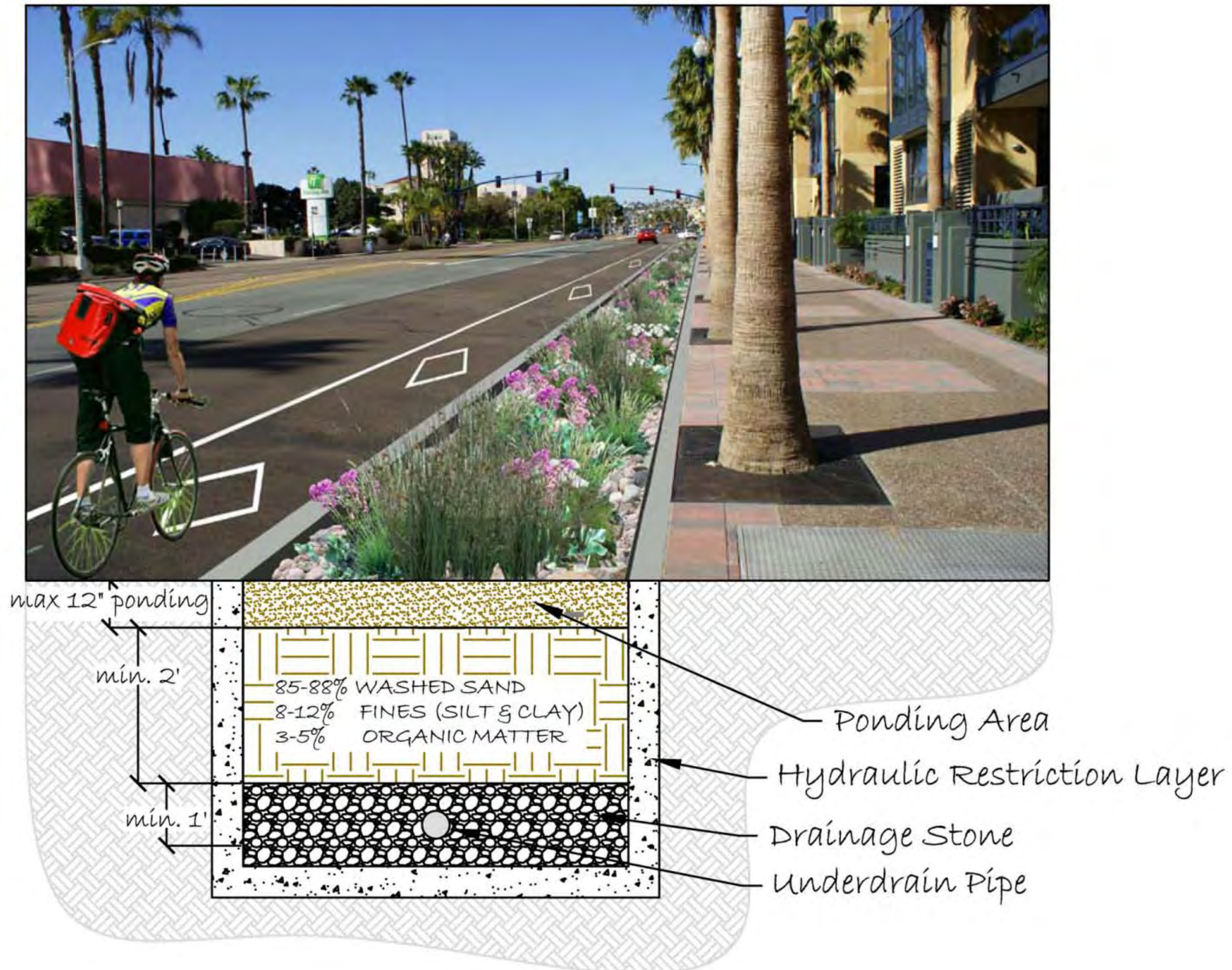


Figure 82. Completely lined bioretention area (planter box).

10.5 Utilities

When implementing bioretention areas, avoid utilities where possible. In many cases, the BMP can be shifted in the landscape to prevent implementation over utilities. In cases where utilities cannot be avoided, take care to prevent effects from infiltration or saturation by using hydraulic restricting layers to direct infiltration away from the utility. The utility should pass through the hydraulic restriction layer, and the liner should be appropriately sealed to prevent any lateral seepage from the BMP. Liners can be easily sealed by using a patch that adheres to the utility line and can be sealed directly to the liner. Figure 83 shows a BMP installed over a common utility.

The location of future utilities should also be considered in the site layout and location of BMPs. Long, linear BMPs, such as a bioretention area or bioswale in the right-of-way, should have periodic breaks to allow for future utility trenches. At least one access point should be placed along any BMP for each parcel where there is a separation or break in the liner for a utility trench. BMPs in such a scenario should be designed as separate systems with separate hydraulic restriction layers, but they could be connected in the subsurface through the underdrain or at the surface by a trench with a grate similar to a covered curb cut. For more details, see Section 10.6 of this appendix.

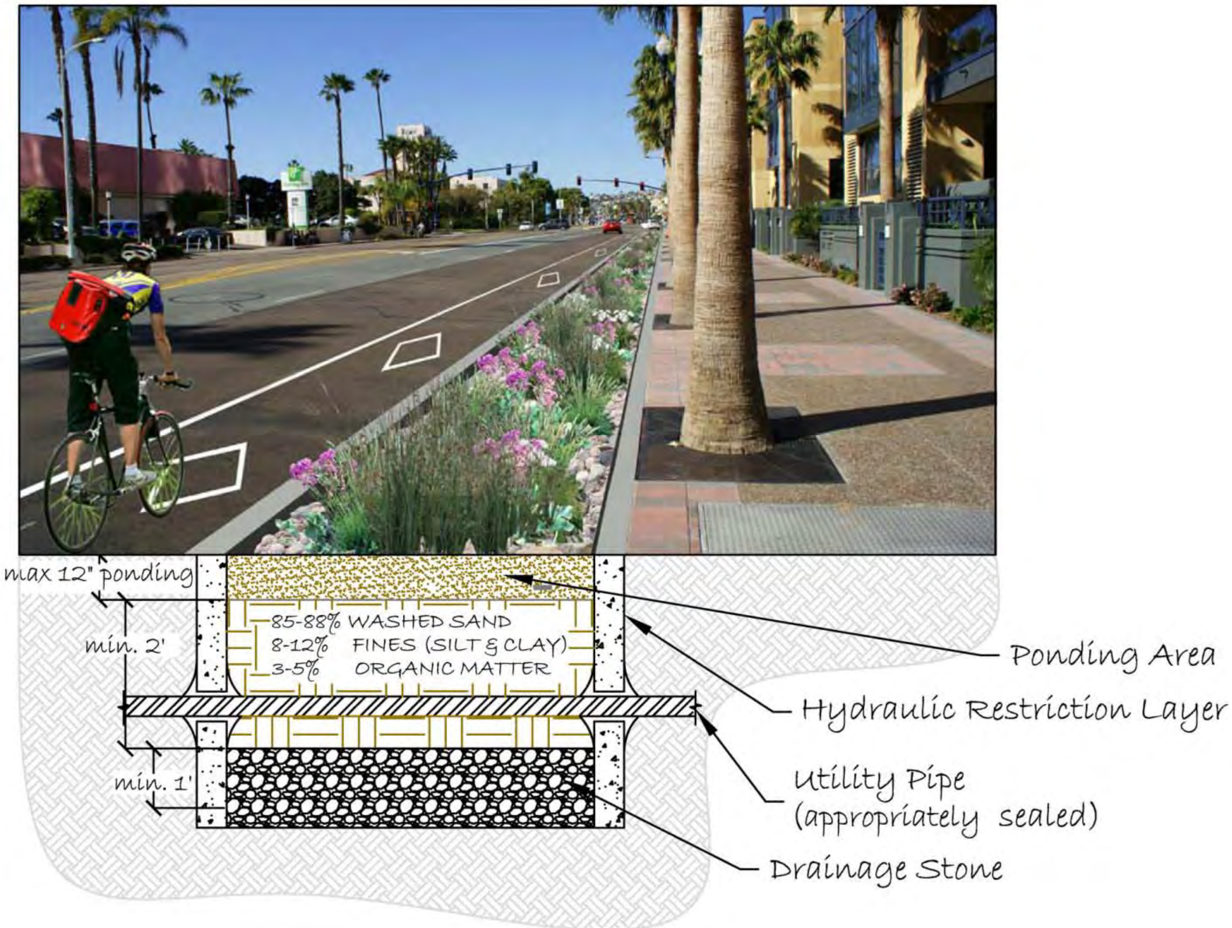


Figure 83. Utility through a hydraulic restriction layer.

10.6 Connectivity

When BMPs are implemented in the right-of-way, it is important to maintain access to property adjacent to the right-of-way to prevent disturbance to the BMP, harm to the public, and provide connections for future utilities. It is also important that sections of the BMP remain hydraulically connected to fully use as much of the BMP as possible. BMPs should be connected by open channels covered with an appropriate grate to allow visual inspection of the channel and ease of maintenance. Figure 84 shows a BMP with access to the right-of-way while maintaining appropriate hydraulic connectivity.

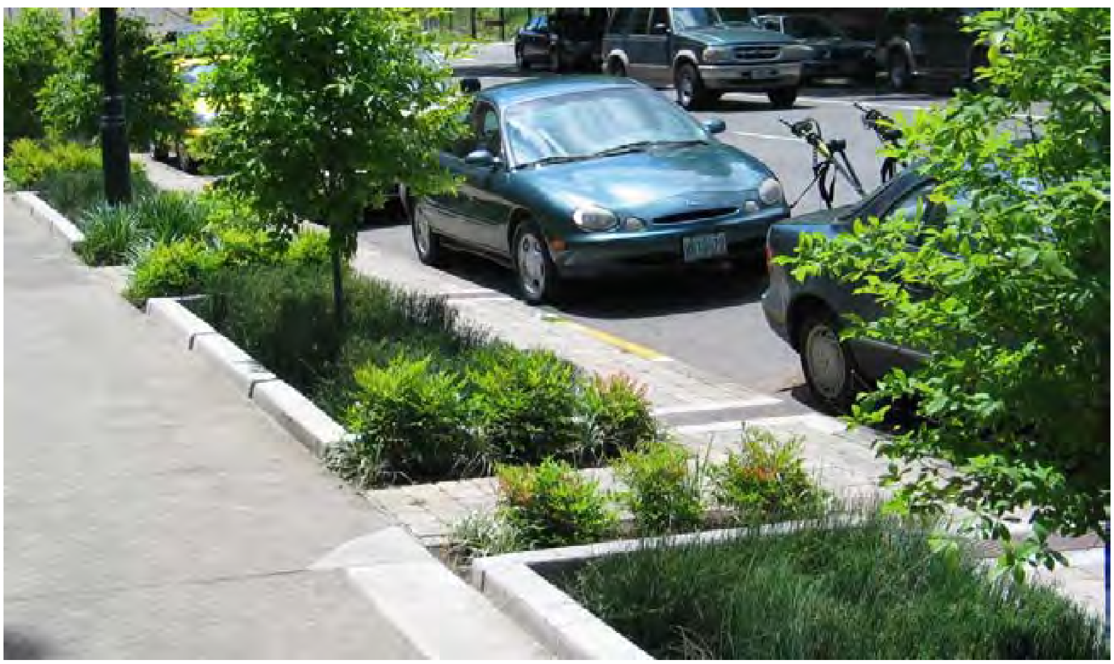
Figure 84. Access over linear BMPs

10.7 ADA Requirements

LID BMPs typically require surfaces with little to no slope, therefore, Americans with Disabilities Act (ADA) requirements are rarely an issue. However, in areas with high pedestrian traffic, some effort should be made to delineate the BMP. Several options—including low-level and decorative fencing, such as the one shown in Figure 85, or a low-profile curb, as shown in Figure 86, can often be used to delineate the space around the BMP and alert pedestrians of the change in grade.

Source: Portland BES

Figure 85. Low-level fencing.



Source: Portland BES

Figure 86. Low-profile curbing.

11 Costs Estimates

Planning-level cost estimates were developed for each BMP type on the basis of labor cost estimates provided by the City and estimates from local vendors. Estimates for each cost component were developed on the basis of the design standards provided in the previous sections. Costs are based on local information and recommendations compiled from local vendors and actual costs from current and previous projects for each individual type of BMP. The range in cost estimates reflects the recommended ranges in the design specifications for the specific components. For example, a range in media depth of 2 to 3 feet results in a cost range of $2.90 to $4.30 per square foot. The following tables summarize component cost estimates for each BMP type.

Common cost consideration in LID planning and design

Common cost elements	
Planning	10% of total project costs
Design	40% of total project costs
Mobilization	10% of total project costs
Contingency	20% of total project costs
Site Preparation	
Clearing and grubbing	$0.72/ft^2
Asphalt removal	$3.35/ft^2
Concrete removal	$3.35/ft^2
Sidewalk removal	$2.00/ft^2

The project manager must refine these numbers throughout the phases of design to prepare a more accurate project construction estimate for bidding purposes. The inclusion of various sizes of projects in the maintenance costs attempts to include those costs in which an economy of scale has been observed. The sizes selected for this analysis were:

- Large LID BMP systems = 4000 ft^2,
- Medium LID BMP system = 2000 ft^2, and
- Small LID BMP system = 500 ft^2.

These categories are based on typically sized LID BMPs. As the LID BMP area represent systems, the area can include the application of multiple LID BMPs. Detailed information on costs based on the frequency and type of maintenance required, such as routine maintenance (costs associated with maintenance required monthly up to every 2 years), intermediate maintenance (costs associated with maintenance required every 6 to 10 years) and replacement maintenance (costs associated with replacement of the system; estimated as a service life of 20 years) are presented below. This will assist in providing full lifecycle cost analyses for these LID BMPs.

Detailed cost estimates of LID installation by practice type

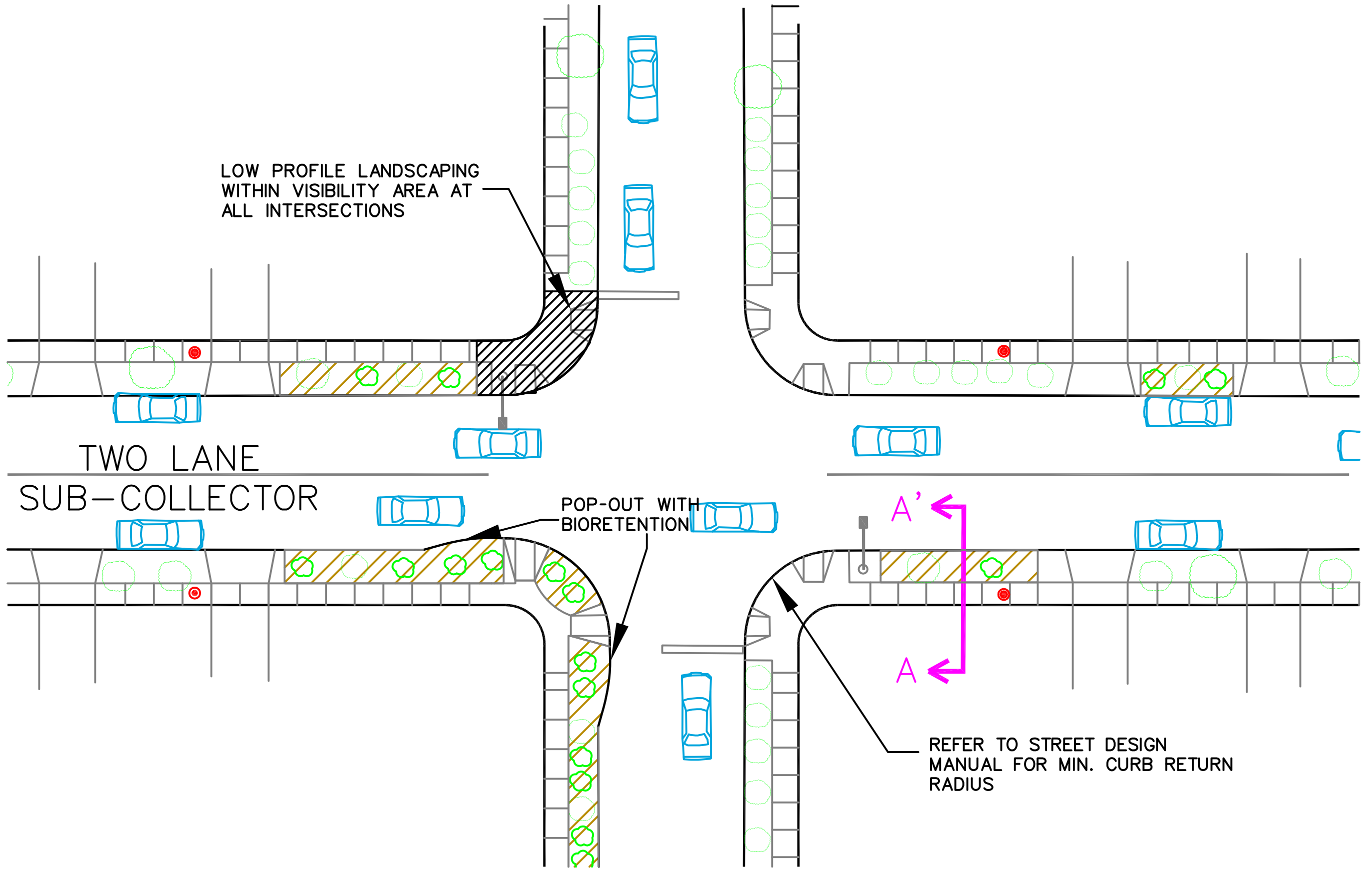
Installation and maintenance activities	LID practice type								
	Bioretention	Bioswale	Permeable pavement	Infiltration trench	Planter boxes	Sand filter	Vegetated filter strip	Vegetated swale	Cisterns/ rain barrels
				Installation					
Excavation			$\$1.35/\text{ft}^2$ to $\$2.65/\text{ft}^2$		$\$5.90/\text{ft}^2$ to $\$7.20/\text{ft}^2$			$\$1.32/\text{ft}^3$	
Without underdrains	$\$4.00/\text{ft}^2$ to $\$5.25/\text{ft}^2$	$\$4.00/\text{ft}^2$ to $\$5.25/\text{ft}^2$		$\$4.00/\text{ft}^2$ to $\$5.25/\text{ft}^2$					
With underdrains	$\$5.90/\text{ft}^2$ to $\$7.20/\text{ft}^2$	$\$5.90/\text{ft}^2$ to $\$7.20/\text{ft}^2$		$\$5.90/\text{ft}^2$ to $\$7.20/\text{ft}^2$		$\$4.60/\text{ft}^2$ to $\$6.00/\text{ft}^2$			
2 feet (minimum) to 3 feet						$\$2.65/\text{ft}^2$ to $\$4.00/\text{ft}^2$			
Fine Grading								$\$0.34/\text{ft}^2$	
Soil Media						$\$2.25/\text{ft}^2$ to $\$3.70/\text{ft}^2$			
Recommended mix	$\$2.90/\text{ft}^2$ to $\$4.30/\text{ft}^2$	$\$2.90/\text{ft}^2$ to $\$4.30/\text{ft}^2$		$\$2.90/\text{ft}^2$ to $\$4.30/\text{ft}^2$	$\$2.90/\text{ft}^2$ to $\$4.30/\text{ft}^2$				
With engineered media	$\$3.60/\text{ft}^2$ to $\$5.40/\text{ft}^2$	$\$3.60/\text{ft}^2$ to $\$5.40/\text{ft}^2$		$\$3.60/\text{ft}^2$ to $\$5.40/\text{ft}^2$	$\$3.60/\text{ft}^2$ to $\$5.40/\text{ft}^2$				
Soil Media Barrier									
Geotextile	$\$0.50/\text{ft}^2$	$\$0.50/\text{ft}^2$		$\$0.50/\text{ft}^2$	$\$0.50/\text{ft}^2$	$\$0.50/\text{ft}^2$			
Washed sand (2-inch layer)	$\$0.25/\text{ft}^2$	$\$0.25/\text{ft}^2$		$\$0.25/\text{ft}^2$	$\$0.25/\text{ft}^2$	$\$0.25/\text{ft}^2$			
No. 8 aggregate (min 2 inches thick)	$\$0.30/\text{ft}^2$	$\$0.30/\text{ft}^2$		$\$0.30/\text{ft}^2$	$\$0.30/\text{ft}^2$	$\$0.30/\text{ft}^2$			
Underdrain Pipe (includes drainage stone, assumes 5-foot spacing)	$\$3.75/\text{ft}^2$	$\$3.75/\text{ft}^2$		$\$3.75/\text{ft}^2$	$\$3.75/\text{ft}^2$	$\$3.75/\text{ft}^2$			
Curb and Gutter	$22/ft	$22/ft		$22/ft	$22/ft				
Mulch (ranges from mixed hardwood to gorilla hair)	$\$0.25/\text{ft}^2$ to $\$0.5/\text{ft}^2$	$\$0.25/\text{ft}^2$ to $\$0.5/\text{ft}^2$			$\$0.25/\text{ft}^2$ to $\$0.5/\text{ft}^2$				
Hydraulic Restriction Layer									
Filter fabric	$\$0.50/\text{ft}^2$	$\$0.50/\text{ft}^2$		$\$0.50/\text{ft}^2$					
Clay	$\$0.65/\text{ft}^2$	$\$0.65/\text{ft}^{2v}$		$\$0.65/\text{ft}^{2v}$					
30-mil liner	$\$0.40/\text{ft}^2$	$\$0.40/\text{ft}^2$		$\$0.40/\text{ft}^2$	$\$0.40/\text{ft}^2$	$\$0.40/\text{ft}^2$			
Concrete barrier	$\$16.00/\text{ft}^2$	$\$16.00/\text{ft}^2$		$\$16.00/\text{ft}^2$	$\$16.00/\text{ft}^2$	$\$16.00/\text{ft}^2$			
Vegetation	$\$0.40/\text{ft}^2$ to $\$4.00/\text{ft}^2$	$\$0.40/\text{ft}^2$ to $\$4.00/\text{ft}^2$			$\$0.40/\text{ft}^2$ to $\$4.00/\text{ft}^2$				
Sod							$\$0.42/\text{ft}^2$	$\$0.42/\text{ft}^2$	
Seeding							$\$0.33/\text{ft}^2$	$\$0.33/\text{ft}^2$	
Permeable Pavement Materials									
Pervious asphalt			$\$2.00/\text{ft}^2$						
Pervious concrete			$\$6.00/\text{ft}^2$						

Installation and maintenance activities	LID practice type								
	Bioretention	Bioswale	Permeable pavement	Infiltration trench	Planter boxes	Sand filter	Vegetated filter strip	Vegetated swale	Cisterns/ rain barrels
PICP			$\$4.00/ft^2$						
Plastic grid pavers			$2.80 ea						
Bedding Layer									
Washed sand (2-inch layer)			$\$0.25/ft^2$						
No. 8 aggregate (min 2 inches thick)			$\$0.30/ft^2$						
No. 57 stone (min 6 inches to 1 foot)			$\$1.00/ft^2$ to $\$2.00/ft^2$						
Tanks/Cisterns									$0.75/gallon
Filter									$35.00 to $360.00
Foundation									
Gravel (assume 6-inch depth)									$\$1.00/ft^2$
Concrete (assume 6-inch depth)									$\$16.00/ft^2$

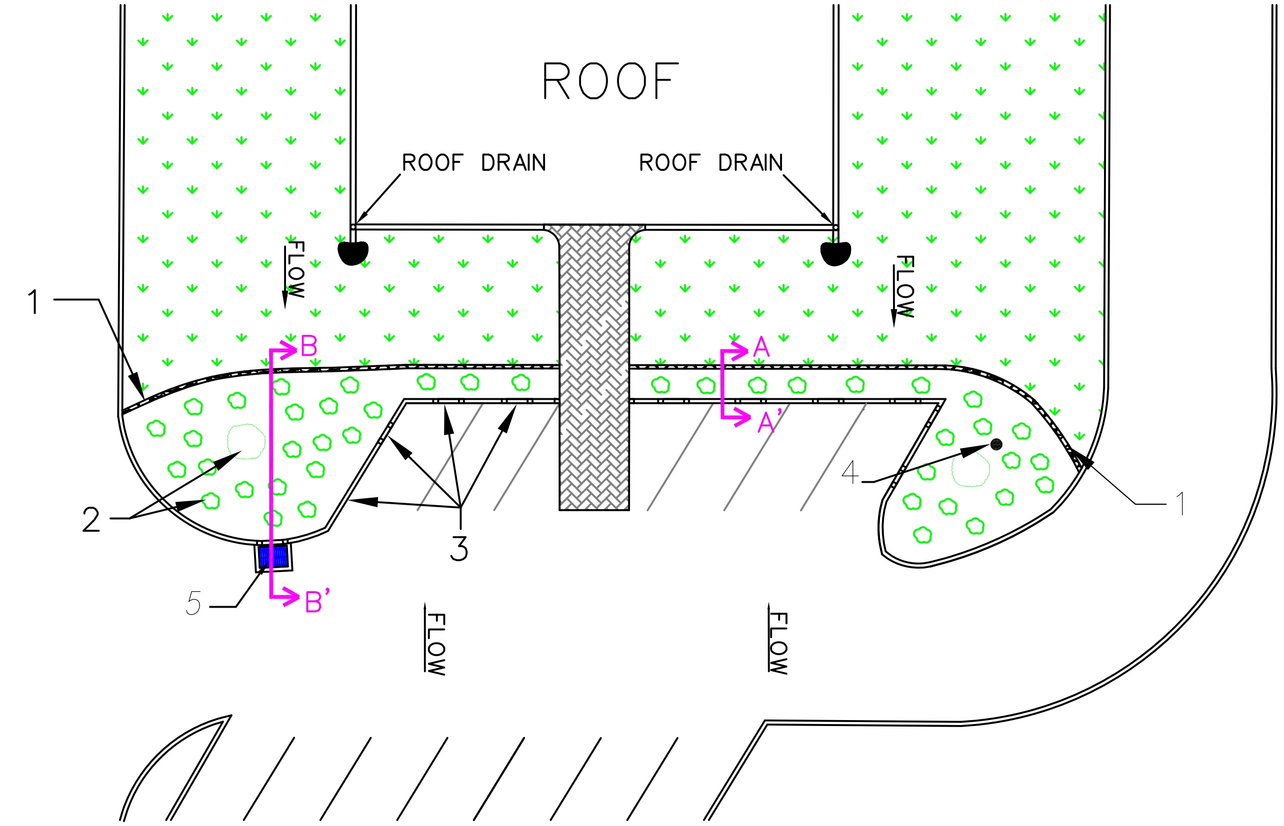
Maintenance	LID practice type								
	Bioretention	Bioswale	Permeable Pavement	Infiltration trench	Planter boxes	Sand filter	Vegetated filter strip	Vegetated swale	Cisterns/rain barrels
Maintenance									
Routine Maintenance (maintenance required monthly to every 2 years)									
Routine (small)	$\$6.07/ft^2$	$\$6.07/ft^2$	$\$1.80/ft^2$	$\$2.63/ft^2$	$\$6.07/ft^2$	$\$2.63/ft^2$	$\$5.26/ft^2$	$\$5.26/ft^2$	
Routine (medium)	$\$2.28/ft^2$	$\$2.28/ft^2$	$\$0.57/ft^2$	$\$0.88/ft^2$	$\$2.28/ft^2$	$\$0.88/ft^2$	$\$1.97/ft^2$	$\$1.97/ft^2$	
Routine (large)	$\$1.66/ft^2$	$\$1.66/ft^2$	$\$0.28/ft^2$	$\$0.44/ft^2$	$\$1.66/ft^2$	-	$\$1.43/ft^2$	$\$1.43/ft^2$	
Intermediate Maintenance (maintenance required every 6 to 10 years)									
Intermediate (small)	$\$7.36/ft^2$	$\$7.36/ft^2$	$\$1.00/ft^2$	$\$3.37/ft^2$	$\$7.36/ft^2$	$\$3.37/ft^2$			
Intermediate (medium)	$\$3.58/ft^2$	$\$3.58/ft^2$	$\$1.00/ft^2$	$\$1.62/ft^2$	$\$3.58/ft^2$	$\$1.62/ft^2$			
Intermediate (large)	$\$2.95/ft^2$	$\$2.95/ft^2$	$\$1.00/ft^2$	$\$1.18/ft^2$	$\$2.95/ft^2$	-			
Replacement (Service Life of 20 years)									
Replacement (small)	$\$11.08/ft^2$	$\$11.08/ft^2$	$\$10.36/ft^2$	$\$8.19/ft^2$	$\$11.08/ft^2$	$\$8.19/ft^2$	$\$4.48/ft^2$	$\$4.48/ft^2$	
Replacement (medium)	$\$10.59/ft^2$	$\$10.59/ft^2$	$\$10.36/ft^2$	$\$6.43/ft^2$	$\$10.59/ft^2$	$\$6.43/ft^2$	$\$1.68/ft^2$	$\$1.68/ft^2$	
Replacement (large)	$\$10.51/ft^2$	$\$10.51/ft^2$	$\$10.36/ft^2$	$\$5.99/ft^2$	$\$10.51/ft^2$	-	$\$1.21/ft^2$	$\$1.21/ft^2$	

Small System = 500 ft^2; Medium System = 2000 ft^2; Large System = 4000 ft^2

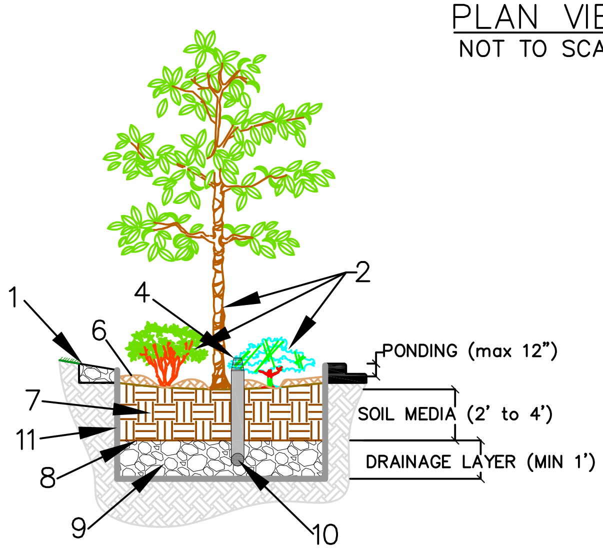
Appendix C. BMP Design Templates



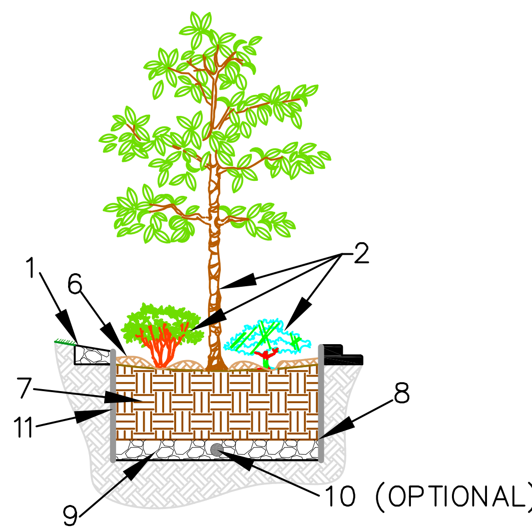
PLAN VIEW
NOT TO SCALE



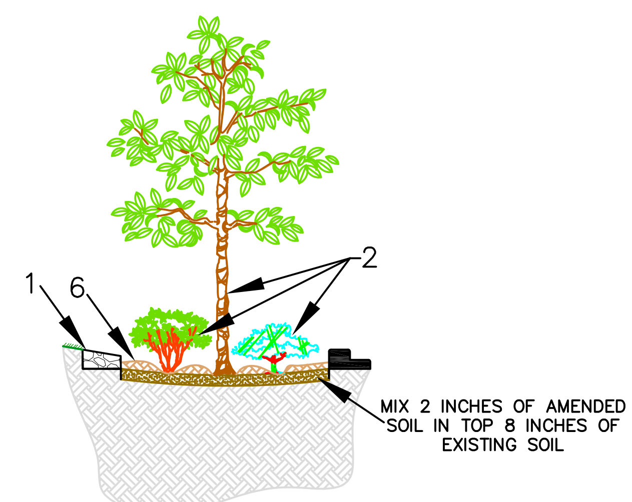
PLAN VIEW
NOT TO SCALE



SECTION A-A' (OPTION 1)
NOT TO SCALE

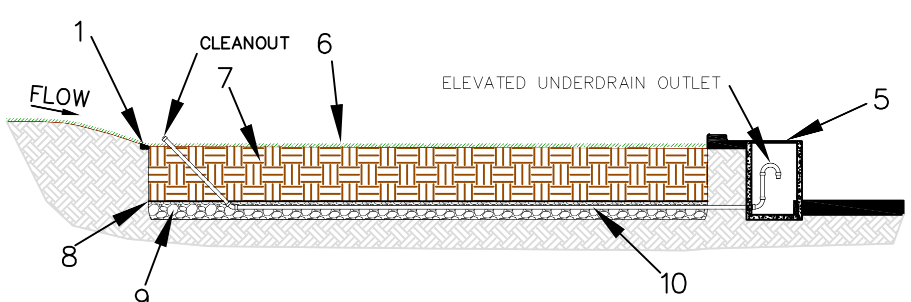


SECTION A-A' (OPTION 2)
NOT TO SCALE



SECTION A-A' (OPTION 3)
NOT TO SCALE

NOTE: OPTION 3 SHOULD ONLY BE USED
WHEN UNDERDRAINS ARE NOT REQUIRED



SECTION B-B'
NOT TO SCALE

NOTES:

1. MIN. 6 INCH GRAVEL VERGE FOR PRE-TREATMENT
2. SELECT APPROPRIATE VEGETATION (SEE APPX D)
3. CURB CUTS SHOULD BE ARMORED (SEE APPX B)
4. OPTIONAL OVERFLOW RISER CONNECTED TO THE UNDERDRAIN (CAN BE USED AS CLEANOUT)
5. CATCH BASIN FOR OVERFLOW
6. GROUND COVER: 3 INCHES OF FINELY SHREDDED HARDWOOD MULCH OR APPROPRIATE SOD
7. SOIL MEDIA
8. BARRIER BETWEEN SOIL MEDIA AND DRAINAGE LAYER. OPTION 1: GEOTEXTILE. OPTION 2: CHOKING LAYERS (SEE APPX B)
9. DRAINAGE LAYER
10. UNDERDRAIN
11. HYDRAULIC RESTRICTION LAYER

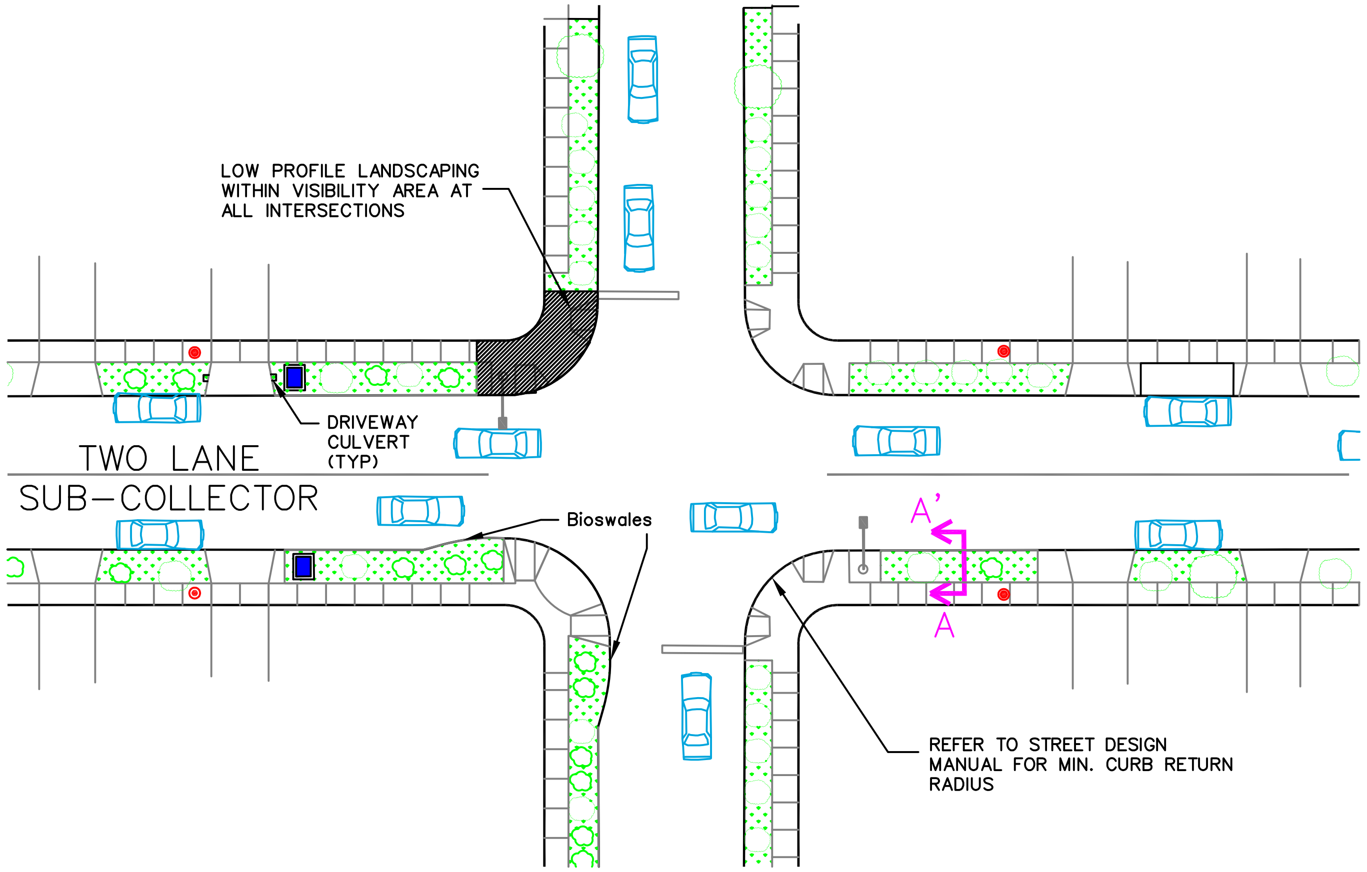
PLANS AND DETAILS

BIORETENTION AREA

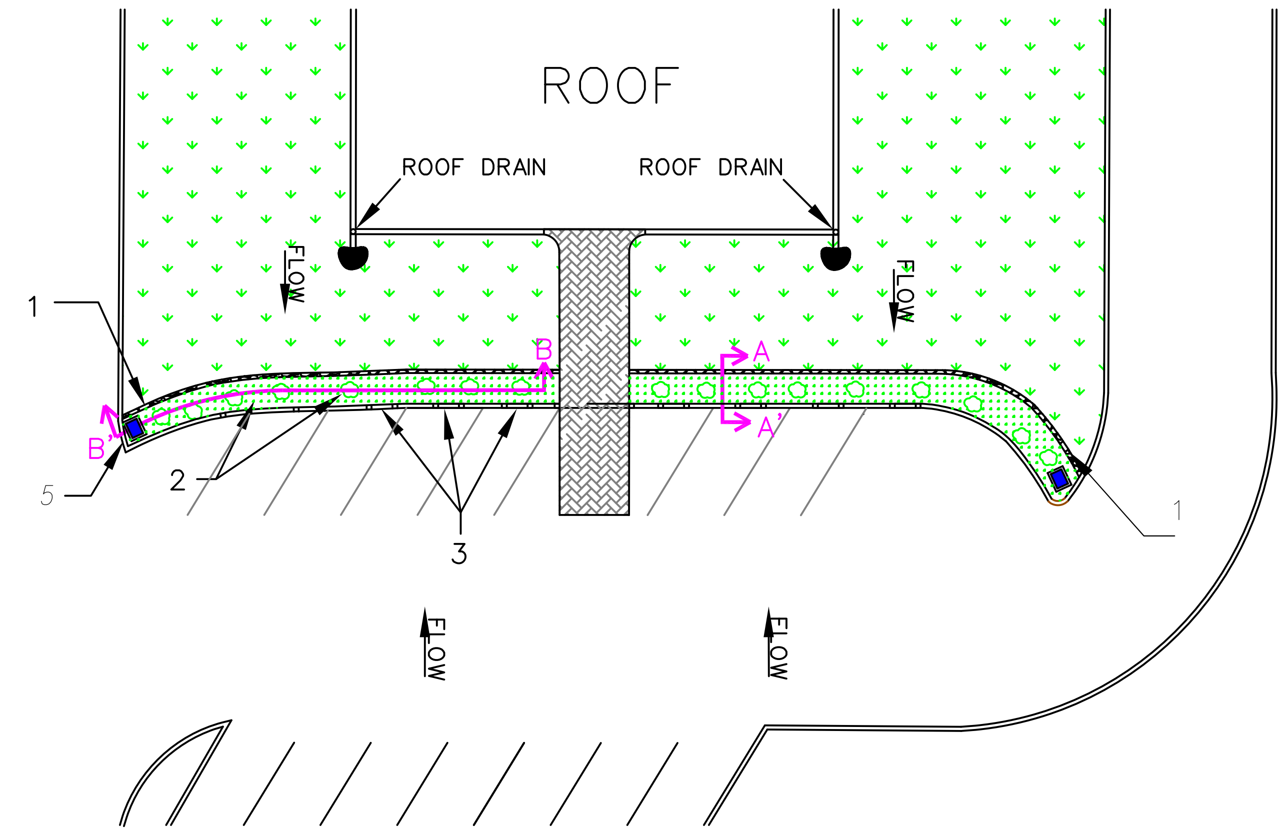
PREPARED BY:
TETRA TECH, INC

JOB NO.: T24453
DESIGNED BY:
DRAWN BY:
PROJECT MGR.:
CHECKED BY:
CHECKED BY:
APPROVED BY:
APPROVED BY:
DATE: 06-08-10
DRAWING NO. 1
SHEET OF
SET SHEET OF

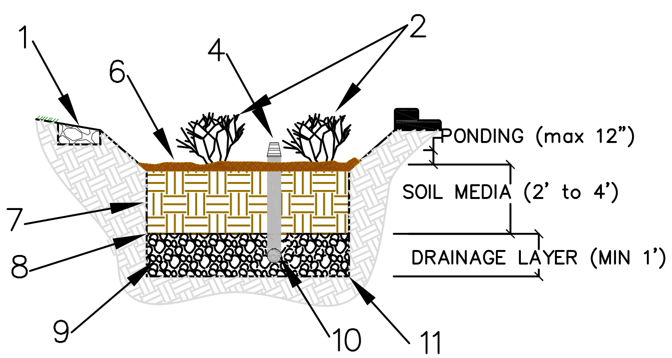
CADD NO.: BIORETENTIONCUTSHEET.DWG



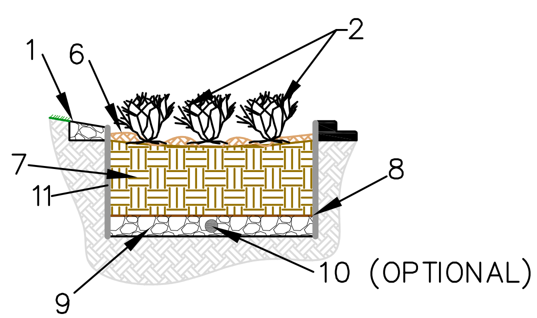
PLAN VIEW
NOT TO SCALE



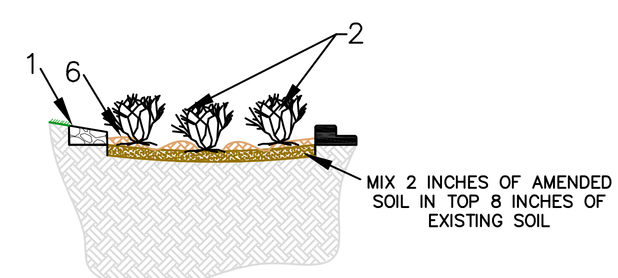
PLAN VIEW
NOT TO SCALE



SECTION A-A' (OPTION 1)
NOT TO SCALE

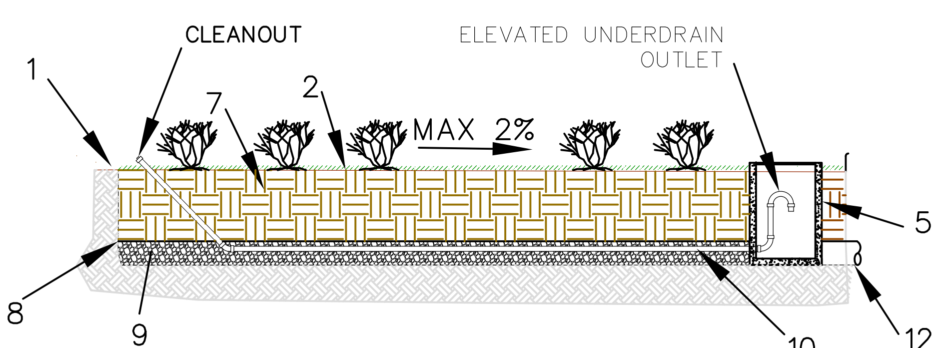


SECTION A-A' (OPTION 2)
NOT TO SCALE



SECTION A-A' (OPTION 3)
NOT TO SCALE

NOTE: OPTION 3 SHOULD ONLY BE USED WHEN UNDERDRAINS ARE NOT REQUIRED



SECTION B-B'
NOT TO SCALE

NOTES:

1. MIN. 6 INCH GRAVEL VERGE FOR PRE-TREATMENT
2. SELECT APPROPRIATE VEGETATION – GRASS OPTIONAL (SEE APPX D)
3. CURB CUTS SHOULD BE ARMORED (SEE APPX B)
4. OPTIONAL OVERFLOW RISER CONNECTED TO THE UNDERDRAIN (CAN BE USED AS CLEANOUT)
5. CATCH BASIN FOR OVERFLOW
6. GROUND COVER: 3 INCHES OF FINELY SHREDDED HARDWOOD MULCH OR APPROPRIATE SOD
7. SOIL MEDIA
8. BARRIER BETWEEN SOIL MEDIA AND DRAINAGE LAYER. OPTION 1: GEOTEXTILE. OPTION 2: CHOKING LAYERS (SEE APPX B)
9. DRAINAGE LAYER
10. UNDERDRAIN
11. HYDRAULIC RESTRICTION LAYER
12. OUTLET PIPE TO STORM DRAIN SYSTEM

PLANS AND DETAILS

BIOSWALE

PREPARED BY:

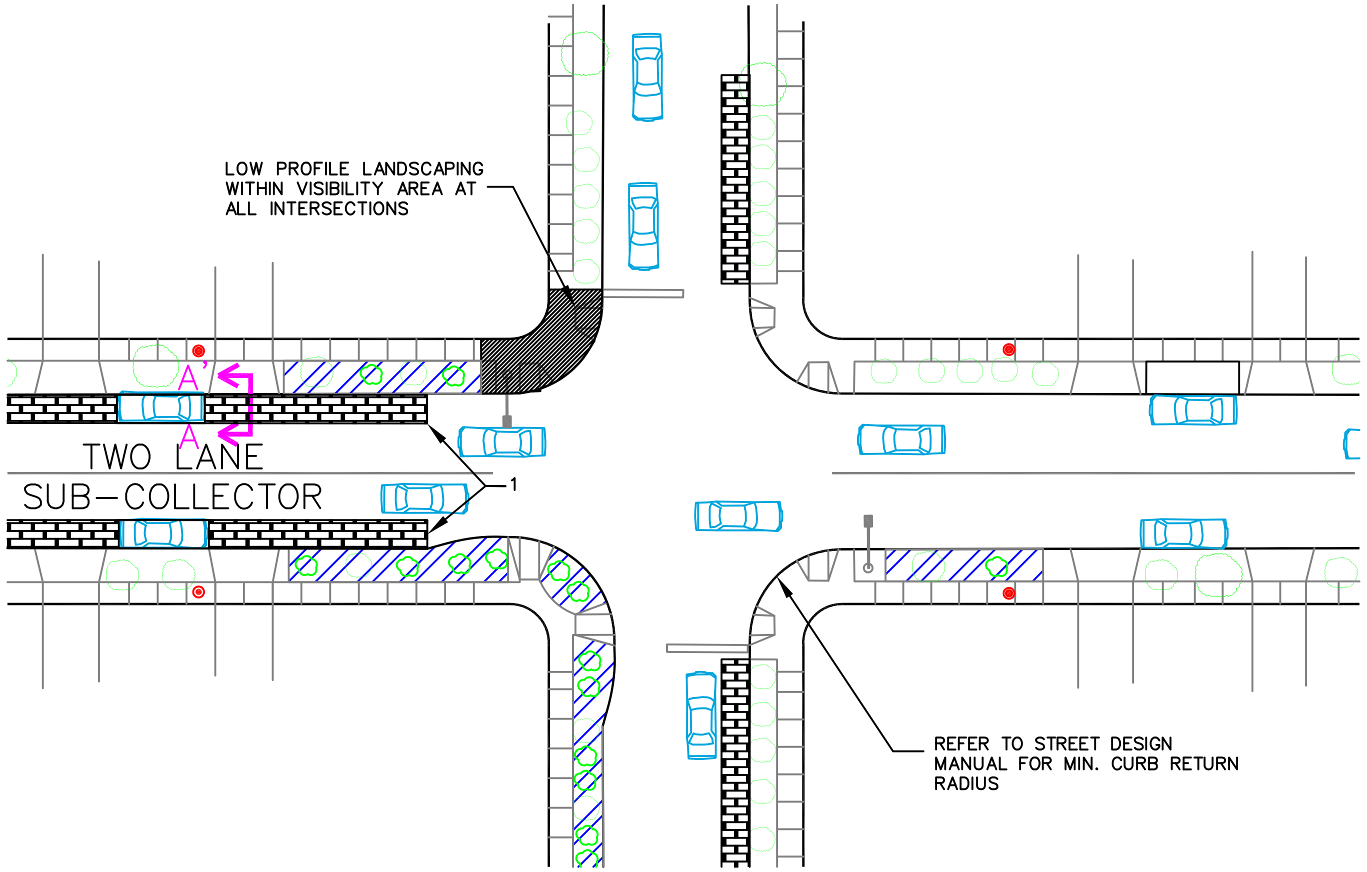
TETRA TECH, INC

T24453

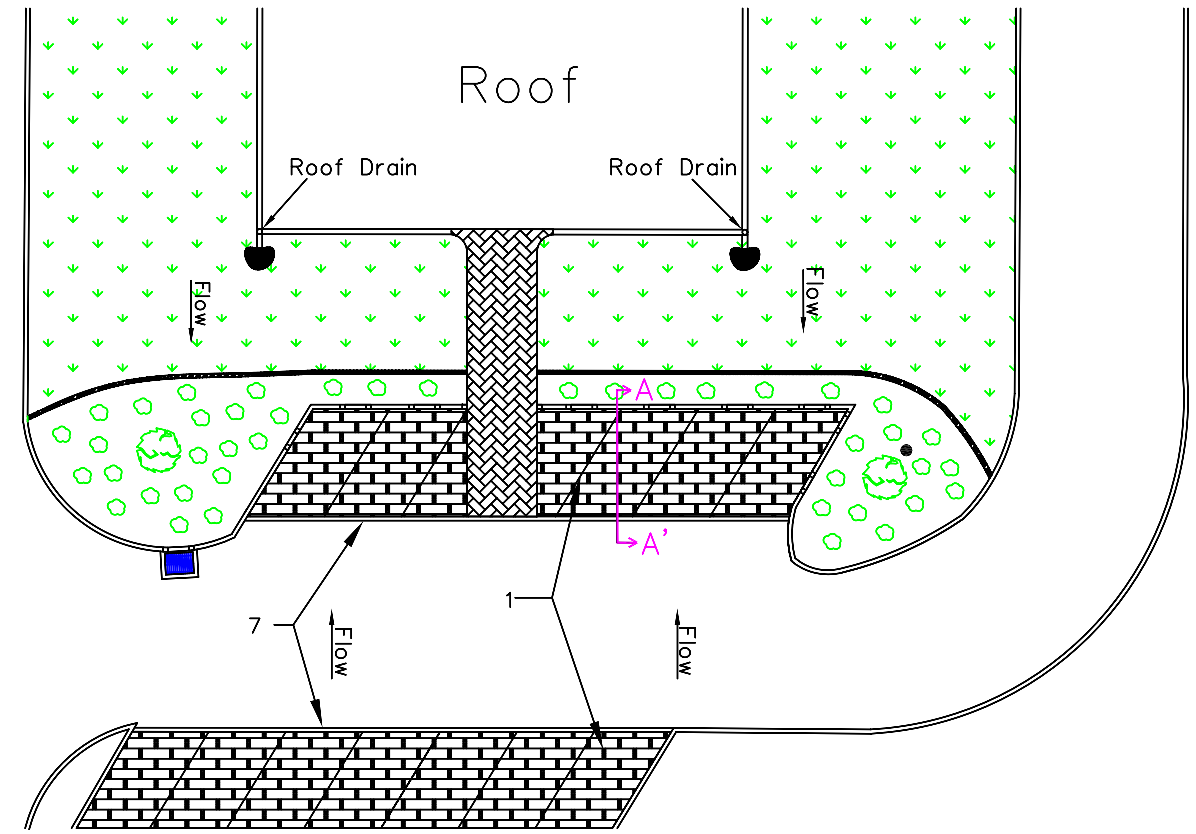
06-08-10

1

CADD NO.: BIOSWALECUTSHEET.DWG



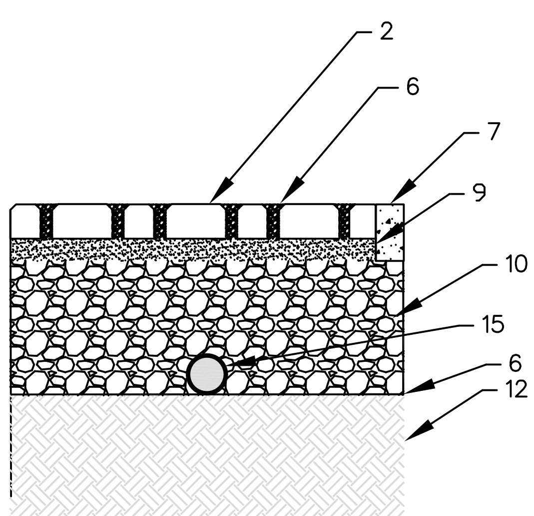
PLAN VIEW
NOT TO SCALE



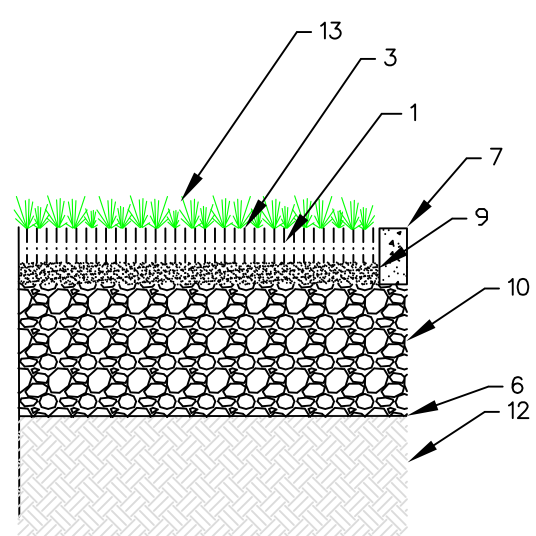
PLAN VIEW
NOT TO SCALE

NOTES:

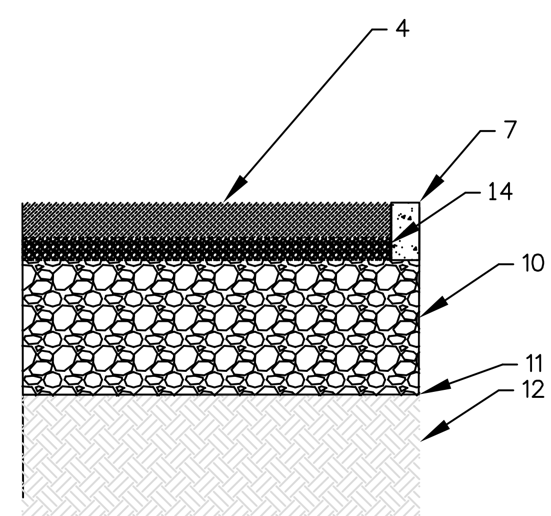
1. PERMEABLE PAVEMENT
2. PERMEABLE INTERLOCKING CONCRETE PAVERS (PICP)
3. PLASTIC GRID SYSTEM
4. POROUS ASPHALT
5. PERVIOUS CONCRETE
6. FILLER MEDIA (SAND or GRAVEL)
7. CONCRETE TRANSITION STRIP
8. PERMEABLE PAVEMENT DRAINAGE LAYER
9. BEDDING LAYER (1" to 2" of SAND or GRAVEL, SEE APP B)
10. STRUCTURAL LAYER (6" MIN)
11. GEOTEXTILE (AS REQUIRED)
12. UNDISTURBED SOIL
13. PLANT WITH NATIVE GRASS SUITABLE FOR SITE CONDITIONS OR FILL WITH GRAVEL
14. CHOKER COURSE (SEE APP B)
15. UNDERDRAIN (IF REQUIRED)



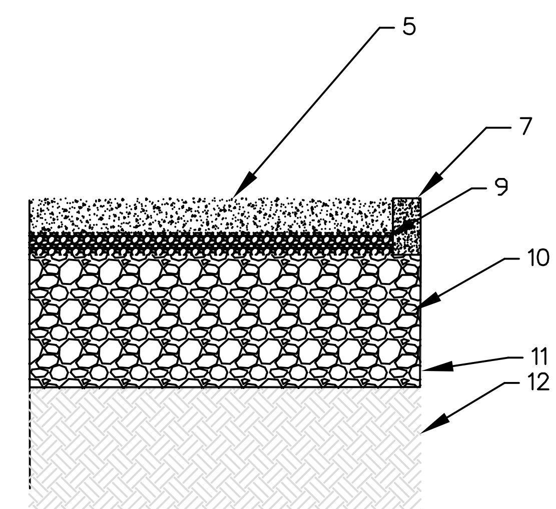
SECTION A–A' Permeable Interlocking Concrete Pavers
NOT TO SCALE



SECTION A–A' Plastic Grid System
NOT TO SCALE



SECTION A–A' Porous Asphalt
NOT TO SCALE



SECTION A–A' Pervious Concrete
NOT TO SCALE

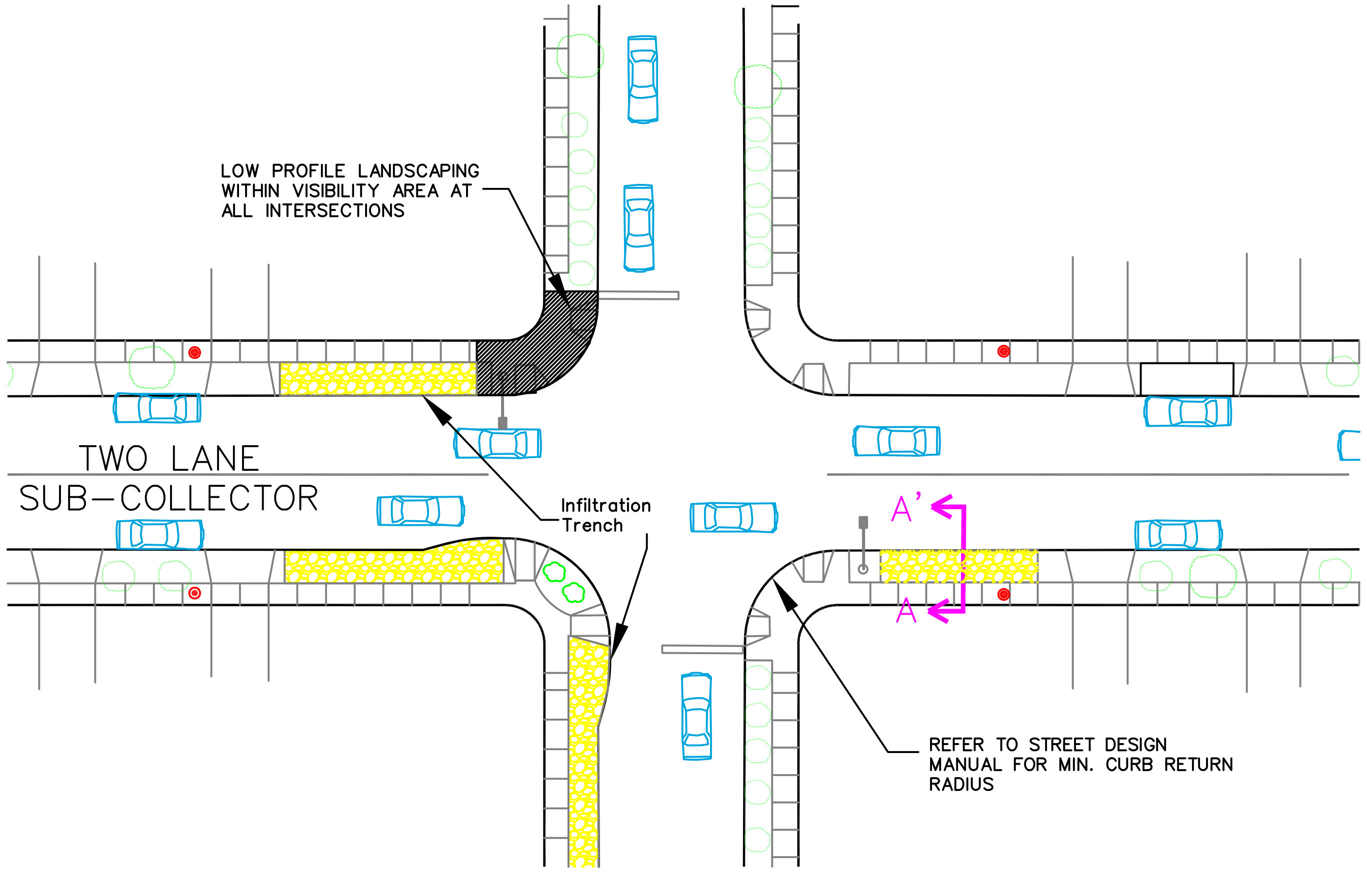
PLANS AND DETAILS

PERMEABLE PAVEMENT

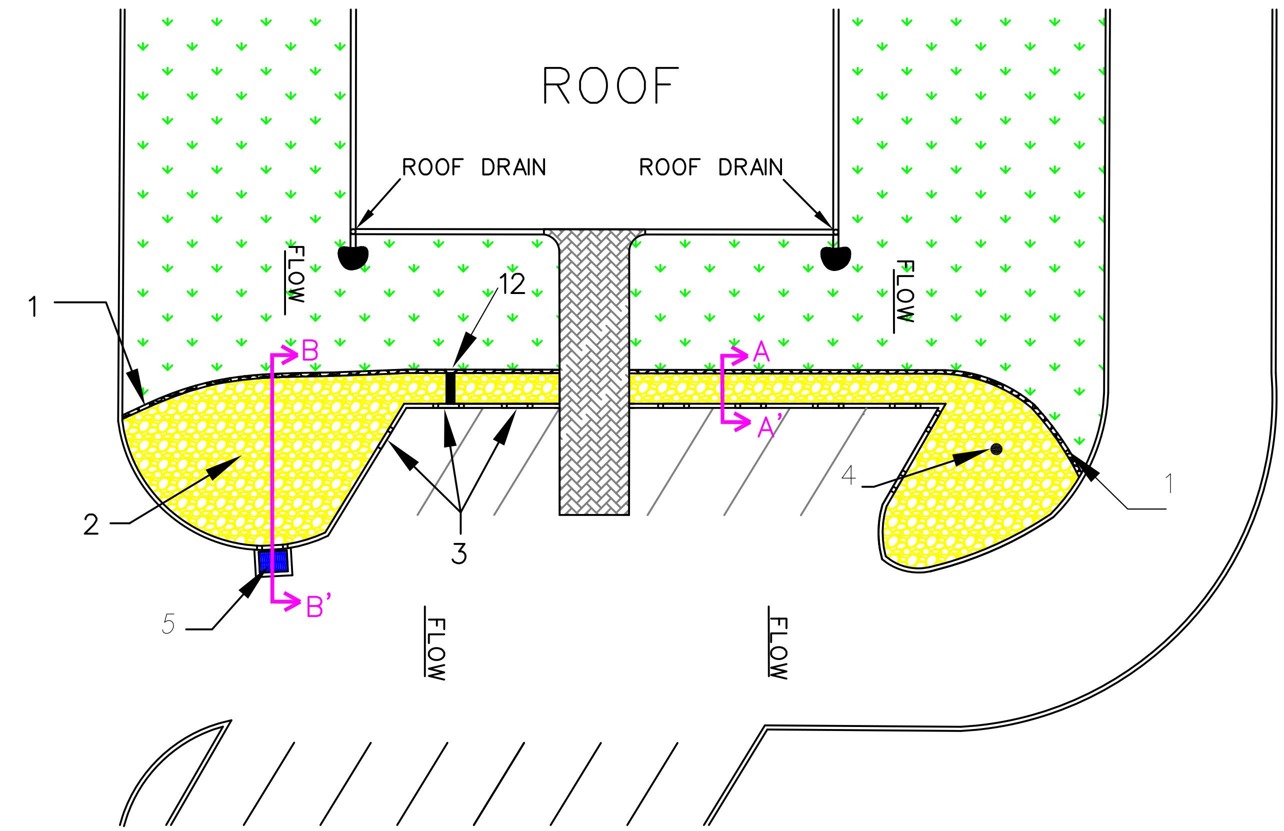
PREPARED BY:
TETRA TECH, INC

T24453
06-08-10
1

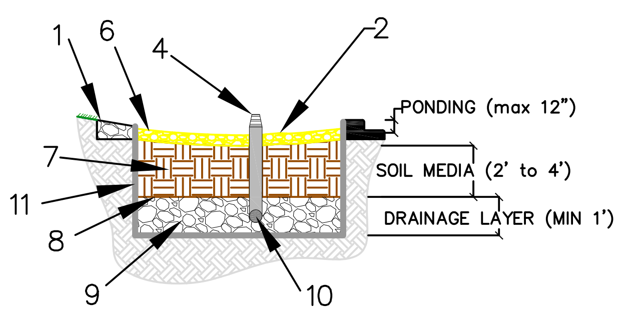
CADD NO.: PERMEABLEPAVEMENTCUTSHEET.DWG



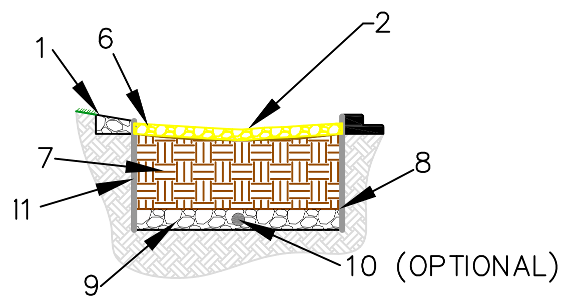
PLAN VIEW
NOT TO SCALE



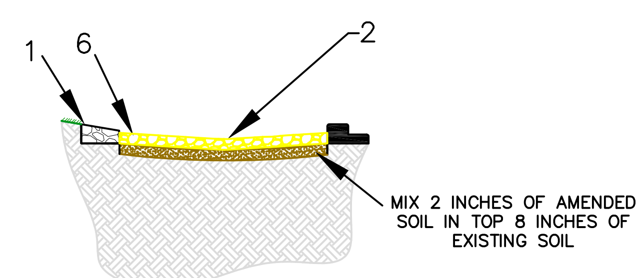
PLAN VIEW
NOT TO SCALE



SECTION A–A' (OPTION 1)
NOT TO SCALE



SECTION A–A' (OPTION 2)
NOT TO SCALE

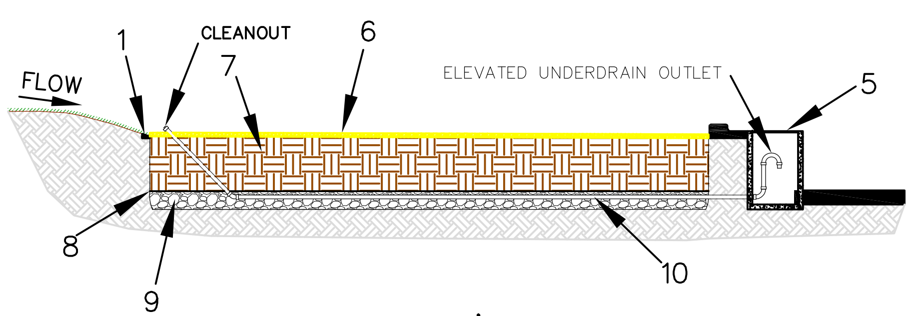


SECTION A–A' (OPTION 3)
NOT TO SCALE

NOTE: OPTION 3 SHOULD ONLY BE USED WHEN UNDERDRAINS ARE NOT REQUIRED

NOTES:

1. MIN. 6 INCH GRAVEL VERGE FOR PRE–TREATMENT
2. GRAVEL OR DECORATIVE STONE
3. CURB CUTS SHOULD BE ARMORED (SEE APPX B)
4. OPTIONAL OVERFLOW RISER CONNECTED TO THE UNDERDRAIN (CAN BE USED AS CLEANOUT)
5. CATCH BASIN FOR OVERFLOW
6. GROUND COVER
7. SOIL MEDIA
8. BARRIER BETWEEN SOIL MEDIA AND DRAINAGE LAYER. OPTION 1: GEOTEXTILE. OPTION 2: CHOKING LAYERS (SEE APPX B)
9. DRAINAGE LAYER
10. UNDERDRAIN
11. HYDRAULIC RESTRICTION LAYER



SECTION B–B'
NOT TO SCALE

PLANS AND DETAILS

INFILTRATION TRENCH

PREPARED BY:

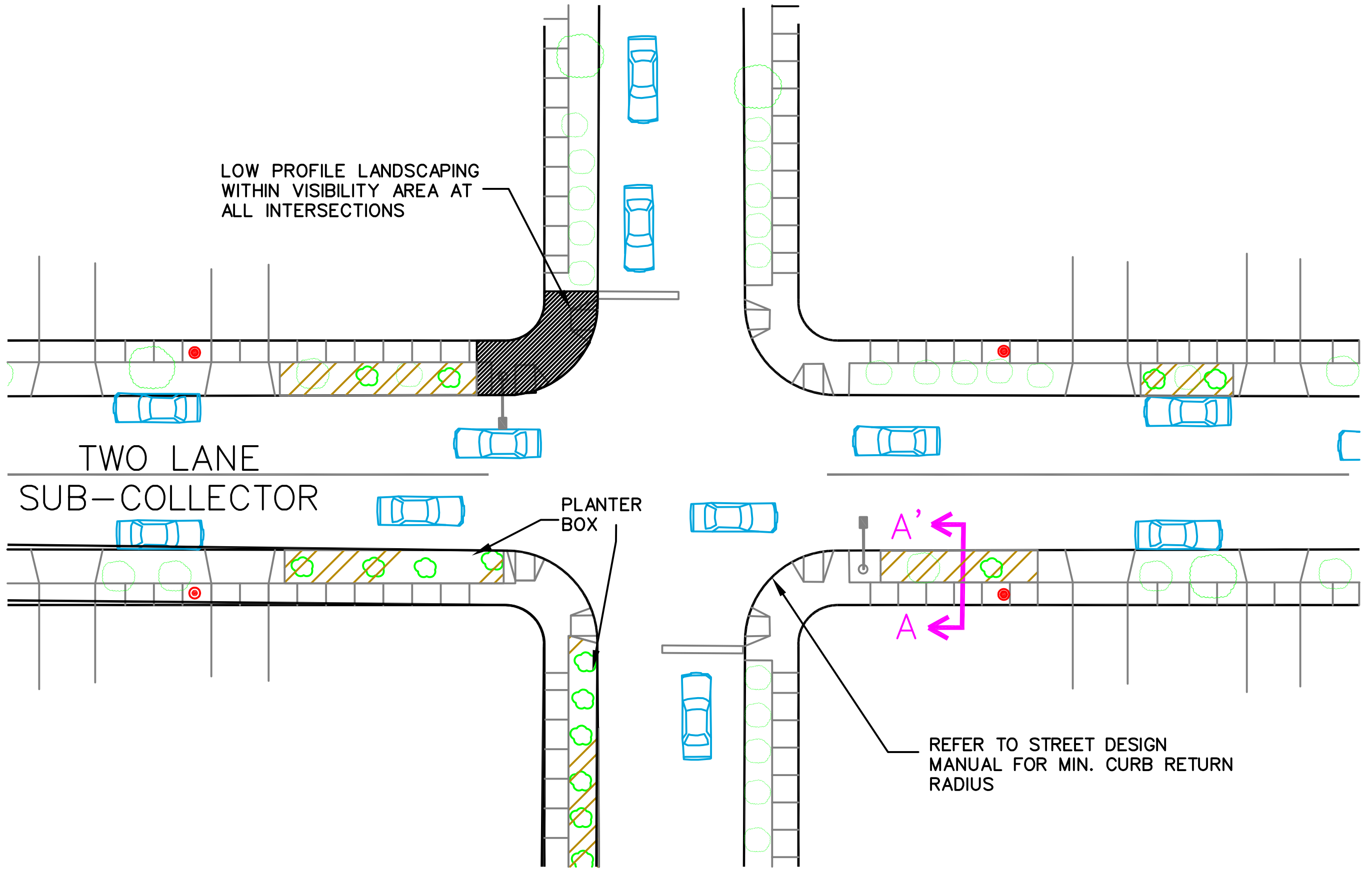
TETRA TECH, INC

T24453

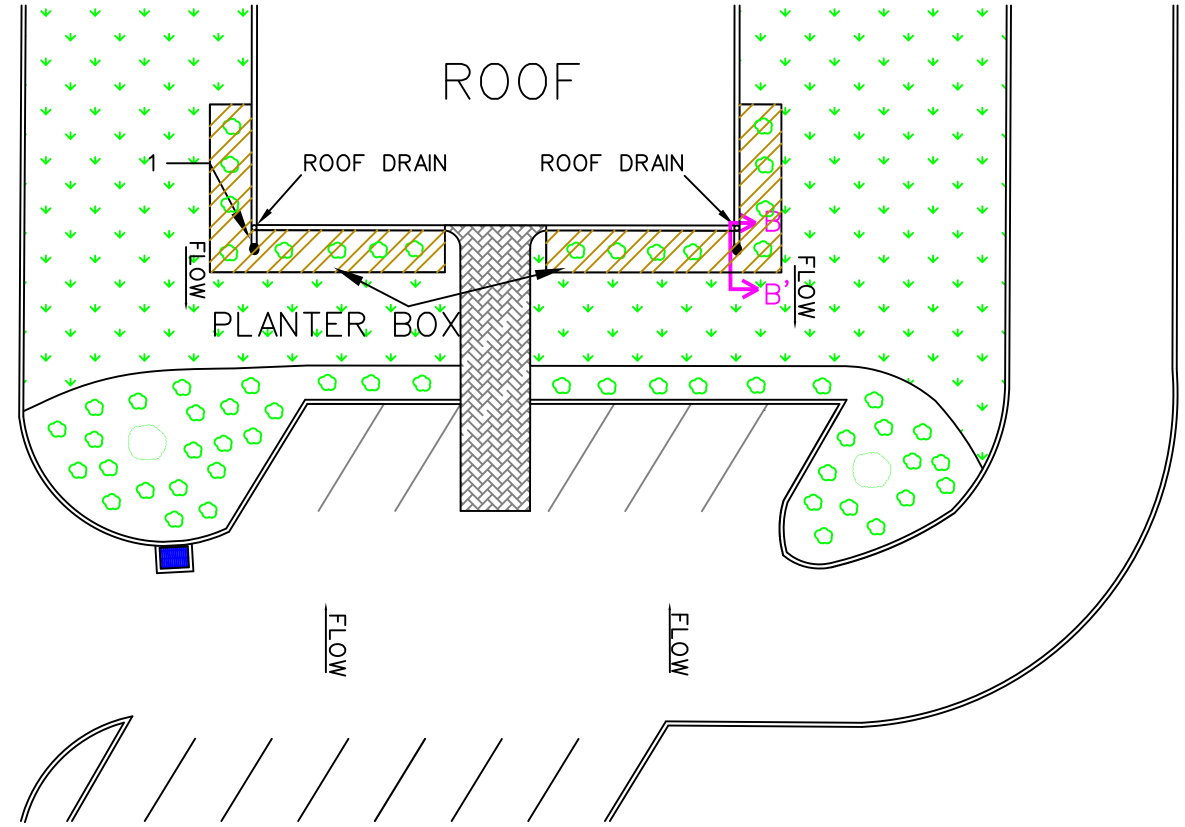
06-08-10

1

CADD NO.: INFILTRATIONTRENCHCUTSHEET.DWG



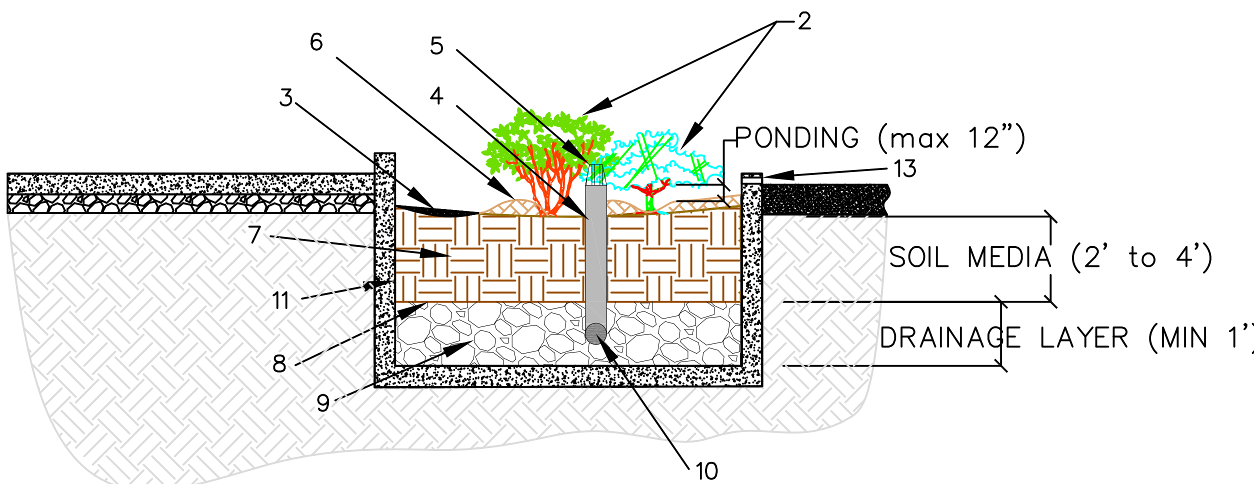
PLAN VIEW
NOT TO SCALE



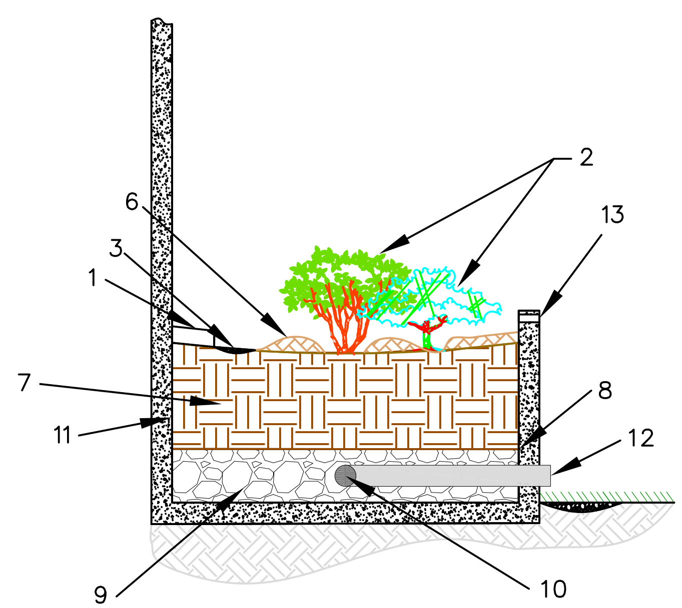
PLAN VIEW
NOT TO SCALE

NOTES:

1. BUILDING DOWNSPOUTS (APPROPRIATELY ARMORED)
2. SELECT APPROPRIATE VEGETATION (SEE APPX D)
3. INLETS SHOULD BE ARMORED (SEE APPX B)
4. OPTIONAL OVERFLOW RISER CONNECTED TO THE UNDERDRAIN (CAN BE USED AS CLEANOUT)
5. VERTICAL RISER SPIDER CAP
6. GROUND COVER: 3 INCHES OF FINELY SHREDDED HARDWOOD MULCH OR APPROPRIATE SOD
7. SOIL MEDIA
8. BARRIER BETWEEN SOIL MEDIA AND DRAINAGE LAYER. OPTION 1: GEOTEXTILE. OPTION 2: CHOKING LAYERS (SEE APPX B)
9. DRAINAGE LAYER
10. UNDERDRAIN
11. HYDRAULIC RESTRICTION LAYER
12. OUTLET (APPROPRIATELY ARMORED)
13. OVERFLOW (APPROPRIATELY ARMORED)



SECTION A-A' (OPTION 1)
NOT TO SCALE



SECTION B-B'
NOT TO SCALE

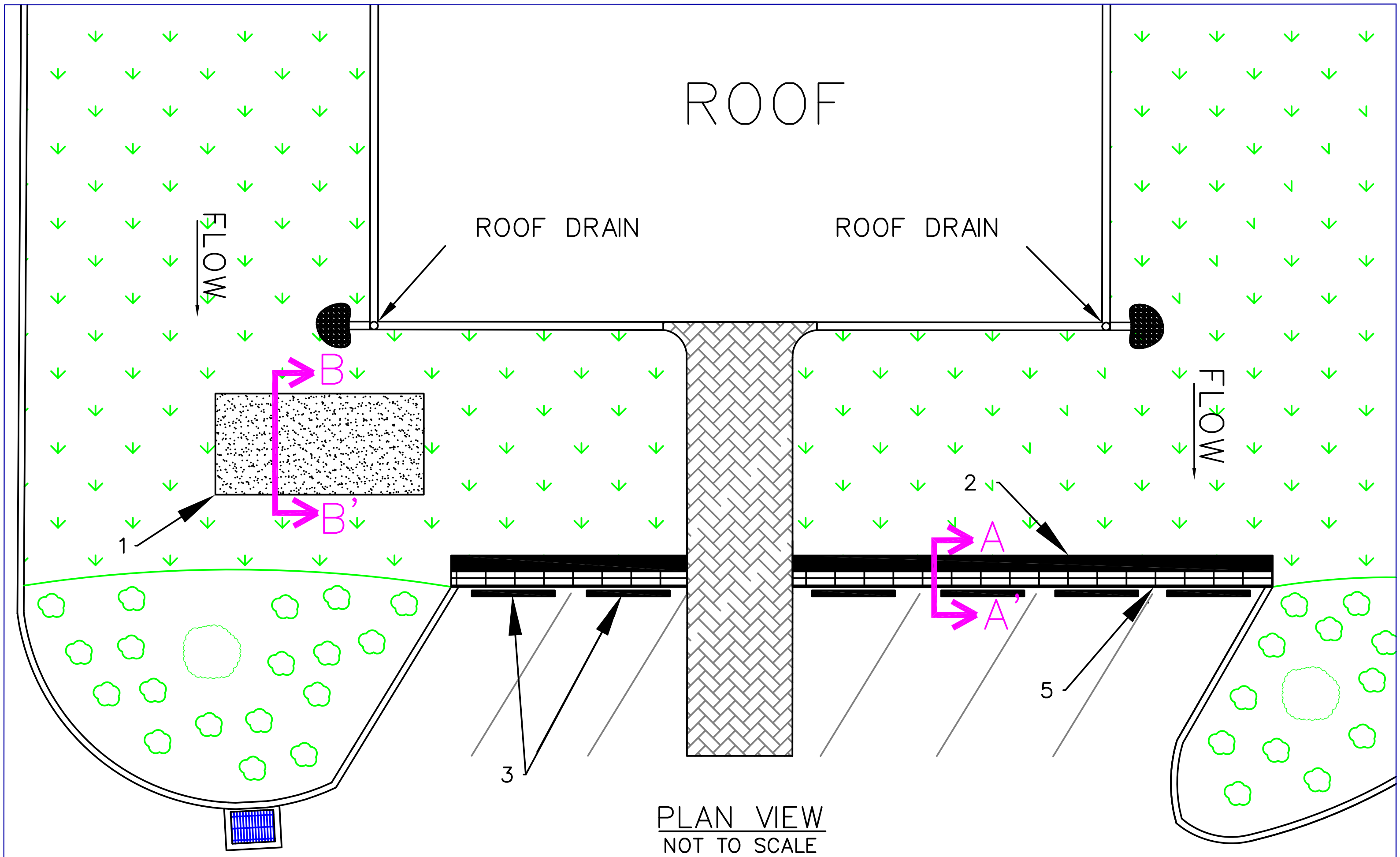
PLANS AND DETAILS

PLANTER BOX

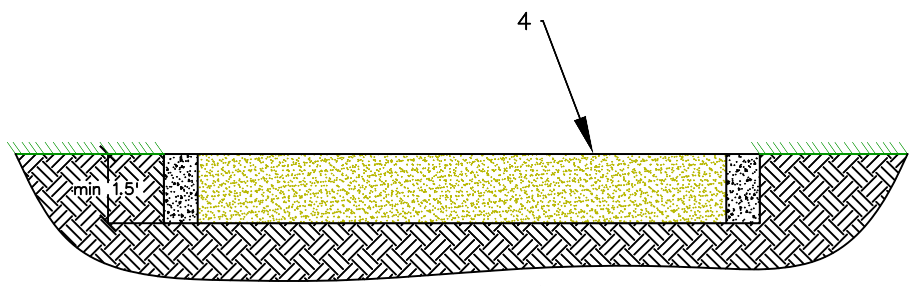
PREPARED BY:
TETRA TECH, INC

T24453
06-08-10
1

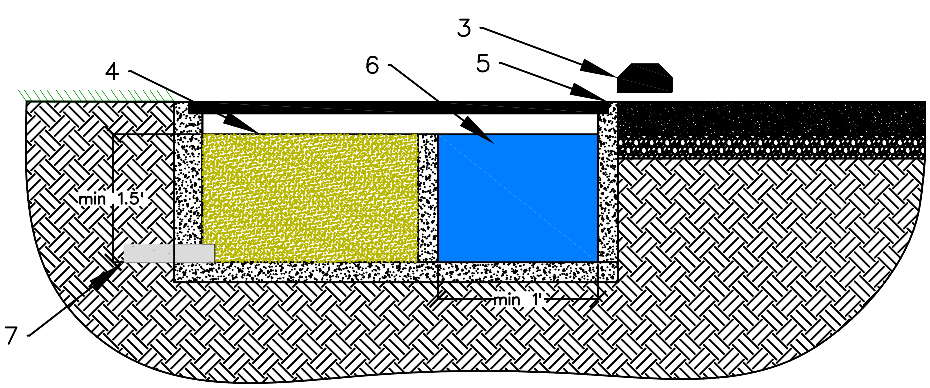
CADD NO.: PLANTERBOXCUTSHEET.DWG



PLAN VIEW
NOT TO SCALE



SECTION B–B'
NOT TO SCALE



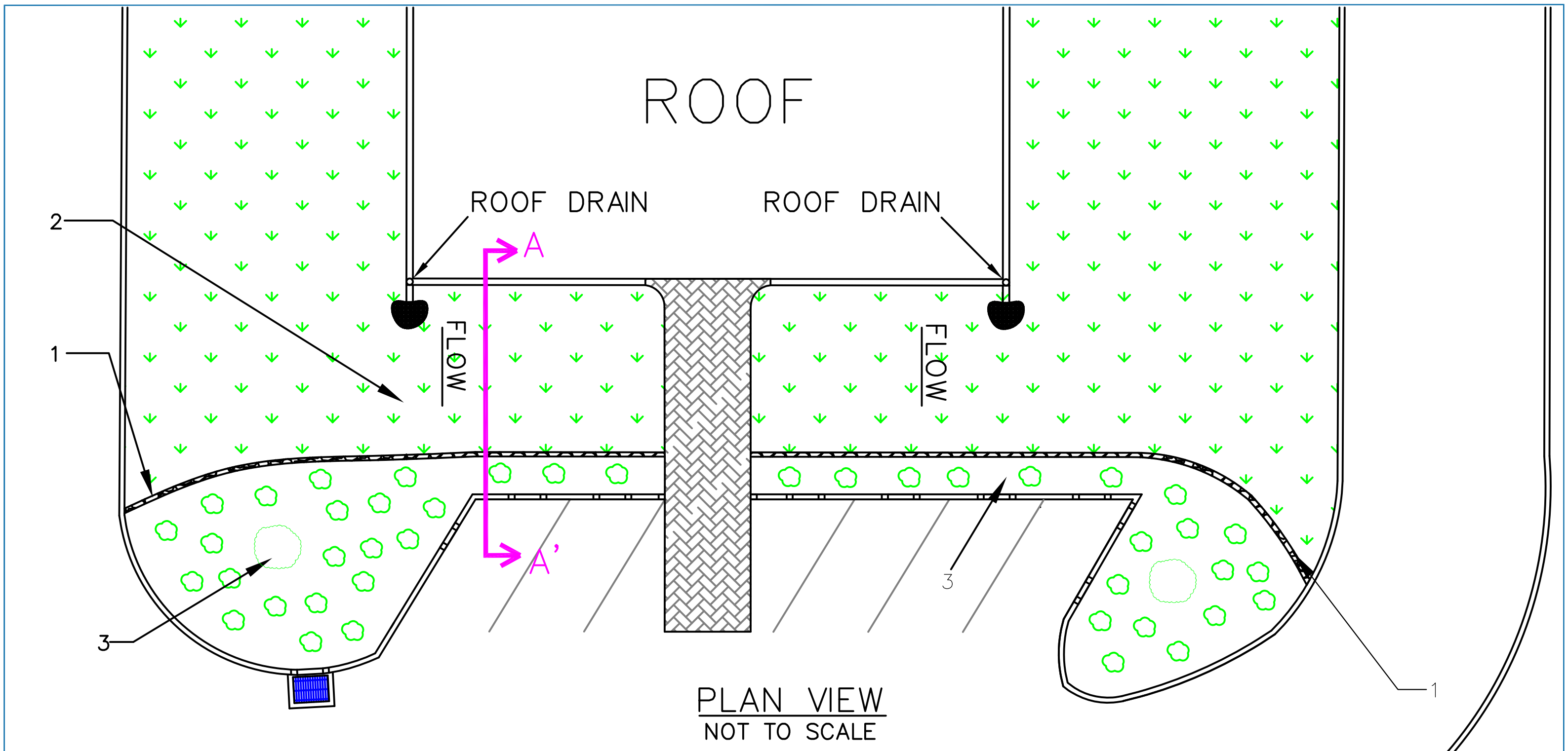
SECTION A–A'
NOT TO SCALE

NOTES:

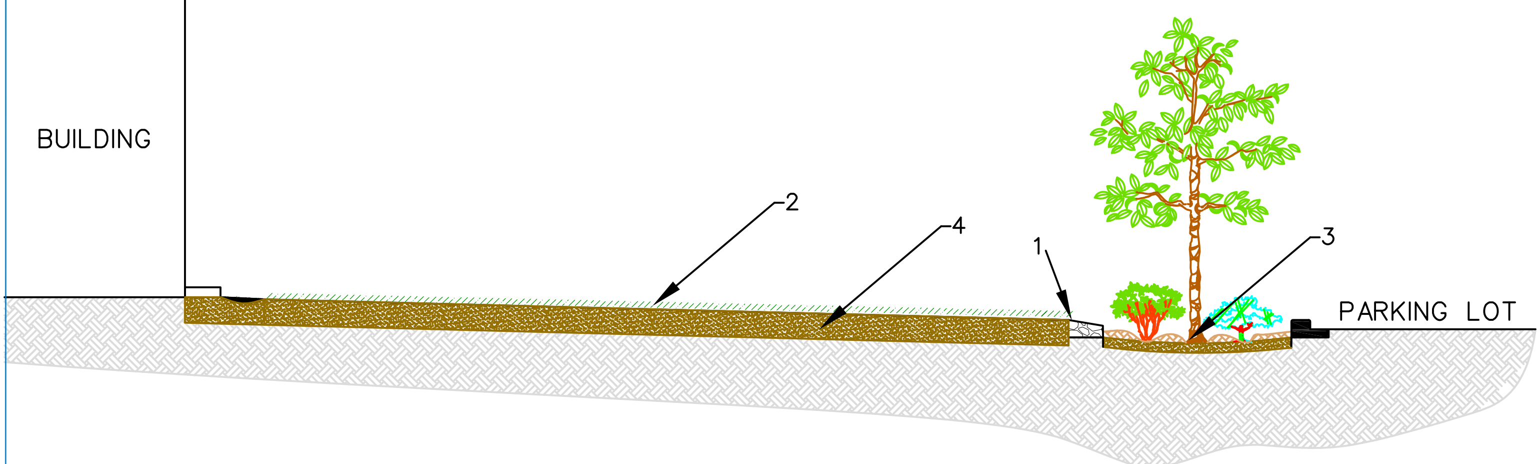
1. ABOVE GROUND SAND FILTER
2. BELOW GROUND SAND FILTER
3. ELEVATED CURB STOPS
4. SOIL MEDIA
5. LEVEL LIP
6. SEDIMENTATION CHAMBER
7. OUTLET

PLANS AND DETAILS	JOB NO.: T24453
SAND FILTER	DESIGNED BY:
	DRAWN BY:
	PROJECT MGR.:
	CHECKED BY:
	CHECKED BY:
	APPROVED BY:
	APPROVED BY:
PREPARED BY: TETRA TECH, INC	DATE: 06–08–10
	DRAWING NO.: 1
	SHEET OF
	SET SHEET OF

CADD NO.: SANDFILTERCUTSHEET(8.5X11).DWG



PLAN VIEW
NOT TO SCALE



SECTION A–A'
NOT TO SCALE

NOTES:

1. MIN. 6 INCH GRAVEL VERGE FOR PRE-TREATMENT
2. VEGETATED FILTER STRIP (2% TO 5% SLOPE, SEE APPX B)
3. BIORETENTION AREA (OPTIONAL, SEE APPX B)
4. AMENDED SOILS (OPTIONAL, SEE APPX B)

PLANS AND DETAILS

VEGETATED FILTER STRIP

PREPARED BY:

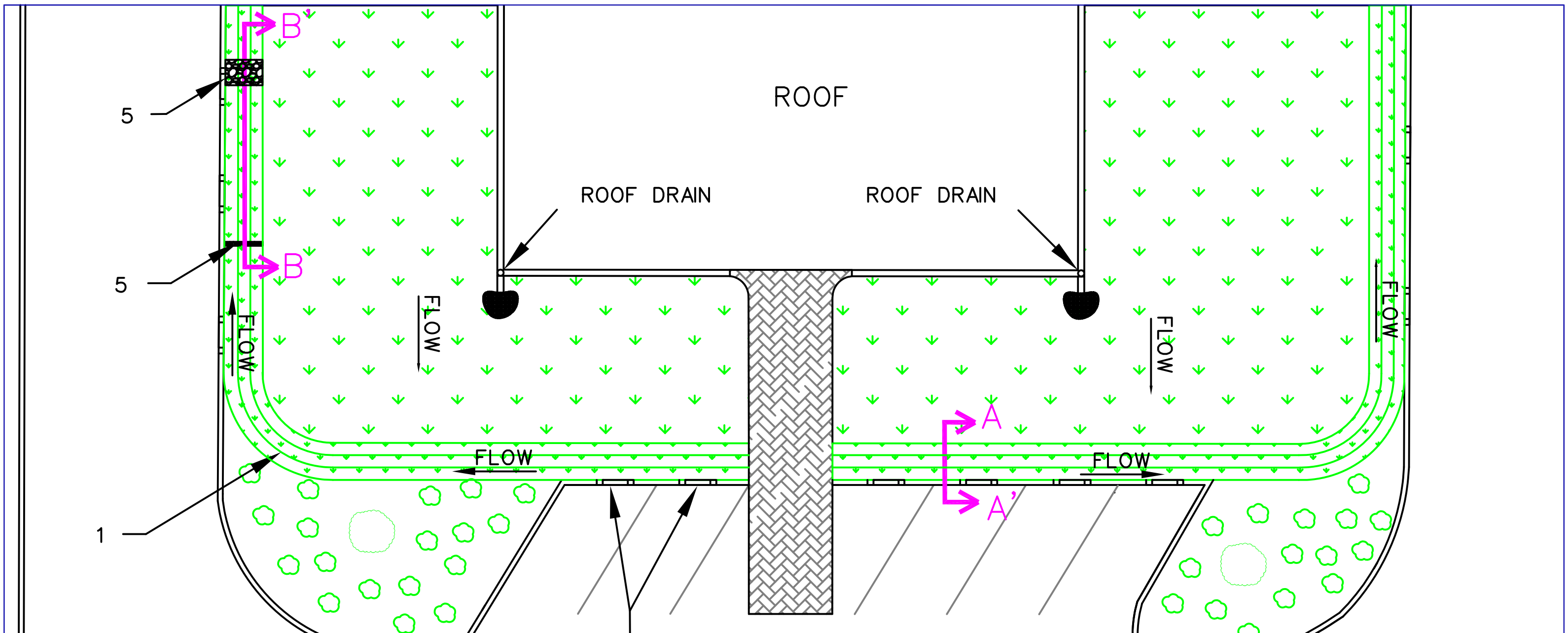
TETRA TECH, INC

T24453

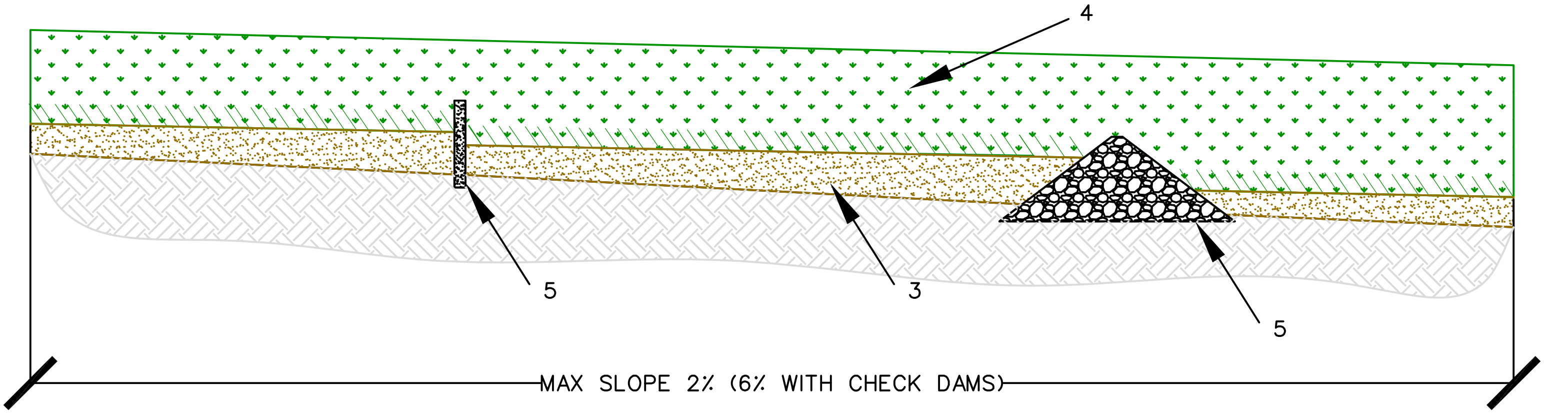
06–08–10

1

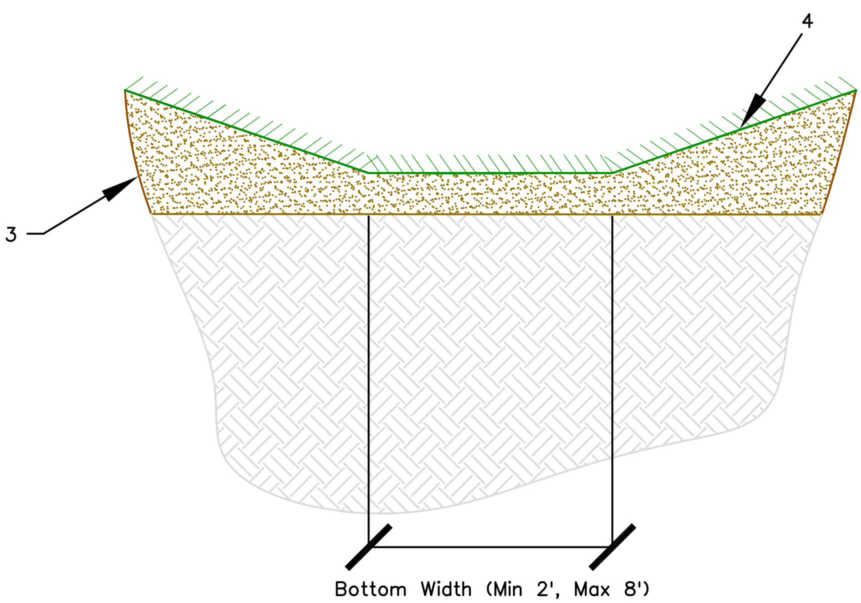
CADD NO.: VEGETATEDFILTERSTRIPCUTSHEET(8.5X11).DWG



PLAN VIEW
NOT TO SCALE



SECTION B–B'
NOT TO SCALE



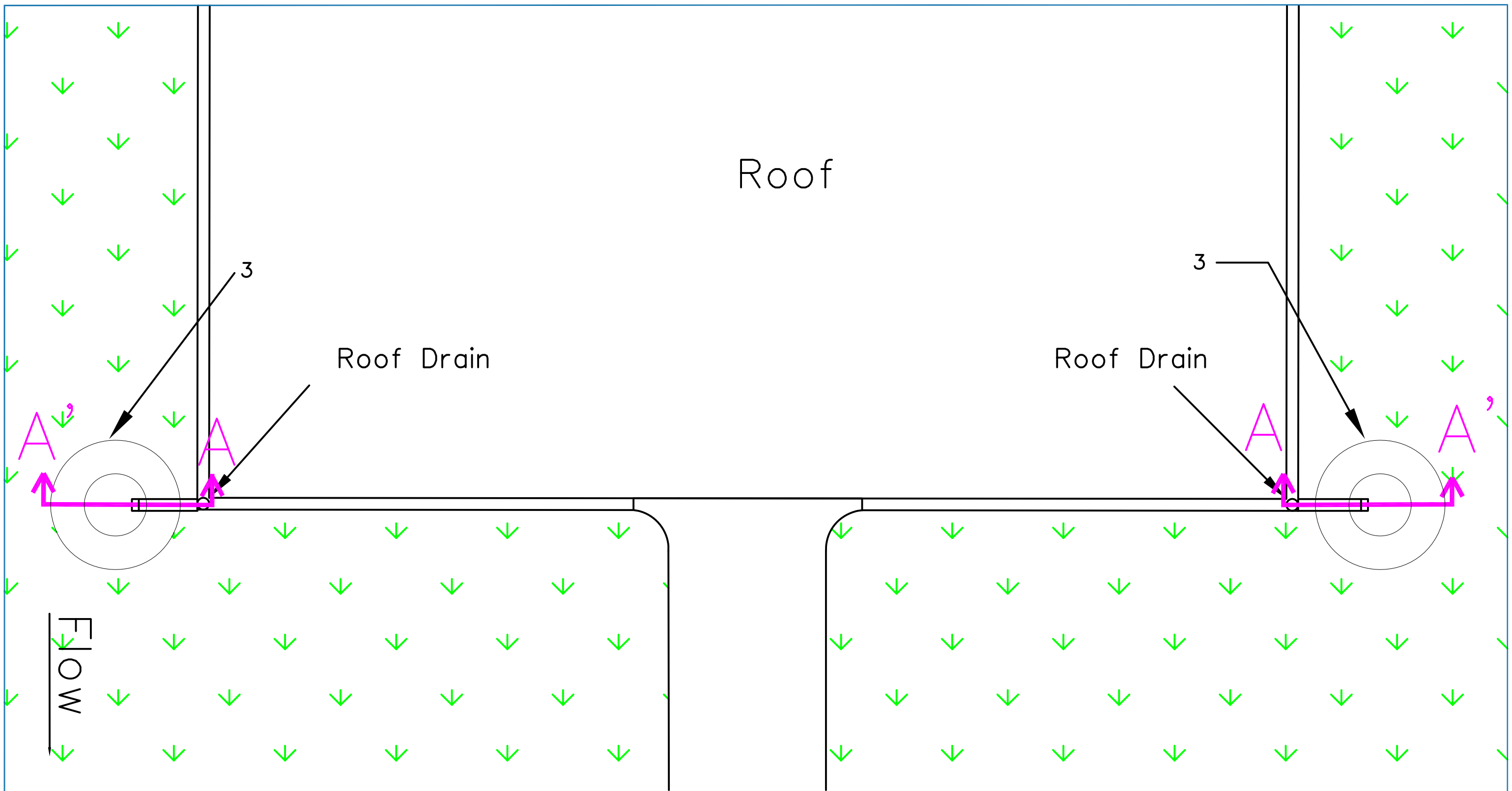
SECTION A–A'
NOT TO SCALE

NOTES:

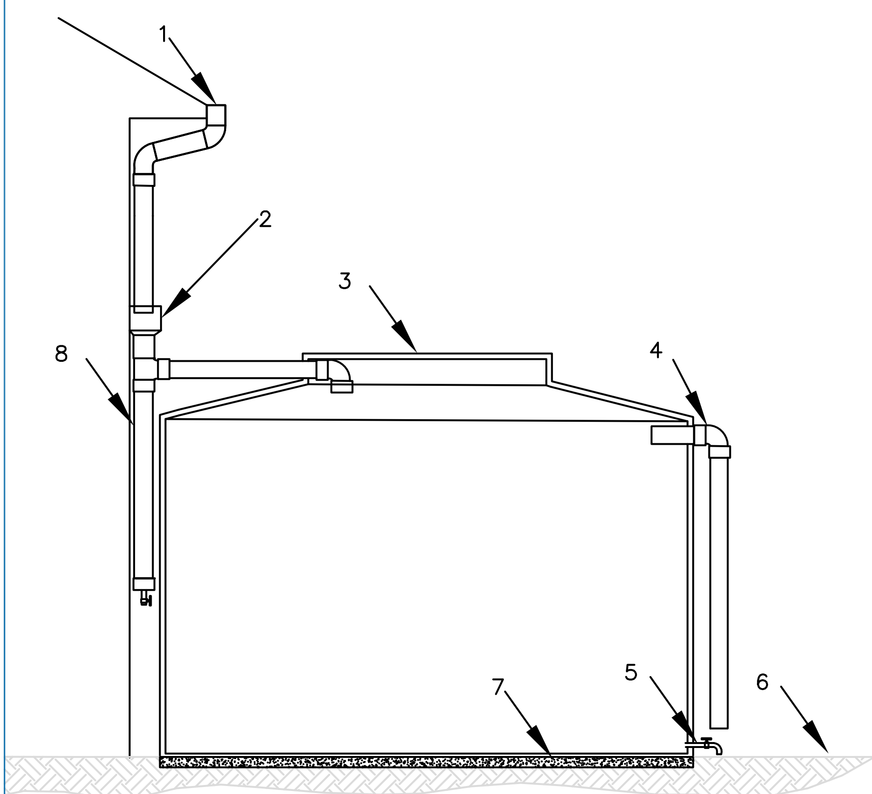
1. VEGETATED SWALE(SEE APPX B)
2. CURB CUTS SHOULD BE ARMORED (SEE APPX B)
3. SOIL AMENDMENTS
4. SIDE SLOPE (3H:1V)
5. CHECK DAM

PLANS AND DETAILS	JOB NO.: T24453
VEGETATED SWALE	DATE: 06-08-10
PREPARED BY: TETRA TECH, INC	DRAWING NO. 1

CADD NO.: VEGETATEDSWALECUTSHEET(8.5X11).DWG



PLAN VIEW
NOT TO SCALE



SECTION A–A' Cistern
NOT TO SCALE

NOTES:

1. GUTTER AND DOWNSPOUT
2. INLET FILTER
3. CISTERN – ABOVE OR BELOW GROUND
4. OVERFLOW
5. SPIGOT FOR IRRIGATION, ETC.
6. UNDISTURBED SOIL
7. CONCRETE OR GRAVEL FOOTING
8. FIRST FLUSH DIVERTER

PLANS AND DETAILS

CISTERN

PREPARED BY:

TETRA TECH, INC

JOB NO.: T24453

DATE: 06–08–10

DRAWING NO.: 1

CADD NO.: CISTERNCUTSHEET(8.5X11).DWG

Appendix D. Fact Sheets

Site Assessment

Bioretention cells offer flexibility in design and can easily be incorporated into new or existing developments such as parking lot islands and edges, street rights-of-way and medians, round-a-bouts, pedestrian walkways, public transit stops, or building drainage areas. The available space and site topography often dictate the geometry and size of the bioretention cells. Additional site objectives include incorporation into the site's natural hydrologic regime and further enhancement of natural landscape features in an urban setting.

Drainage Area: Less than 5 acres.

Available Space: The footprint of the cell is dependent on drainage area, typically sized as 4 to 8 percent of the surrounding drainage. If space allows, pretreatment can be incorporated into design.

Underground Utilities: A complete utilities inventory should be done to ensure that site development will not interfere with or affect utilities.

Existing Buildings: Assess building effect (runoff, solar shadow) on the site. Bioretention systems must be set away from building foundations at least 10 feet.

Water Table: Bioretention facilities are applicable where depth to water table is more than 10 feet. If the depth is 2 to 10 feet, soil should be amended or underdrains should be included.

Soil Type: Examine site compaction and soil characteristics. Determine site specific permeability, ideal to have well-drained soils. If native soils show less than 0.5 in/hr infiltration rate, underdrains should be included.

Areas of Concern: Bioretention is not suggested for sites with known soil contamination or *hot spots*, such as gas stations. An impermeable membrane can be used to contain infiltration within areas of concern.

Design Considerations & Specifications:

Topography: Bioretention facilities must not be used where slopes are greater than 15 percent, or in drainage areas that are not permanently stabilized.

Flow regulation: Design should consider the natural flow regime. To avoid erosion, direct and dissipate flow as needed. Proper inlets and outlets should be designed on the basis of anticipated volume and peak-velocity control.

Pretreatment: An optional component when space allows, specifically in areas with higher sediment loading. Commonly includes vegetated filter strip, vegetated swale, or forebay. The objective of pretreatment is to enhance filtration and sedimentation of larger particles and debris from heavily trafficked areas.

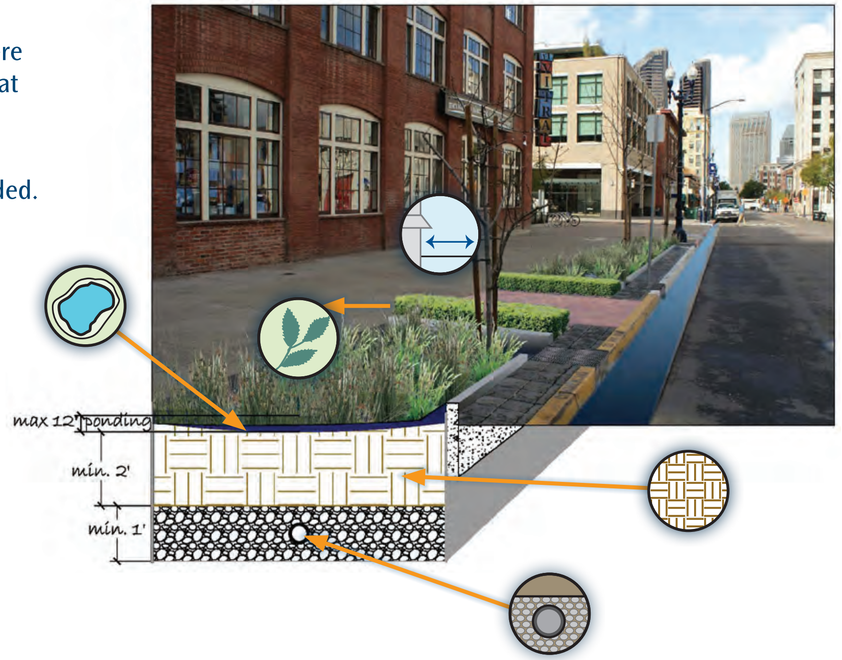
Shallow ponding area: Designed to control peak flow velocities and enhance sedimentation. Ponded water must completely drain into the soil within 24 hours, with 12 hours preferred as a safety factor.

Vegetation: Vegetation is crucial to both the function and appearance. Consider native plants resilient to variable flow. Mimic nature with a high diversity of plant types. Plants must be tolerant of summer drought, ponding fluctuations, and saturated soil conditions.

Media layers: The soil media provides a beneficial root zone for the chosen plant palette and adequate water storage for the water quality design volume. The top, organic mulch layer is designed to filter and bond finer particles; below, planting layers provide nutrients and water for vegetation; a lower sand bed filter is suggested for areas susceptible to runoff of finer particulates.

Underdrain system: Below the media layers, the underdrain system is designed to further dissipate flow. Combining traditional conveyance, a perforated pipe is embedded in the gravel layer; flow filters through the gravel layer, into the pipe. The pipe can either connect to the structural storm drain system or route to surface conveyance. Underdrains should have a 6 inch minimum diameter and a minimum slope of 0.5 percent.

Overflow system: During high-volume storm events, the overflow system conveys overflow to in-line catchments, including the storm drain system, drain ditches or additional ponding areas.



Bioretention

Drainage area	Soil infiltration rate	Water table separation	Depth to bedrock	Facility slope	Inflow rate
< 5 ac	> 0.5 in/hr *(if < 0.5 in/hr, install UD)*	> 10 ft *(if > 2 but < 10 ft, install UD)*	> 10 ft *(if > 2 but < 10 ft, install UD)*	< 2%	Mulch: 1 cfs, Grass: 3 cfs

Pollutant Removal			Runoff volume reduction	Groundwater recharge
	Sediments: High Trash: High Bacteria: High Organics: High	Nutrients: Medium Metals: High Oil and Grease: High	High no UD; Medium with UD	High no UD; Low with UD

Functional unit processes:

- Absorption
- Microbial activity
- Evapotranspiration
- Detention
- Denitrification
- Volatilization
- Infiltration
- Recharge

Maintenance Considerations

Task	Frequency	Maintenance Notes
Pruning	1–2 times/year	Nutrients in runoff often cause bioretention vegetation to flourish.
Mowing	2–12 times/year	Frequency depends on location and desired aesthetic appeal.
Mulching	1–2 times/year	Between 1"–3" of mulch depth is ideal.
Mulch removal	1 time/2–3 years	Mulch accumulation reduces available water storage volume. Removal of mulch also increases surface infiltration rate of fill soil.
Watering	1 time/2–3 days for first 1–2 months; Sporadically after establishment	If drought conditions exist, watering after the initial year might be required.
Fertilization	1 time initially	One time spot fertilization for *first year* vegetation.
Remove and replace dead plants	1 time/year	Within the first year, 10% of plants can die. Survival rates increase with time.
Inlet inspection	Once after first rain of the season, then monthly during the rainy season	Check for sediment accumulation to ensure that flow into the bioretention is as designed. Remove any accumulated sediment.
Outlet inspection	Once after first rain of the season, then monthly during the rainy season	Check for erosion at the outlet and remove any accumulated mulch or sediment.
Miscellaneous upkeep	12 times/year	Tasks include trash collection, plant health, spot weeding, removing invasive species, and removing mulch from the overflow device.

Bioretention

Background

Bioretention cells are small-scale, vegetated depressions designed to increase storm water storage and filtration through engineered media. Using detention, sedimentation, filtration and adsorption, bioretention is designed to enhance the uptake of contaminants from storm water by both plants and soils.

Bioretention can also incorporate pretreatment (i.e., vegetated filter strips, vegetated swales or settling forebays), allowing increased sedimentation and capture of debris from heavily trafficked areas. Finally, bioretention can be used in-line with traditional storm water conveyance systems.

Bioretention is effective for removing

- Sediments
- Trash
- Bacteria
- Organics
- Metals
- Oil and Grease

think BLUE San Diego

Bioswale

Site Assessment

Bioswales are highly versatile storm water BMPs that effectively reduce pollutants. With a narrow width, bioswales can be integrated into site plans with various configurations and components. Ideal sites for bioswales include the right-of-way of linear transportation corridors and along borders or medians of parking lots. In heavily trafficked areas, curb cut outs can be used to delineate boundaries.

Design capacity should be based on the *Storm Water Design Standards* Manual specifications and consider how flow is routed to the bioswale. In addition, bioswales can be combined with other basic and storm water runoff BMPs to form a treatment train, reducing the required size of a single BMP unit. Bioswales must not be used in watersheds where slopes are greater than 15 percent. Underdrains should be utilized where the seasonally high water table is less than 10 feet below the bottom of the unit.

Drainage Area: To be less than 2 acres.

Available Space: Bioswales are typically long and narrow with widths between 2 and 8 feet. Sizing must take into account all runoff at ultimate build-out including off-site drainage.

Underground Utilities: Complete a utilities inventory to ensure that site development will not interfere with or affect utilities. In many cases, infiltration trenches can be shifted in the landscape to prevent implementation over utilities. In cases where utilities cannot be avoided take care to prevent effects from infiltration or saturation by using hydraulic restricting layers to direct infiltration away from the utility.

Existing Buildings/Setbacks: Must be a minimum of 100 feet from water supply wells and septic system drain fields and 10 feet from any structures.

Water Table: Bioswales must not be used where the seasonally high water table or confining layer is less than 10 feet below.

Soil Type: Soil testing should be performed at the site by a licensed soil scientist or geological engineer to determine the infiltration rate of the in-situ soils. Bioswales should not be used in sites with highly erodible soils unless turf reinforcement is used. The soil media within the infiltration trench should be highly permeable (an infiltration rate of at least 0.5 in/hr) and have an appropriate amount of organic material to support plant growth (e.g., loamy sand mixed thoroughly with an organic material).

Areas of Concern: Bioswales should not be used to receive storm water runoff from *hot spots* such as gas stations, auto repair shops unless adequate pretreatment is provided upstream.

Design Considerations & Specifications:

Topography: Bioswales must not be used in watersheds where surrounding slopes are greater than 15 percent, or in areas that are not permanently stabilized. Overall longitudinal slopes should not exceed 5 percent, but check dams should be used so that one continuous section does not exceed 2 percent.

Flow regulation: Inflow must be non-erosive sheet flow (3 feet per second for grass cells) or use energy-dissipating devices. Bioswales can be used effectively in areas with slopes of 2 to 5 percent by installing check dams to prevent erosive flow velocities; slopes between each check dam should not exceed 2 percent.

Pretreatment: In general, pretreatment at some level is suggested for bioswales. Bioswales that treat runoff from residential roofs or other cleaner surfaces will not require pretreatment.

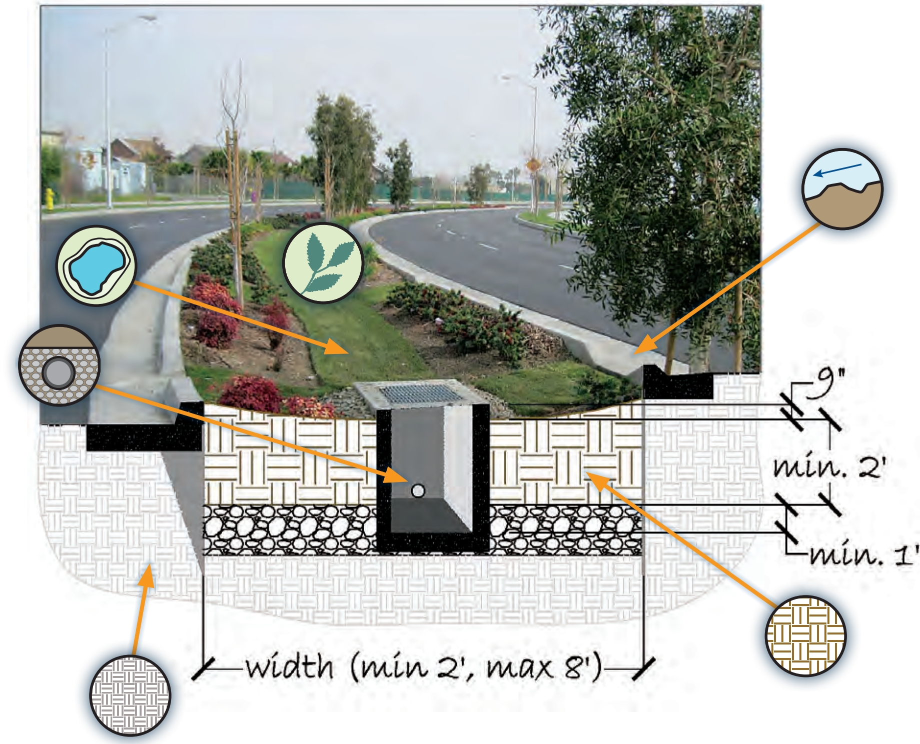
Shallow ponding area: Ponded water must completely drain into the soil within 24 hours, but 12 hours is preferred. It must drain to a level below the soil media (2 to 3 feet) within 48 hours. Ponding depth should be less than 12 inches, 9 inches is preferable.

Vegetation: Bioswales are typically planted with grasses, shrubs, and trees that can withstand short periods of saturation followed by longer periods of drought. Native plant species or hardy cultivars that are not invasive and do not require chemical inputs are recommended.

Media layers: Media depth must be a minimum of 2 feet. The soil media must comply with the city's *Storm Water Standards*. If existing soils do not meet the criteria, a substitute media must be used.

Underdrain system: An underdrain must be installed if in-situ soil drainage is less than 0.5 in/hr. The underdrain pipe should be at least 6 inches in diameter and installed at a 0.5 percent minimum slope. An underdrain must be installed if the infiltration trench is within 50 feet of a sensitive, steep slope. Clean-out pipes must be provided if underdrains are required.

Overflow system: Select the appropriate overflow or bypass method. Offline bioswales do not require an overflow system.



Bioswale

Drainage area	Soil infiltration rate	Water table separation	Depth to bedrock	Facility slope	Inflow rate
< 2 ac	> 0.5 in/hr *(if < 0.5 in/hr, install UD)*	> 10 ft *(if > 2 but < 10 ft, install UD)*	> 10 ft *(if > 2 but < 10 ft, install UD)*	< 2%	Mulch: 1 cfs, Grass: 3 cfs

Pollutant Removal			Runoff volume reduction	Groundwater recharge
	Sediments: High Trash: High Bacteria: High Organics: High	Nutrients: Medium Metals: High Oil and Grease: High	High no UD; Medium with UD	High no UD; Low with UD

Functional unit processes:

- Absorption
- Microbial activity
- Plant uptake
- Sedimentation
- Filtration

Maintenance Considerations

Task	Frequency	Maintenance Notes
Pruning	1–2 times/year	Nutrients in runoff often cause bioswale vegetation to flourish.
Mowing	2–12 times/year	Frequency depends on location and desired aesthetic appeal.
Mulching	1–2 times/year	Recommend maintaining 1"–3" uniform mulch layer.
Mulch removal	1 time/2–3 years	Mulch accumulation reduces available water storage volume. Removal of mulch also increases surface infiltration rate of fill soil.
Watering	1 time/2–3 days for first 1–2 months; sporadically after establishment	If drought conditions exist, watering after the initial year might be required.
Fertilization	1 time initially	One time spot fertilization for first year vegetation.
Remove and replace dead plants	1 time/year	Within the first year, 10% of plants can die. Survival rates increase with time.
Inlet inspection	Once after first rain of the season, then monthly during the rainy season	Check for sediment accumulation to ensure that flow into the bioswale is as designed. Remove any accumulated sediment.
Outlet inspection	Once after first rain of the season, then monthly during the rainy season	Check for erosion at the outlet and remove any accumulated mulch or sediment.
Miscellaneous upkeep	12 times/year	Tasks include trash collection, plant health, spot weeding, and removing mulch from the overflow device.

The City of San Diego • State of California • Semper Vigilans

Background

Bioswales are shallow, open channels that are designed to reduce runoff volume through infiltration. Additionally, bioswales remove pollutants such as trash and debris by filtering water through vegetation within the channel. Swales can serve as conveyance for storm water and can be used in place of traditional curbs and gutters; however, when compared to traditional conveyance systems the primary objective of a bioswale is infiltration and water quality enhancement rather than conveyance. In addition to reducing the mass of pollutants in runoff, when properly maintained, bioswales can enhance the aesthetics of a site.

Bioswales are effective for removing

- Runoff volume
- TSS
- Trash/debris
- Organics
- Bacteria
- Nutrients
- Heavy metals
- Oil and grease

think BLUE San Diego

Permeable Pavement

Site Assessment

The use of permeable pavement is encouraged for sites such as parking lots, driveways, rights-of-way, and other lightly traveled areas. Numerous types and forms of permeable pavers exist and offer a range of utility, strength, and permeability. Permeable pavement must be designed to support the maximum anticipated traffic load but should not be used in highly trafficked areas as pavers can wear with heavy traffic and structurally breakdown.

For designs that include infiltration, surrounding soils must allow for adequate infiltration. Precautions must be taken to protect soils from compaction during construction. While the specific design can vary, all permeable pavements have a similar structure, consisting of a surface pavement layer, an underlying stone aggregate reservoir layer and a filter layer or fabric or an additional BMP. These systems can also be designed without an underdrain with storm water infiltrating into the surrounding soils if amenable.

Available Space: Permeable pavement is typically designed to treat storm water that falls on the pavement surface area and runon from other impervious surfaces. It is most commonly used at commercial, institutional, and residential locations in area that are traditionally impervious. Permeable pavement should not be used in high-traffic areas.

Underground Utilities: Complete a utilities inventory to ensure that site development will not interfere with or affect utilities.

Existing Buildings: Assess building effects on the site. Permeable pavement must be set away from building foundations at least 10 feet and 50 feet from steep slopes.

Water Table: Permeable pavement is applicable where depth to water table is more than 10 feet. If the depth is 2 to 10 feet, underdrains should be included.

Soil Type: Examine site compaction and soil characteristics. Minimize compaction during construction; do not place the bed bottom on compacted fill. Determine site-specific permeability; it is ideal to have well-drained soils.

Areas of Concern: Permeable pavement that includes infiltration in design is not recommended for sites with known soil contamination or *hot spots* such as gas stations. Impermeable membrane can be used to contain flow within areas of concern.

Design Considerations & Specifications:

Topography: Completed permeable pavement installation must have a slope of less than 0.5 percent.

Flow regulation: Design should consider the natural flow regime. Sheet flow velocities should not exceed 3 feet per second.

Pretreatment: Pretreatment may extend the required frequency of maintenance.

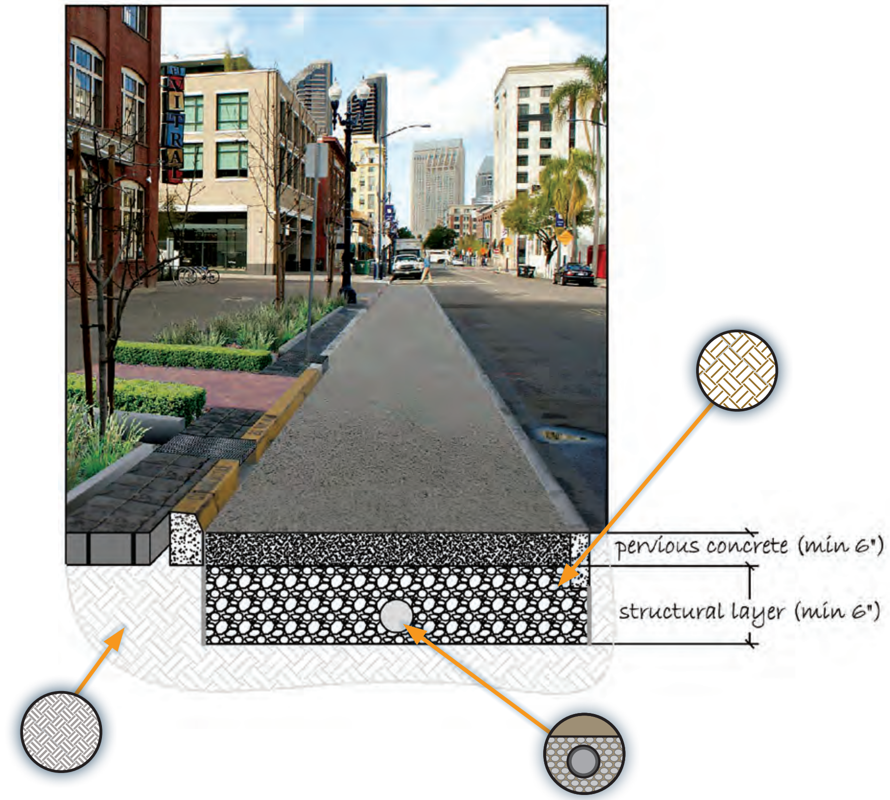
Shallow ponding area: N/A

Vegetation: N/A

Media layers: Permeable pavement consists of a surface pavement layer, an underlying stone aggregate reservoir layer and a filter layer or fabric. In general, the open-graded subbase is designed to have a 40 percent void space and a depth of at least 6 inches.

Underdrain system: Below the media (aggregate stone) layers, an underdrain system can be used to route infiltrated stormwater. The pipe can either connect to the structural storm drain system, or route to surface conveyance or other storm water treatment BMPs. The underdrain pipe should be at least 6 inches in diameter and installed at a 0.5 percent minimum slope.

Overflow system: During high-volume storm events, the overflow system conveys overflow to in-line catchments, including storm drain system, drainage ditches, or additional ponding areas.



Permeable Pavement

Drainage area	Soil infiltration rate	Water table separation	Depth to bedrock	Facility slope	Inflow rate
N/A	> 0.5 in/hr *(if < 0.5 in/hr, install UD)*	> 10 ft *(if > 2 but < 10 ft, install UD)*	> 10 ft *(if > 2 but < 10 ft, install UD)*	< 0.5%	3 cfs

Pollutant Removal			Runoff volume reduction	Groundwater recharge
	Sediments: High Trash: High Bacteria: Medium Organics: Low	Nutrients: Low Metals: Medium Oil and Grease: Medium	High no UD; Medium with UD	Medium no UD; Low with UD

Functional unit processes:

- Absorption
- Microbial activity
- Evapotranspiration
- Detention
- Denitrification
- Volatilization
- Infiltration
- Recharge

Maintenance Considerations

Task	Frequency /Conditions When Maintenance is Needed	Maintenance Notes
Inlet inspection	Once after first rain of the season then monthly during the rainy season	Check for sediment accumulation to ensure that flow onto the permeable pavement is not restricted. Remove any accumulated sediment. Stabilize any exposed soil.
Vacuum street sweeper	Twice a year as needed	Pavement should be swept within a vacuum power street sweeper at least twice per year or as needed to maintain infiltration rates.
Mowing (for grass filled pavers)	2–12 times per year	Pavers filled with turf require mowing. Frequency depends upon location and desired aesthetic appeal.
Replace fill materials	4 times per year	Fill materials will need to be replaced after each sweeping and as needed to keep voids with the paver surface.
Watering (for grass filled pavers)	1 time every 2–3 days for fires 1–2 months; sporadically after establishment	If drought conditions exist, watering after the initial year may be required.
Fertilization	4 times per year or as needed for aesthetics	One time spot fertilization for "first year" vegetation
Miscellaneous upkeep	4 times per year or as needed for aesthetics	Tasks include trash collection, sweeping, and spot weeding.

Background

Permeable pavement allows for percolation of storm water through media and offers an alternative to conventional concrete and asphalt paving. Typically, storm water that drains through the permeable surface, is captured in a perforated underdrain system, and is directed to the storm water conveyance system. A wide variety of permeable pavement types are available and can be incorporated into rights-of-way, sidewalks, and driveways.

Permeable pavement is effective for removing

- Sediment
- Trash
- Oil and grease
- Metals
- Bacteria

think BLUE San Diego

Infiltration Trench

Site Assessment

Infiltration trenches are well suited for roadway medians or shoulders and for locations with limited space such as edges or medians of parking lots. When infiltration is incorporated into highly impervious areas, curb cuts may be required to allow surface runoff to enter the infiltration trench. Rates of soil infiltration are required to be greater than 0.5 inch per hour, in sites with clay-based or compacted soils; the infiltration trench should be designed with subsurface storage or an underdrain. Pretreatment, such as a vegetated filter strip, is suggested for infiltration trenches to remove sediment and prevent clogging.

Drainage Area: Less than 2 acres.

Available Space: Infiltration trenches are narrow with a linear configuration and are intended to fit along the edges of parking lots and roads. They can vary from 2 to 8 feet in width.

Underground Utilities: A complete utilities inventory should be done to ensure that site development will not interfere with or affect utilities. In many cases, infiltration trenches can be placed in the landscape to prevent conflicts with utilities. In cases where utilities cannot be avoided care should be taken to prevent effects from infiltration or saturation to utilities by using hydraulic restricting layers to prevent infiltration near the utility.

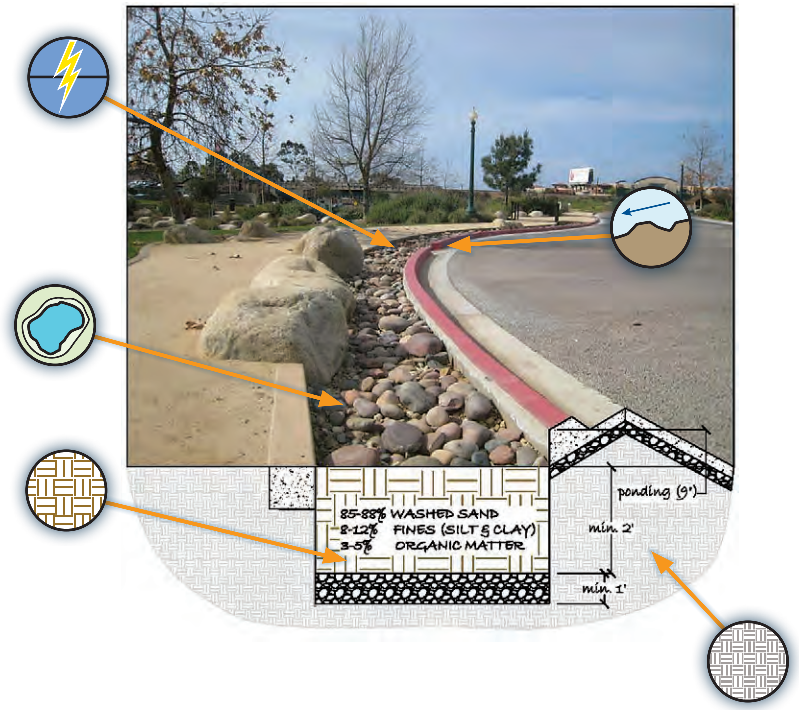
Existing Buildings/Setbacks: Must be a minimum of 100 feet from water supply wells and septic system drain fields and 10 feet from any structures.

Water Table: Unlined infiltration trenches must not be used where the seasonally high water table or confining layer is less than 10 feet below the bottom of the infiltration trench.

Soil Type: Soil testing should be performed at the site by a licensed soil scientist or geological engineer to determine the infiltration rate of the in-situ soils. The soil media within the infiltration trench should be highly permeable (an infiltration rate of at least 0.5 in/hr) and have an appropriate amount of organic material to support plant growth (e.g., loamy sand mixed thoroughly with an organic material).

Areas of Concern: Infiltration trenches are not suggested for sites with known soil contamination or *hot spots*, such as gas stations. An impermeable membrane can be used to prevent infiltration within areas of concern.

Design Considerations & Specifications:



Topography: Drainage area should be completely stabilized before bringing on-line. Longitudinal slope should be less than 2 percent. Slope can exceed 2 percent, but check dams should be used so that one continuous section does not exceed 2 percent. Overall slope should not exceed 5 percent.

Flow regulation: Inflow must be non-erosive sheet flow (3 feet per second for grass cells) or use energy-dissipating devices. Infiltration trenches can be used effectively in areas with slopes from 2 to 5 percent by installing check dams to prevent erosive flow velocities.

Pretreatment: Infiltration trenches can be used in conjunction with pretreatment BMPs such as filter strips or other sediment-capturing devices to prevent sediments from clogging the trench. Appropriate pretreatment will be needed to enhance filtration and sedimentation of larger particles, and debris from heavily trafficked areas.

Shallow ponding area: Ponded water must completely drain into the soil within 24 hours, but 12 hours is preferred. It must drain to a level below the soil media (2 to 3 feet) within 48 hours.

Vegetation: Infiltration trenches are intended to be installed in areas where vegetation might not be feasible, such as the edge of a parking lot or in rights-of-way where vegetation could prevent appropriate site distances or where survival rates would be minimal. In such cases, the surface of the infiltration trench should be stabilized with gravel or a decorative stone. In cases where vegetation is desired, organic matter can be used as an additive to help establish vegetation and should be minimized.

Media layers: Media depth must be a minimum of 2 feet. The soil media in the infiltration trench should be highly permeable (at least 0.5 in/hr) and have an appropriate amount of organic material to support plant growth (e.g., loamy sand mixed thoroughly with an organic material). If existing soils do not meet the criteria, a substitute media must be used. A deeper soil media depth will allow for a smaller surface area footprint.

Underdrain system: An underdrain must be installed if in-situ soil drainage is less than 0.5 in/hr. The underdrain pipe should be at least 6 inches in diameter and installed at a 0.5 percent minimum slope. An underdrain must be installed if the infiltration trench is within 50 feet of a sensitive, steep slope. Clean-out pipes must be provided if underdrains are required.

Overflow system: Select the appropriate overflow or bypass method. On-line BMPs require an overflow system for passing larger storms. Off-line BMPs do not require an overflow system but do require freeboard (the distance from the overflow device and the point where storm water would overflow the system) and a diversion structure.

Infiltration Trench

Drainage area	Soil infiltration rate	Water table separation	Depth to bedrock	Facility slope	Inflow rate
< 2 ac	> 0.5 in/hr	> 10 ft	> 10 ft	< 2%	3 cfs

Pollutant Removal			Runoff volume reduction	Groundwater recharge
	Sediments: High Trash: High Bacteria: High Organics: High	Nutrients: High Metals: High Oil and Grease: High	High no UD; Medium with UD	High no UD; Low with UD

Functional unit processes:

- Microbial activity
- Evapotranspiration
- Detention
- Denitrification
- Volatilization
- Infiltration
- Recharge
- Filtration
- Sorption
- Chemical degradation

Maintenance Considerations

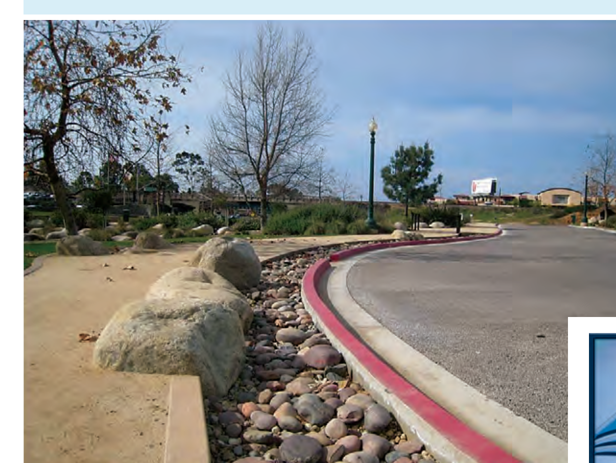
Task	Frequency	Maintenance Notes
Inlet inspection	Once after first rain of the season, then monthly during the rainy season	Check for sediment accumulation to ensure that flow into the system is as designed. Remove any accumulated sediment.
Outlet inspection	Once after first rain of the season, then monthly during the rainy season	Check for erosion at the outlet and remove any accumulated sediment.
Miscellaneous upkeep	12 times/year	Tasks include trash collection, spot weeding, and occasional verification of infiltration rates.

Background

An infiltration trench is an excavated, long, narrow trench lined with filter fabric and backfilled with stone or a bioretention media that allows storm water to infiltrate into subsurface soils. Runoff that infiltrates into the soils is stored in the void spaces between the stones or is infiltrated into the ground. In addition to reducing runoff volume, infiltration trenches remove fine sediment and allow for groundwater recharge. Infiltration trenches can be integrated naturally into landscaping and when properly maintained, can enhance aesthetics.

Infiltration trenches are effective in removing

- Sediments
- Trash
- Bacteria
- Organics
- Nutrients
- Metals
- Oil and grease



think BLUE San Diego

Planter Boxes

Site Assessment

Planter boxes require relatively little space and can be easily adapted for urban retrofits such as building and rooftop runoff catchments or into new street and sidewalk designs. Because planter boxes are typically contained systems, available space presents the most significant limitation. Contained planter boxes can be used in areas of concern as runoff is retained within the unit; when properly contained, setbacks related to building foundations may not apply. To ensure healthy vegetation in the planter box, proper plant and media selection are important considerations for accomodating the drought, ponding fluctuations, and brief periods of saturated soil conditions.

Drainage Area: Less than .35 acres.

Available Space: The footprint of the cell is dependent on drainage area and available space, typically sized 0.5–3 percent of the surrounding drainage. With treatment of roof runoff minimal pretreatment is necessary. If received runoff is expected to contain significant pollutants, then design of the planter boxes should include pretreatment.

Underground Utilities: Complete a utilities inventory to ensure that site development will not interfere with or affect the utilities.

Existing Buildings: Assess building effects (runoff, solar shadow) on the site. When completely contained, building setbacks are less of a concern.

Water Table: N/A (Planter boxes are typically completely contained).

Soil Type: Soils within the drainage area must be stabilized. If planter boxes are fully contained, local soils must provide structural support.

Areas of Concern: Contained planter boxes can be used in areas of concern as flows are usually contained within the unit.

Design Considerations & Specifications:

Topography: N/A (Planter boxes are completely contained systems consisting of a soil media bed, ponding area, and plants.)

Flow regulation: Designers should consider the natural flow regime. To avoid erosion, direct and dissipate flow as needed. Proper inlets and outlets are to be designed on the basis of anticipated volume and peak-velocity control.

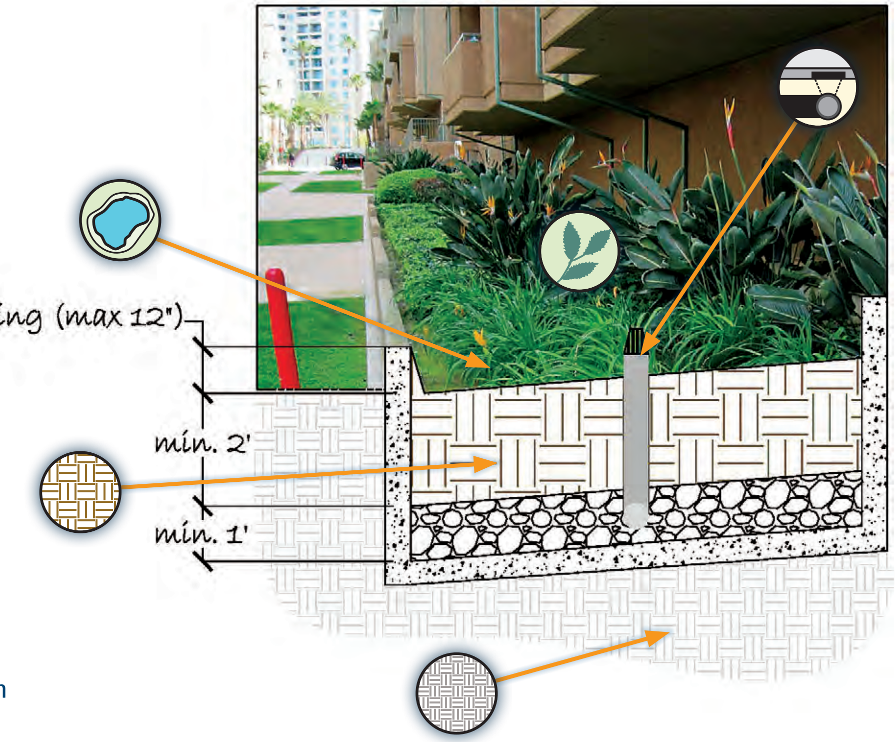
Pretreatment: If space allows, pretreatment can be incorporated into design. As upstream control devices, however, minimal pretreatment is typically incorporated into the planter box design.

Shallow ponding area: Designed to control peak flow velocities and enhance sedimentation. Ponded water must completely drain into the soil within 24 hours, with 12 hours preferred as a safety factor.

Vegetation: Vegetation is crucial to both the function and appearance. Consider native plants resilient to variable flow and climate conditions. Plants must be tolerant of drought, ponding fluctuations, and saturated soil conditions. Mimic nature with a high diversity of plant types.

Media layers: The soil media provides a rooting layer for the chosen plant palette and adequate water storage for the water quality design volume. This planting layer provides nutrients and water for vegetation. The top, organic mulch layer is designed to filter and bond finer particles. A lower sand bed filter is suggested for regions susceptible to runoff of finer particulates.

Overflow system: During high-volume storm events, the overflow or bypass system conveys overflow to in-line catchments, including storm drain system, drain ditches, or additional ponding areas.



Planter Boxes

Drainage area	Soil infiltration rate	Water table separation	Depth to bedrock	Facility slope	Inflow rate
< 0.35 ac	N/A	N/A	N/A	N/A	Mulch: 1 cfs, Grass: 3 cfs

Pollutant Removal			Runoff volume reduction	Groundwater recharge
	Sediments: High Trash: High Bacteria: High Organics: High	Nutrients: Medium Metals: High Oil and Grease: High	Low	N/A

Functional unit processes:

- Absorption
- Microbial activity
- Evapotranspiration
- Volatilization
- Infiltration
- Recharge

Maintenance Considerations

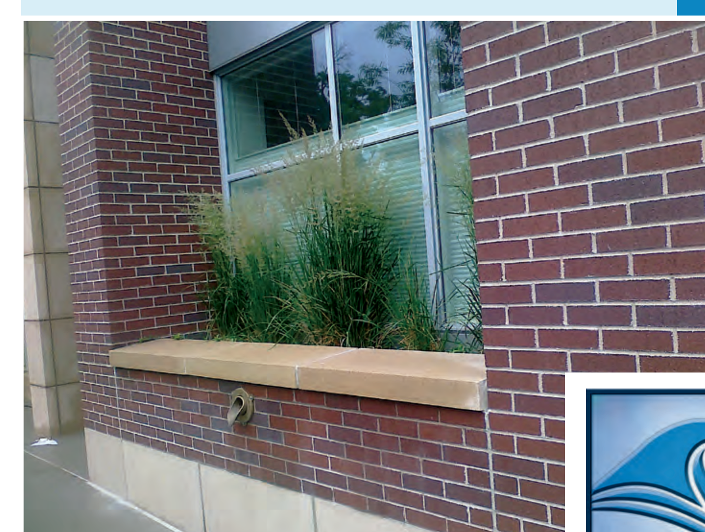
Task	Frequency	Maintenance Notes
Pruning	1–2 times/year	Nutrients in runoff often cause bioretention vegetation to flourish.
Mowing	2–12 times/year	Frequency depends on location and desired aesthetic appeal.
Mulching	1–2 times/year	Recommend maintaining a 1"–3" uniform mulch layer.
Mulch removal	1 time/2–3 years	Mulch accumulation reduces available water storage volume. Removal of mulch also increases surface infiltration rate of fill soil.
Watering	1 time/2–3 days for first 1–2 months; sporadically after establishment	If drought conditions exist, watering after the initial year may be required.
Fertilization	1 time initially	One time spot fertilization for first year may be required to establish vegetation.
Remove and replace dead plants	1 time/year	Within the first year, 10% of plants can die. Survival rates increase with time.
Inlet inspection	Once after first rain of the season, then monthly during the rainy season	Check for sediment accumulation to ensure that flow into the planter box is as designed. Remove any accumulated sediment.
Outlet inspection	Once after first rain of the season, then monthly during the rainy season	Check or erosion at the outlet and remove any accumulated mulch or sediment.
Miscellaneous upkeep	12 times/year	Tasks include trash collection, plant health, spot weeding, removing invasive species, and removing mulch from the overflow device.

Background

Planter boxes are vegetated BMP units that capture, temporarily store, and filter storm water runoff. The vegetation, ponding areas, and soil media in the planter boxes remove contaminants and retain storm water flows from small drainage areas before directing the treated storm water to an underdrain system. Typically, planter boxes are completely contained systems; for this reason, they can be used in areas where geotechnical constraints prevent or limit infiltration or in areas of concern where infiltration should be avoided. Planter boxes offer considerable flexibility and can be incorporated into small spaces, enhancing natural aesthetics of the landscape.

Planter boxes are effective for removing

- Total suspended solids and sediment
- Trash
- Heavy metals
- Bacteria
- Oil and grease
- Organics



think BLUE San Diego

Sand Filters

Site Assessment

Sand filters require less space than many LID BMPs and are typically used in areas with restricted space such as parking lots or other highly impervious areas. Sizing should be based on the *Storm Water Design Standards* Manual specifications and should take into account all runoff at ultimate build-out, including off-site drainage. The design phase should also identify where pretreatment will be needed. Aboveground units should be designed with a vegetated filter strip as a pretreatment element, and belowground units should incorporate a forebay sediment chamber.

Drainage Area: Less than 5 acres.

Available Space: The footprint of a sand filter is dependent on drainage area and available space, typically sized 2 to 3 percent the surrounding drainage. If space allows, pretreatment can be incorporated into the design.

Underground Utilities: A complete utilities inventory should be done to ensure that site development will not interfere with or affect the utilities.

Existing Buildings: If used underground, ensure that the sand filter will not interfere with existing foundations.

Water Table: Sand filters are applicable where depth to water table is more than 10 feet. If the depth is between 2 to 10 feet, underdrains should be included.

Soil Type: If infiltration is planned to existing soils, examine site compaction and soil characteristics. Determine site-specific permeability. It is ideal to have well-drained soils. If native soils show less than 0.5 in/hr infiltration rate, underdrains should be included.

Areas of Concern: Sand filters, if lined, can be used for sites with known soil contamination or *hot spots* such as gas stations. Impermeable membranes must be used to contain infiltration within areas of concern.

Design Considerations & Specifications:

Topography: While sand filters can be installed in a wide range of topography because they can be placed either at the surface or sub-surface, special cares should be added when these facilities are used where slopes are greater than 6 percent, or in areas that are not permanently stabilized drainage areas.

Flow regulation: Designers should consider the natural flow regime. To avoid erosion, direct and dissipate flow as needed. Proper inlets and outlets should be designed on the basis of anticipated volume and peak-velocity control.

Pretreatment: Two basic pretreatment configurations for sand filters are a vegetated filter strip for surface sand filter and a forebay sediment chamber for subsurface sand filter. The objective of pretreatment is to remove large solids and reduce the velocity of storm water entering the sand filter.

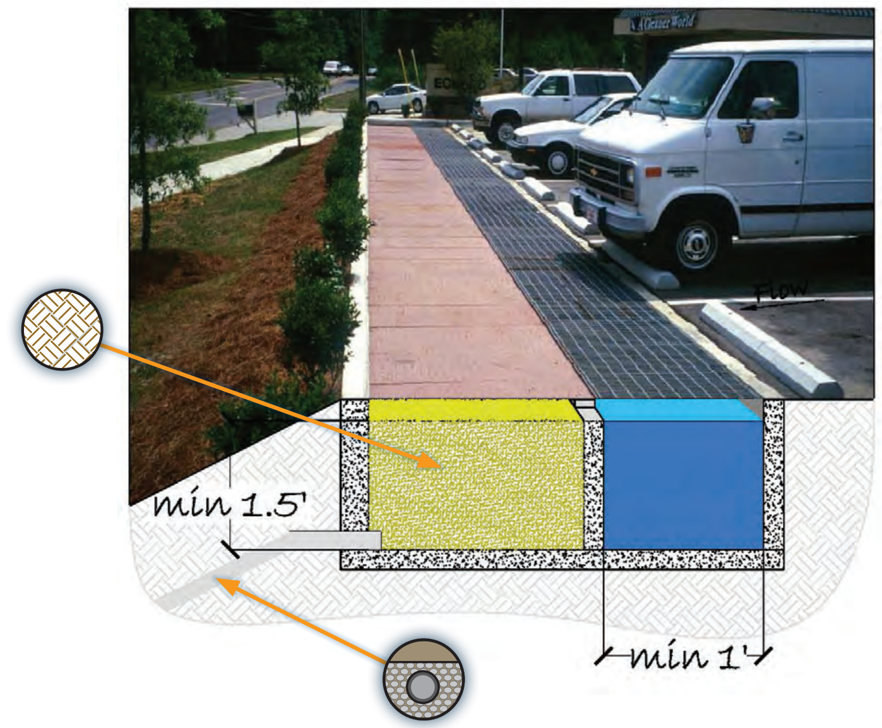
Shallow ponding area: Designed to control peak flow velocities and enhance sedimentation. Depth will be determined by the ability of the sand filter to completely drain within 24 hours and therefore will be a function of the surface area and infiltration rate of the sand media. Ponding depth should not exceed 3 feet as a safety precaution.

Vegetation: Sand filters above ground may require vegetation for pretreatment purposes.

Media layers: The media in the sand filter should be highly permeable, free of fines, stones, and other debris. Media must be more than 1.5 feet deep with at least 1 inch per hour permeability. All media should be analyzed for background levels of nutrients. Total phosphorus should not exceed 15 ppm.

Underdrain system: An underdrain must be installed if in-situ soil drainage is less than 0.5 in/hr. Below the media, the underdrain system is designed to further dissipate flow. The underdrain pipe should be at least 6 inches in diameter and installed at a 0.5 percent minimum slope.

Overflow system: During high-volume storm events, the overflow and bypass system conveys overflow to in-line catchments, including: storm drain system, drain ditches or additional ponding areas.



Sand Filters

Drainage area	Soil infiltration rate	Water table separation	Depth to bedrock	Facility slope	Inflow rate
< 2 ac	1 in/hr (UD if *insitu* soil is < 0.5 in/hr	> 10 ft (*if > 2 but < 10 ft, install UD)*	> 10 ft (*if > 2 but < 10 ft, install UD)*	< 6%	3 cfs

Polutant Removal			Runoff volume reduction	Groundwater recharge
	Sediments: High Trash: High Bacteria: Medium Organics: High	Nutrients: Low Metals: High Oil and Grease: High	Medium no UD; Low with UD	Medium no UD; Low with UD

Functional unit processes:

- Filtration
- Absorption
- Volatilization
- Infiltration
- Recharge

Maintenance Considerations

Task	Frequency	Maintenance Notes
Inlet inspection	Once after first rain of the season, then monthly during the rainy season	Check for sediment accumulation to ensure that flow into the sand filter is as designed. Remove any accumulated sediment.
Outlet inspection	Once after first rain of the season, then monthly during the rainy season	Check for erosion at the outlet and remove any accumulated sediment.
Media Inspection	2 times/year	Ispect infiltration capability and clogging of media.
Miscellaneous upkeep	12 times/year	Tasks include trash collection, spot weeding, and removing trash ans visual contamination.

Background

Either on the surface or below the surface, sand filters are filtering BMPs that remove trash and pollutants by straining storm water vertically through a sand media. They also function similarly to bioretention units as infiltration practices, though they lack the pollutant removal provided by plant uptake and biological remediation. Sand filters are often used for land uses with a large fraction of impervious surfaces and ultra-urban locations. Because sand filters can be underground, they are an ideal BMP to be used in areas with limited available surface space. However, this may make operation and maintenance more difficult.

Sand filters are effective for removing

- Total suspended solids and sediment
- Trash
- Bacteria
- Oil and grease
- Metals
- Organics

City of Portland

think BLUE San Diego

Vegetated Filter Strips

Site Assessment

Vegetated filter strips are well suited for treating runoff from roads, highways, driveways, roof downspouts, small parking lots, and other impervious surface. Vegetated filter strips require moderately permeable soil and should be designed to treat and convey runoff from the adjacent impervious surfaces; yet care must be taken as vegetated filter strips might not be suitable for large drainage areas or industrial sites. Thick vegetation must be established for vegetated filter strips to function properly; establishing vegetation might present a challenge in some situations.

Drainage Area: Should be less than 1 acre. Contributing area should not exceed twice the filter strip area. Vegetated filter strips might not be suitable for large drainage areas or industrial sites.

Available Space: The contributing area should not exceed twice the filter strip area. It should not be placed in areas where they can be highly trafficked by automobiles or foot traffic.

Underground Utilities: A complete utilities inventory should be done to ensure that site development will not interfere with or affect utilities.

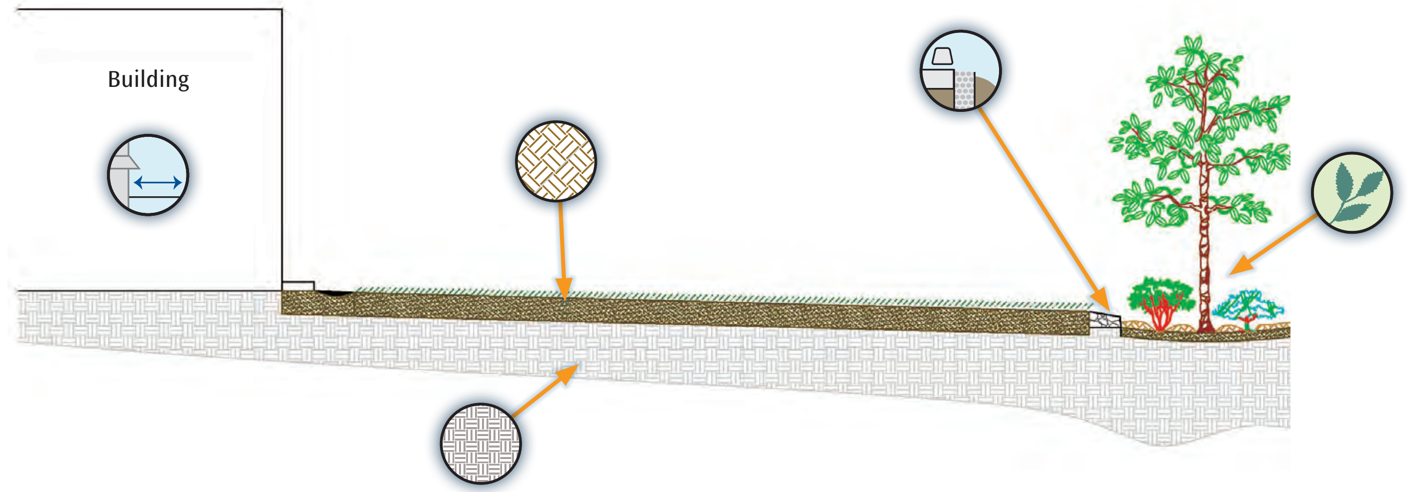
Existing Buildings: Assess building effects on the site. Vegetated filter strips must be set away from building foundations at least 10 feet.

Water Table: Vegetated filter strips must be separated from groundwater by at least 10 feet.

Soil Type: Vegetated filter strips rely on dense turf vegetation with a thick thatch, requiring a moderately permeable soil. Soil amendments may be required based on soil properties determined through testing and compared to the needs of the vegetation requirements.

Areas of Concern: Vegetated filter strips are not suggested for sites with known soil contamination or *hot spots* such as gas stations. Impermeable membrane can be used to contain flow within areas of concern.

Design Considerations & Specifications:



Topography: The filter strip should be constructed on a level contour to encourage sheet flow across the filter. To prevent ponding, the lateral slope of the filter strip should be a minimum of 2 percent and no more than 5 percent.

Flow regulation: Maintain sheet flow of runoff. Hydraulical design should be completed according to two primary criteria: maximum depth of flow and maximum flow velocity. Flow should not be concentrated; sheet flow is optimal. Depth of runoff flow in the filter strip should be limited to less than or equal to 1 inch. Maximum flow velocity should be limited to 1 foot per second. A gravel flow spreader, consisting of a gravel filled trench perpendicular to the direction of flow, can be used as an energy dissipater.

Pretreatment: A vegetated filter strip is commonly operated as a pretreatment BMP upstream of other BMPs capable of greater pollutant-removal rates. As a stand-alone BMP, vegetated filter strips can treat only low-intensity rainfall events. Length of flow is a minimum 15 feet (25 feet is preferred); however, if used as pretreatment, the minimum can be 4 feet.

Shallow ponding area: The filter strip must be constructed on a level contour to encourage sheet flow across the filter. To prevent ponding, the lateral slope of the filter strip should be 2 percent minimum and no more than 5 percent.

Vegetation: The designer should select vegetative cover for the filter strip that is appropriate for local soil and climate conditions. Consider requirements for maintenance, irrigation, and fertilization. Selected grasses or vegetation should be able to withstand storm water flows and remain viable through wet and dry periods.

Media layers: Existing soils can be used if they support adequate density of desired vegetation. Amended soils are recommended to improve infiltration capabilities and assure type and density of desired vegetation.

Overflow system: During high-volume storm events, the overflow system conveys overflow to in-line catchments, including storm drain system, drain ditches, or additional ponding areas.

Vegetated Filter Strips

Drainage area	Soil infiltration rate	Water table separation	Depth to bedrock	Facility slope	Inflow rate
< 1 ac	Any soil except fill	> 10 ft	> 10 ft	< 6%	3 cfs

			Runoff volume reduction	Groundwater recharge
Pollutant Removal	Sediments: High Trash: Medium Bacteria: Low Organics: Medium	Nutrients: Low Metals: High Oil and Grease: High	Low	Low

Functional unit processes:

- Absorption
- Microbial activity
- Evapotranspiration
- Retention
- Denitrification
- Volatilization
- Infiltration
- Recharge

Maintenance Considerations

Task	Frequency	Maintenance Notes
Mowing	2–12 times per year	As needed to maintain aesthetics. Grass height should be a minimum of 2 inches.
Inlet inspection	Once after the first rain of the season, then monthly during the rainy season.	Check for sediment accumulation to ensure that flow into the system is designed. Remove any accumulated sediment.
Miscellaneous upkeep	12 times per year	Tasks include trash collection and spot weeding.

Background

Vegetated filter strips are broad, sloped, vegetated areas that enhance storm water treatment and conveyance. Vegetated filter strips are effective for treating low-intensity storms and are commonly used as first-in-line pretreatment for sequential treatment train BMPs.

Often requiring minimal earthwork, planting and construction materials, vegetated filter strips offer a relatively inexpensive method to treat and convey storm water. As an additional benefit, when designed and maintained properly, vegetated filter strips create an aesthetically pleasing landscape.

Vegetated filter strips are effective for removing

- Total suspended solids and sediment
- Trash
- Oil and grease
- Organics
- Metals

Vegetated Swales

Site Assessment

Site evaluation must first determine the volume of water to be conveyed through the vegetated swale. To accommodate the volume, design considerations must incorporate three components: the longitudinal slope, resistance to flow, and cross-sectional area. Incorporating vegetated filter strips along the top of the channel banks and using sheet flow for entry can enhance treatment in vegetated swales. Avoid slopes and soil conditions that limit infiltration as they could lead to excessive ponding.

Drainage Area: Less than 2 acres.

Available Space: The footprint of vegetated swales is dependent on drainage area, typically sized as 10 to 20 percent of the upstream drainage. If space allows, pretreatment can be incorporated into design.

Underground Utilities: A complete utilities inventory should be done to ensure that site development will not interfere with or affect utilities.

Existing Buildings: Assess building effects (runoff, solar shadow) on the site. Vegetated swales must be setback from building foundations at least 10 feet.

Water Table: Vegetated swales are applicable where depth to water table is more than 2 feet to limit the potential of undesired ponding.

Soil Type: Examine site compaction and soil characteristics. Determine site-specific permeability; it is ideal to have well-drained soils for volume reduction and treatment in vegetated swales.

Areas of Concern: Vegetated swales should not be used to receive storm water runoff from storm water *hot spots*, unless adequate pretreatment is provided upstream

Design Considerations & Specifications:

Topography: The longitudinal slope over the length of the swale should not exceed 2 percent. Bioswales can be used effectively in areas with slopes from 2 to 5 percent by installing check dams to prevent erosive flow velocities. Check dams should be constructed as required such that the slope of each section between check dams does not exceed 2 percent.

Flow regulation: Designers should consider the natural flow regime. To avoid erosion, direct and dissipate the flow as needed; proper inlets and outlets should be designed on the basis of anticipated volume and peak-velocity control.

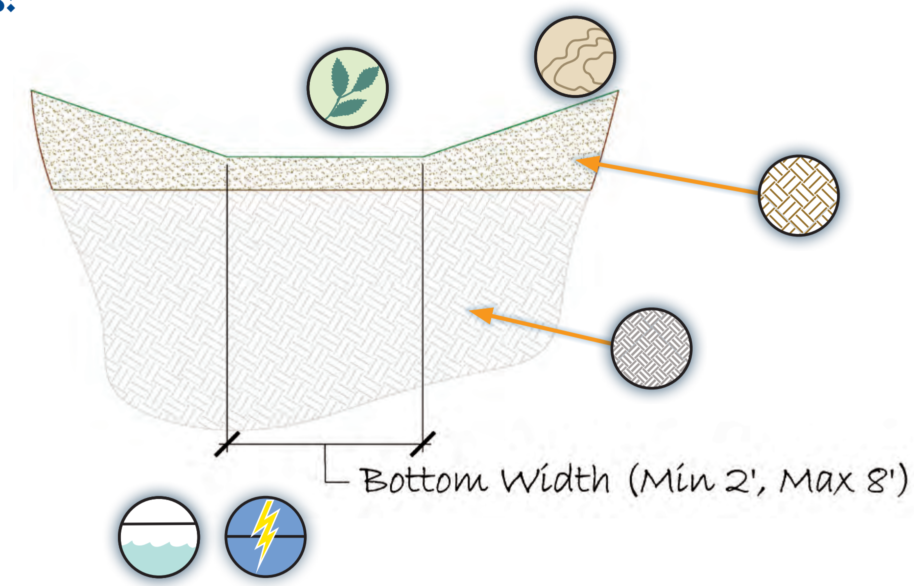
Pretreatment: Pretreatment is an optional component when space allows. Pretreatment is recommended in areas with high sediment loading. Commonly includes a filter strip or grass buffer. Objective of pretreatment is to enhance filtration and sedimentation of larger particles and debris from heavily trafficked areas.

Shallow ponding area: Designed to enhance sedimentation and infiltration. Ponded water must completely drain into the soil within 24 hours, with 12 hours preferred as a safety factor.

Vegetation: Vegetation is crucial to both the function and appearance. Consider native plants resilient to variable flow. Mimic nature with a high diversity of plant types. Plants must be somewhat tolerant of drought, ponding fluctuations, and saturated soil conditions.

Media layers: A vegetated swale may use bioretention soil media to improve water quality, reduce the runoff volume, and modulate the peak runoff rate while also providing conveyance of excess runoff. Soil media depth must be 2 feet minimum for grassed cells and 3 feet minimum for shrub/tree cells. The soil media provides treatment through filtration, adsorption, and biological uptake.

Overflow system: During high-volume storm events, the overflow system conveys overflow to in-line storm drain systems.



Vegetated Swales

Drainage area	Soil infiltration rate	Water table separation	Depth to bedrock	Facility slope	Inflow rate
< 2 ac	> 0.5 in/hr *(if < 0.5 in/hr, install UD)*	> 2 ft	> 10 ft *(if > 2 but < 10 ft, install UD)*	< 4%	Mulch: 1 cfs, Grass: 3 cfs

Pollutant Removal		Runoff volume reduction	Groundwater recharge
Sediments: Medium Trash: Low Bacteria: Low Organics: Medium	Nutrients: Low Metals: Medium Oil and Grease: Medium	Low	Low

Functional unit processes:

- Absorption
- Microbial activity
- Evapotranspiration
- Filtration
- Volatilization
- Infiltration

Maintenance Considerations

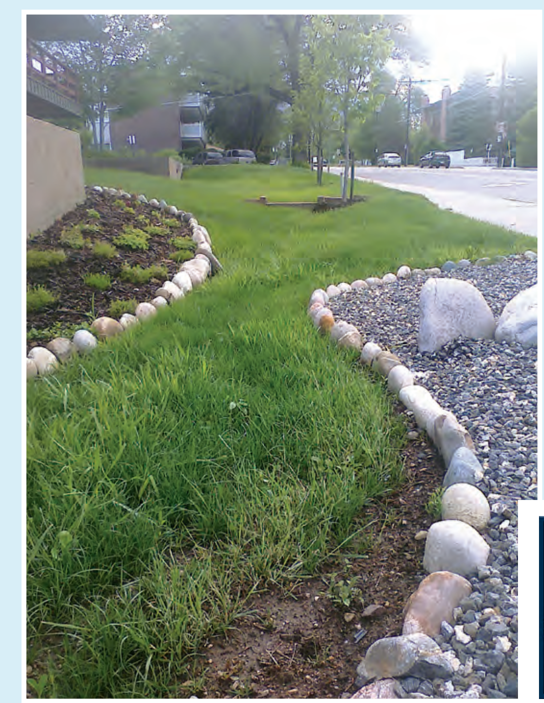
Task	Frequency	Maintenance Notes
Inlet Inspection	Twice annually	Check for sediment accumulation and erosion within the swale.
Mowing	2–12 times per year	Frequency depends upon location and desired aesthetic appeal.
Watering	1 time per 2–3 days for first 1–2 months; sporadically after establishment	If drought conditions exist, watering after the initial year may be required.
Fertilization	1 time initially	One time spot fertilization for "first year" vegetation.
Remove and replace dead plants	1 time per year	Within first year 10 percent of plants may die. Survival rates increase with time.
Check dams	One prior to the wet season and monthly during the wet season	Check for sediment accumulation and erosion around or underneath the dam materials.
Miscellaneous upkeep	12 times per year	Tasks include trash collection and spot weeding.

Background

Vegetated swales are shallow, open channels that are designed remove pollutants such as sediment by physically straining and filtering water through vegetation within the channel. Additionally, swales can serve as conveyance for storm water and can be used in place of traditional curbs and gutters; however, when compared to traditional conveyance systems the primary objective of a vegetated swale is filtration and water quality enhancement rather than conveyance. Some designs also include infiltration through subsurface soil media, or underlying soils to reduce peak runoff volume during storms.

Vegetated swales are effective for removing

- Total suspended solids and sediment
- Oil and grease
- Organics
- Metals



think BLUE San Diego

Cisterns & Rain Barrels

Site Assessment

Cisterns should be placed near a roof downspout. If the structural base of the site is in question, complete a geotechnical evaluation to determine the structural capacity of soils. Cisterns are available commercially in numerous sizes, shapes, and materials. Many are made to custom fit the available space and can be short and fat, tall and skinny, round, rectangular, or almost any size. Before entering the cistern, flows should be adequately filtered to remove debris and larger particles that could clog the inlet or outlet; first-flush diverters direct an initial volume of water past the cistern to ensure that debris and particles have washed away. Cistern design must incorporate an overflow system to ensure that excess flow is properly directed away from adjacent structures.

Drainage Area: Rooftop area

Available Space: The available space and resources, rooftop drainage area, and the design storm volume will dictate the size of the cistern or rain barrel.

Underground Utilities: Complete a utilities inventory to ensure that site development will not interfere with or affect utilities.

Existing Buildings: Ideally, cistern overflows should be set away from building foundations at least 5 feet.

Soil Type: Ensure that the cistern is securely mounted on stable soils to avoid erosion around the base or significant soil compaction with the weight of a full cistern. If structural capacity of the site is in question, complete a geotechnical report to determine the structural capacity of soils.

Areas of Concern: Overflow volume or outflow volume should not be directed to areas where infiltration is not desired. Such areas may include *hot spots*, where soils can be contaminated, such as gas stations.

Design Considerations & Specifications:

Topography: Determine how to incorporate cisterns into the site layout, topography should be considered to ensure that the cistern is securely installed.

Flow regulation: Inflow is determined by the capacity of the rain gutters. First flush diverters can be used to prevent small particles from entering the system. The outflow volume of the cistern/rain barrel should be allowed to slowly release, preferably into an inline infiltration BMP.

Pretreatment: Inlet filters should be installed to remove debris and large particles. First-flush diverters should be installed after the inlet filter to divert the initial volume of water away from the cistern.

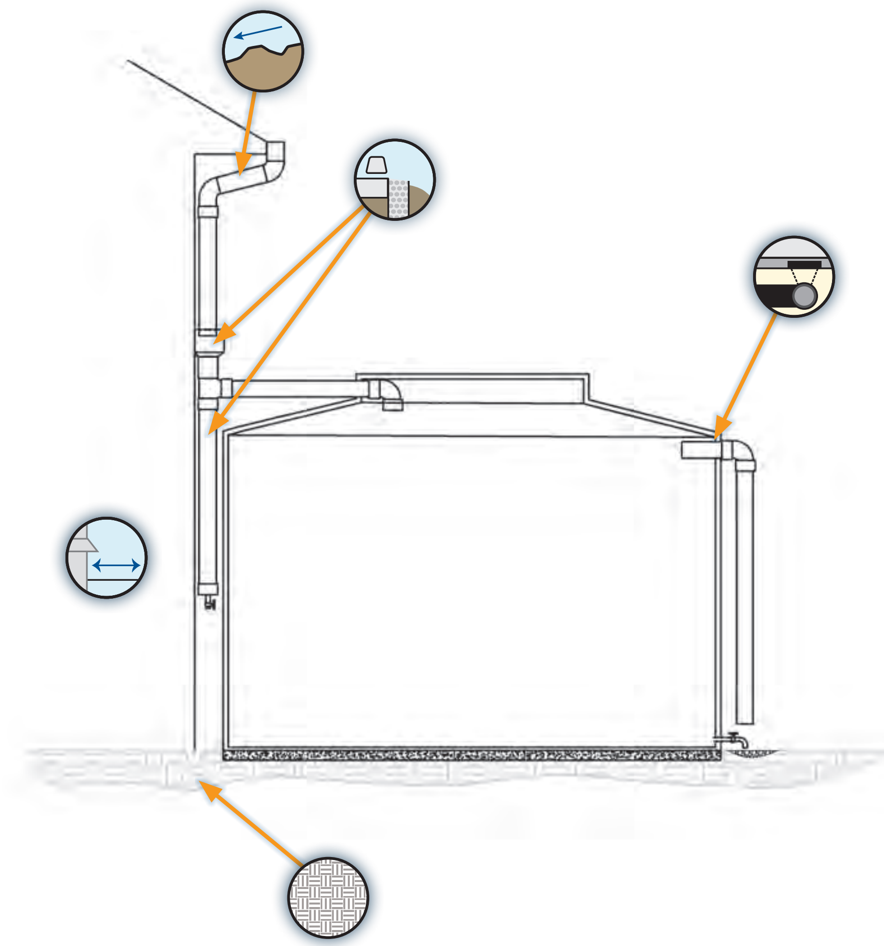
Shallow ponding area: N/A

Vegetation: Overflow from cistern should be directed into a vegetated area such as a bioretention unit.

Media layers: N/A

Underdrain system: N/A

Overflow system: All cisterns should have an overflow for runoff volumes that exceed the capacity of the cistern. During high-volume storm events, the overflow system conveys overflow to traditional conveyance or, preferably, storm water BMPs such as a bioretention cell or other pervious surfaces that enhance infiltration.



Cisterns & Rain Barrels

Drainage area	Soil infiltration rate	Water table separation	Depth to bedrock	Facility slope	Inflow rate
Rooftop area	Dependent upon downstream area	Below-grade tanks must be above the water table and bedrock		< 5%	Capacity of rain gutters

Pollutant Removal	Pollutant removal provided by downstream BMP, refer to specific downstream BMP (or BMPs) for pollutant removal	Runoff volume reduction	Groundwater recharge
		Medium	Dependent upon downstream BMP

Functional unit processes:

- Detention
- Peak flow reduction

Maintenance Considerations

Task	Frequency	Maintenance Notes
Inlet inspection	Annually before the rainy season	Clean gutters of debris that have accumulated, check for leaks.
Remove accumulated debris	Monthly (during the rainy season)	Clean debris screen to allow unobstructed storm water flow into the cistern.
Structure inspection	Biannual (before and after the rainy season)	Check cistern for stability, anchor system if necessary.
Structure inspection	Annual	Check pipe and valve connection for leaks.
Miscellaneous upkeep	Annual	Make sure cistern manhole is accessible, operational, and secure.
Miscellaneous upkeep	Before any major wind-related storms	Add water to half full (if the tank is less than half full).

Background

Cisterns are storage vessels that can collect and store rooftop runoff from a downspout for later use. Sized according to rooftop area and desired volume, cisterns can be used to collect both residential and commercial building runoff. By temporarily storing the runoff, less runoff enters the storm water drainage system, thereby reducing the amount of pollutants discharged to surface waters. Additionally, cisterns and their smaller counterpart referred to as rain barrels are typically used in a treatment train system where collected runoff is slowly released into another BMP or landscaped area for infiltration. Because of the peak-flow reduction and storage for potential beneficial uses, subsequent treatment train BMPs can be reduced in size. Cisterns can collect and hold water for commercial uses, most often for irrigation. Smaller cisterns (a.k.a., rain barrels with less than 100 gallons) can be used on a residential scale.

Cisterns are effective in

- Treatment-train flow control
- Peak flow reduction
- Non-potable beneficial use

think BLUE San Diego

Appendix E. Plant List

The following Plant List was developed to aid in the selection of plant material for BMPs in the City of San Diego. Plants listed below for 'Landscape Position 1' are mostly documented in literature, or by vendors, as capable of withstanding brief seasonal flooding. Due to the wide range of species that thrive in San Diego, the designer may have knowledge of additional species that will function well in specific BMPs. In using this plant list as a starting point for selection of plant material, the designer should also consider the requirements of the individual site and its microclimatic conditions before making final plant selections. Only native non-invasive species will be planted in City of San Diego Multi-Habitat Planning Areas (MHPAs), or in areas designated as natural open space.

Plant List for BMPs in the City of San Diego

Trees		San Diego Co. Native - SD California Native - CA Non-Native - X	Landscape Position: 1 - Low[1], 2 - Mid[2], 3 - High[3]	Mature Size (height x width)	Irrigation Demands: High - H ▪ Moderate - M Low - L ▪ Rainfall Only - N	Light Requirements Sun - SU ▪ Shade - SH Part Shade - PS	Season Evergreen - E, Deciduous – D Semi-Evergreen - SE	Coastal Exposure? Yes - Y	Sunset Zones City of San Diego zones: 21, 23 and 24
Acer negundo californicum[4]	**California Box Elder**	**SD**	**1**	**60'x60'**	**M-H**	**SU, PS**	**D**		**A2-3; 1-10, 12-24**
Alnus rhombifolia[4]	**White Alder**	**SD**	**1**	**50-90' x 40'**	**H**	**SU, PS, SH**	**D**	**Y**	**1b-10, 14-21**
Cercis occidentalis[4]	**Western Redbud**	**SD**	**1**	**10-18' x 10-18'**	**M**	**SU, PS**	**D**		**2-24**
Chilopsis linearis[4]	**Desert Willow**	**SD**	**1**	**15-30' x 10-20'**	**L-M**	**SU**	**D**		**3b, 7-14, 18-23**
Gleditsia triacanthos var. internis	Thornless Honeylocust	X	1	35-70'x 25-35'	M-H	SU	D		1-16, 18-20
Ilex vomitoria	Yaupon Holly	X	1	15-20' x 10-15'	H	SU, PS	E		4-9, 11-24
Liquidambar styraciflua	Sweet Gum	X	1	60' x 20-25'	M-H	SU	D		3-9, 14-24
Magnolia grandiflora	Southern Magnolia	X	1	80' x 60'	H	SU, PS	E	Y	4-12, 14-24, H1-2
Metasequoia glyptostroboides	Dawn Redwood	X	1	90' x 20'	H	SU	D		A3, 3-10, 14-24
Myrica californica	Pacific Wax Myrtle	CA	1	10-30 x 10-30'	M	SU	E	Y	4-9, 14-24
Olneya tesota	Desert Ironwood	SD	2	15-30' x 15-30'	N-M	SU	E		8,9,11-14, 18-23

Trees		San Diego Co. Native - SD California Native - CA Non-Native - X	Landscape Position: 1 - Low[1], 2 - Mid[2], 3 - High[3]	Mature Size (height x width)	Irrigation Demands: High - H ▪ Moderate - M Low - L ▪ Rainfall Only - N	Light Requirements Sun - SU ▪ Shade - SH Part Shade - PS	Season Evergreen - E, Deciduous - D Semi-Evergreen - SE	Coastal Exposure? Yes - Y	Sunset Zones City of San Diego zones: 21, 23 and 24
Platanus racemosa[4]	**California Sycamore**	**SD**	**1**	**30-80' x 20-50'**	**M-H**	**SU**	**D**	**Y**	**4-24**
Populus fremontii[4]	**Western Cottonwood**	**SD**	**1**	**40-60' x 30'**	**H**	**SU**	**D**		**1-12, 14-21**
Quercus agrifolia[4]	**Coast Live Oak**	**SD**	**1**	**20-70' x 20-70'**	**N-L**	**SU**	**E**	**Y**	**7-9, 14-24**
Quercus engelmannii*	Engelmann Oak	SD	2	40-50' x 70'	N-L	SU	E		7-9, 14-24
* Species not recommended for areas of coastal influence. Better suited to locations east of I-15 (north Hwy. 52) and areas east of Hwy 125 (south of Hwy. 52).									
Salix gooddingii[4]	**Western Black Willow**	**SD**	**1**	**20-40'x20-30'**	**H**	**SU**	**D**		**-**
Sambucus mexicana[4]	**Mexican Elderberry**	**SD**	**1**	**10-30' x 8-20'**	**M-H**	**SU, PS**	**SE**		**2-24, H1**
Taxodium ascendens	Pond Cypress	X	1	50-60'x10-15'	L-H	SU	D		-
Taxodium distichum	Bald Cypress	X	1	50-70' x 20-30'	L-H	SU	D		2-10, 12-24
Umbellularia californica	California Bay	CA	1	20-25' x 20-25'	L-H	SU, PS, SH	E	Y	4-9, 14-24
Washingtonia filifera[4]	**California Fan Palm**	**SD**	**1**	**60' x 20'**	**L-M**	**SU**	**E**		**8,9,10,11-24,H1-2**

Shrubs		**San Diego Co. Native** - SD **California Native** - CA **Non-Native** - X	**Landscape Position:** 1 - Low[1], 2 - Mid[2], 3 - High[3]	**Mature Size** (height x width)	**Irrigation Demands:** High - H ▪ Moderate - M Low - L ▪ Rainfall Only - N	**Light Requirements** Sun - SU ▪ Shade - SH Part Shade - PS	**Season** Evergreen - E, Deciduous - D Semi-Evergreen - SE	**Coastal Exposure?** Yes - Y	**Sunset Zones** City of San Diego zones: 21, 23 and 24
Baccharis pilularis 'Pigeon Pt.'	Dwarf Coyote Bush	CA	3	1-2' x 6'	L-M	SU	E	Y	5-11, 14-24
Baccharis salicifolia[4]	**Mulefat**	**SD**	**1**	**4-10'x8'**	**M-H**	**SU, PS, SH**	**SE**		**-**
Carpenteria californica	Bush Anemone	CA	1	4-6' x 4-6"	L-M	SU, PS	E		5-9, 14-24
Heteromeles arbutifolia	Toyon	SD	3	6-10' x 6-10'	M	SU, PS	E	Y	5-9, 14-24
Ilex burfordii 'Nana'	Dwarf Burford Holly	X	1	6' x 6'	H	SU, PS	E		4-24
Mahonia aquifolium 'Compacta'	Compact Oregon Grape	CA	1	2-3' x 5'	L-H	SU, PS	E		2-12, 14-24
Mahonia repens	Creeping Oregon Grape	CA	2	1' x 3'	N-L	SU, PS	E		2B-9, 14-24
Philadelphus lewisii	Wild Mock Orange	CA	2	4-10' x 4-10'	M-H	SU, PS	E		1-10, 14-24
Rhamnus californica 'Little Sur'	Dwarf California Coffeeberry	SD	2	3-4' x 3'	N-M	SU, PS	E	Y	4-9, 14-24, H1, H2
Rosa californica[4]	**California Rose**	**SD**	**1**	**3-6' x 6'**	**M-H**	**SU, PS, SH**	**SE**	**Y**	**-**
Ruellia peninsularis	Desert Ruellia	X	3	4' x 6'	N-M	SU, PS	E		12-13, 21-24
Russelia equisetiformis	Coral Fountain	X	2	5' x 5'	M-H	SU, PS	E		14, 19-24, H1, H2
Russelia x St. Elmo's Fire	Red Coral Fountain	X	2	4' x 6-8'	M-H	SU, PS	E		-
Styrax officinalis	Snowdrop Bush	SD	2	6-8' x 5'	H	SU, PS	D		4-9, 14-21
Symphoricarpos mollis	Southern California Snowberry	SD	2	1-3'x3'	L-M	PS	D	Y	2-10, 14-24

Perennials		San Diego Co. Native - SD California Native - CA Non-Native - X	Landscape Position: 1 - Low[1], 2 - Mid[2], 3 - High[3]	Mature Size (height x width)	Irrigation Demands: High - H ▪ Moderate - M Low - L ▪ Rainfall Only - N	Light Requirements Sun - SU ▪ Shade - SH Part Shade - PS	Season Evergreen - E, Deciduous - D Semi-Evergreen - SE	Coastal Exposure? Yes - Y	Sunset Zones City of San Diego zones: 21, 23 and 24
Achillea millefolium[4]	**Common Yarrow**	**SD**	**1**	**3' x 2'**	**L-M**	**SU**	**SE**	**Y**	**A1-A3, 1-24**
Anemopsis californica[4]	**Yerba Mansa**	**SD**	**1**	**1'x2-4'**	**H**	**SU, PS, SH**	**D**		**-**
Aquilegia formosa	Western Columbine	SD	2	1-3' x 1.5'	H	SU, PS	SE		A1-3, 1-11, 14-24
Artemisia palmeri[4]	**San Diego Sagewort**	**SD**	**2**	**2-3'x3'**	**H**	**SU, PS**	**SE**	**Y**	**-**
Asarum caudatum	Wild Ginger	CA	2	1' x 3'	H	SH	E		4-6, 14-24
Dietes iridioides	White Fortnight Lily	X	2	3' x 3'	M-H	SU, PS	E		8-9, 12-24, H1, H2
Epilobium californica[4]	**California Fuscia**	**CA**	**1**	**1-2'x3-5'**	**L-M**	**SU**	**SE**		**2-11, 14-24**
Fragaria chiloensis[4]	**Beach Strawberry**	**CA**	**1**	**4-8" x spreading**	**H**	**SU, PS**	**E**	**Y**	**4-24**
Hemerocallis spp.	Daylily	X	2	2-4' x 2-4'	H	SU, PS	E	Y	1-24, H1, H2
Iris douglasiana	Pacific Coast Iris	CA	1	2' x 2'	M	SU, PS	E	Y	4-9, 14-24
Iris missouriensis	Western Blue Flag Iris	SD	1	2' x 2'	M-H	SU, PS	D		1-10, 14-24
Iva hayesiana[4]	**San Diego Marsh Elder**	**SD**	**2**	**1' x 5'**	**N**	**SU, PS**	**SE**	**Y**	**17, 23-24**
Jaumea carnosa	Jaumea	SD	1	<1' x spreading	H	SU	E		-
Polystichum munitum	Western Sword Fern	CA	2	2-4' x 2-4'	H	SH	E	Y	A3, 2-9, 14-24
Potentilla glandulosa	Sticky Cinquefoil	SD	1	2' x 3'	M-H	SU, PS, SH	E	Y	-
Ribes viburnifolium	Evergreen Currant	SD	3	3-6' x 12'	N-M	SU, PS	E	Y	5,7-9,14-17, 19-24

Perennials		San Diego Co. Native - SD California Native - CA Non-Native - X	Landscape Position: 1 - Low[1], 2 - Mid[2], 3 - High[3]	Mature Size (height x width)	Irrigation Demands: High - H ▪ Moderate - M Low - L ▪ Rainfall Only - N	Light Requirements Sun - SU ▪ Shade - SH Part Shade - PS	Season Evergreen - E, Deciduous - D Semi-Evergreen - SE	Coastal Exposure? Yes - Y	Sunset Zones City of San Diego zones: 21, 23 and 24
Salicornia pacifica (or virginica)[4]	**Pickleweed**	**SD**	**1**	**1-2' x spreading**	**H**	**SU**	**SE**	**Y**	**-**
Salvia uliginosa	Bog Sage	X	2	4-6' x 3-4'	M-H	SU	E		6-9, 14-24
Satureja douglasii	Yerba Buena	CA	2	<1' x 3'	H	PS	E		4-9, 14-24
Satureja mimuloides	Monkeyflower Savory	CA	1	1-3' x 1-3'	M-H	SU, PS	D		-
Sisyrinchium bellum[4]	**Blue-eyed Grass**	**SD**	**1**	**6-18" x 6-18"**	**M-H**	**SU, PS**	**E**	**Y**	**2-9, 14-24**
Trifolium wormskioldii	Coast Clover	SD	1	2' x spreading	H	SU	D		-
Zantedeschia aethiopica	Common Calla	X	2	2-4' x 2-4'	H	SU, PS	E		5-6, 8-9, 12-24, H1, H2

Grasses & Grass-Like Plants		San Diego Co. Native - SD California Native - CA Non-Native - X	Landscape Position: 1 - Low[1], 2 - Mid[2], 3 - High[3]	Mature Size (height x width)	Irrigation Demands: High - H ▪ Moderate - M Low - L ▪ Rainfall Only - N	Light Requirements Sun - SU ▪ Shade - SH Part Shade - PS	Season Evergreen - E, Deciduous - D Semi-Evergreen - SE	Coastal Exposure? Yes - Y	Sunset Zones City of San Diego zones: 21, 23 and 24
Bouteloua gracilis	Blue Grama	CA	2	1-2' x 1'	L	SU	D		1-3, 7-11,14,18-21
Buchloe dactyloides 'UC Verde'	'UC Verde' Buffalograss	X	1	6-8" x spreading	L-H	SU	D		-
Carex praegracilis	California Field Sedge	SD	1	1' x 2'	M-H	SU, PS, SH	E	Y	-
Carex spissa[4]	**San Diego Sedge**	**SD**	**1**	**5' x 5'**	**H**	**SU, PS**	**SE**	**Y**	**7-9, 14-17, 19-24**
Chondropetalum tectorum	Small Cape Rush	X	1	3-4' x 3-4'	M-H	SU, PS	E	Y	8-9, 14-24
Cyperus eragrostis[4]	**Umbrella Sedge**	**SD**	**1**	**2-3'x spreading**	**H**	**SU, PS**	**SE**		**-**
Distichlis spicata[4]	**Salt Grass**	**SD**	**1**	**1' x 3'**	**M-H**	**SU, PS**	**D**	**Y**	**-**
Eleocharis macrostachya[4]	**Common Spike Rush**	**SD**	**1**	**1-3' x 2'**	**H**	**SU, PS**	**E**	**Y**	**-**
Elymus glaucus[4]	**Blue Wild Rye**	**SD**	**1**	**2-4' x 5'**	**L-M**	**SU, PS**	**SE**		**-**
Equisetum hyemale ssp. affine	Horsetail Reed	SD	1	4' x spreading	H	SU, PS	E		1-24
Festuca californica	California Fescue	CA	1	2-3' x 1-2'	M-H	SU, PS	E	Y	4-9, 14-24
Festuca rubra	Creeping Red Fescue	CA	1	1-2' x spreading	H	SU, PS	E		A2-3, 1-10, 14-24
Juncus effusus	Soft Rush	SD	1	2.5' x 2.5	M-H	SU, PS	E		1-24, H1
Juncus mexicanus[4]	**Mexican Rush**	**SD**	**1**	**2' x 2'**	**M-H**	**SU, PS**	**E**		**-**
Juncus patens[4]	**California Gray Rush**	**CA**	**1**	**2' x 2'**	**L-H**	**SU, PS**	**E**		**4-9, 14-24**

Grasses & Grass-Like Plants		San Diego Co. Native - SD California Native - CA Non-Native - X	Landscape Position: 1 - Low[1], 2 - Mid[2], 3 - High[3]	Mature Size (height x width)	Irrigation Demands: High - H ▪ Moderate - M Low - L ▪ Rainfall Only - N	Light Requirements Sun - SU ▪ Shade - SH Part Shade - PS	Season Evergreen - E, Deciduous - D Semi-Evergreen - SE	Coastal Exposure? Yes - Y	Sunset Zones City of San Diego zones: 21, 23 and 24
Muhlenbergia rigens[4]	**Deer Grass**	**SD**	**1**	**2-4' x 3-4'**	**L**	**SU**	**E**		**4-24**
Sesleria nitida	Gray Moore Grass	X	2	18"x15"	M	SU, PS	E		-
Schoenoplectus californicus[4]	**California Bulrush**	**SD**	**1**	**10' x spreading**	**H**	**SU, PS, SH**	**E**		**-**
Sporobolus airoides	Alkali Dropseed	CA	1	3' x 3'	L-M	SU	D		1-24
Zephyranthes candida	Rain Lily	X	1	12"x12"	H	SU, PS	E		4-9, 12-24, H1, H2

Annuals and Short-Lived Perennials		San Diego Co. Native - SD California Native - CA Non-Native - X	Landscape Position: 1 - Low[1], 2 - Mid[2], 3 - High[3]	Mature Size (height x width)	Irrigation Demands: High - H ▪ Moderate - M Low - L ▪ Rainfall Only - N	Light Requirements Sun - SU ▪ Shade - SH Part Shade - PS	Season Evergreen - E, Deciduous - D Semi-Evergreen - SE	Coastal Exposure? Yes - Y	Sunset Zones City of San Diego zones: 21, 23 and 24
Limnanthes douglasii	Meadowfoam	CA	1	6-12" x 6-12"	H	SU	-		1-9, 14-24
Limnanthes gracilis ssp. Parishii	Parish Meadowfoam	SD	2	6-12" x 6-12"	H	SU	-		-
Lupinus succulentus[4]	**Arroyo Lupine**	**SD**	**2**	**3'x3'**	**M-H**	**SU**	**-**		**7-24**
Oenothera elata[4]	**Yellow Evening Primrose**	**SD**	**1**	**2-3' x 2-3'**	**L-H**	**SU, PS**	**E**		**5-7, 14-24**
Pluchea odorata[4]	**Salt Marsh Fleabane**	**SD**	**1**	**2-3' x 1-2'**	**H**	**SU, PS**	**SE**		**-**
Vines									
Vitis californica	California Grape	SD	1	30'	N-L	SU, PS	D		4-24

Footnotes

1. Landscape Position 1 (Low): These areas are the base or lowest point of the BMP and experience seasonal flooding. Seasonal flooding for bioretention areas is typically 9" deep, for up to 24 hours (the design infiltration period for a bioretention area). If parts of the bioretention area are to be inundated for longer durations or greater depth the designer should develop a plant palette with longer term flooding in mind. Several of the species listed as tolerant of seasonal flooding may be appropriate, but the acceptability of each species considered should be researched and evaluated on a case-by-case basis.

2. Landscape Position 2 (Mid): These areas are typically along the side slopes of the BMP and may be low but are not expected to flood. However, they are likely to have saturated soils for extended periods of time.

3. Landscape Position 3 (High): These areas are generally on well-drained slopes adjacent to stormwater BMPs. These areas will not be inundated and will typically dry out quickly after the storm event.

4. **Bolded species have been observed within the City of San Diego and are know to be suitable for the recommended landscape position.**

General Notes

1. The Landscape Position is the lowest area recommended for each species. Plants in areas 1 and 2 may also be appropriate for higher locations.

2. When specifying plants, availability should be confirmed by local nurseries. Some species may need to be contract-grown and it may be necessary for the contractor to contact the nursery well in advance of planting as some species may not be available on short notice.

References

Bornstein, Carol et. al., *California Native Plants for the Garden*. Los Olivos, CA: Cachuma Press, 2007.

Brenzel, Kathleen N. et. al., eds. *Sunset Western Garden Book*. Menlo Park, CA: Sunset Publishing Corporation, 2001.

Faber, Phyllis M. and Robert F. Holland. *Common Riparian Plants of California, a Field Guide for the Layman*. Mill Valley, CA: Pickleweed Press, 1996.

Jull, Laura G., *EXTENSION RESPONDS: FLOOD 'The Effects of Flooding on Plants and Woody Plants Tolerant to Wet Soil'*. Agriculture & Natural Resources, University of Wisconsin-Extension <http://www.uwex.edu/CES/ag/issues/effectsoffloodingonplants.html>

Lightner, James. *San Diego County Native Plants*. San Diego, CA: San Diego Flora, 2006

Ranney, Thomas G. et. al., *'Qualifiers for Quagmires: Landscape Plants for Wet Sites'*. Horticulture Information Leaflets, North Carolina State University <http://www.ces.ncsu.edu/depts/hort/hil/hil-646.html>

Sigg, J. et. al., *'LID Native Plant List for San Francisco'*. September 2008. California Native Plant Society <https://infrastructure.sfwater.org/fds/fds.aspx?lib=SFPUC&doc=428957&ver=1&data=165148445>

Appendix 3 'Bioretention Plant List'. Kingcounty.gov. <http://www.kingcounty.gov/transportation/kcdot/Roads/Environment/LowImpactDevelopment_MilitaryRd/~/media/transportation/kcdot/roads/engineering/documents/militarys272/PSATLIDManualPlantList.ashx>

Appendix F. Inspection and Maintenance Checklist

Inspection and Maintenance Checklist for a Bioretention Area

Property Address: ______________________ Property Owner: ______________________

Treatment Measure No.: __________ Date of Inspection: __________ Type of Inspection: ☐ Monthly ☐ Pre-Wet Season ☐ End of Wet Season ☐ After heavy runoff

Inspector(s): ______________________ ☐ Other: ______________

Defect	Conditions when Maintenance is Needed	Maintenance Needed? (Y/N)	Comments[a]	Results Expected when Maintenance is Performed
1. Standing water	Water stands in the bioretention area between storms and does not drain within 24 hours after rainfall.			There should be no areas of standing water once inflow has ceased. Any of the following could apply: sediment or trash blockages removed, improved grade from head to foot of bioretention area, scarify media surface, flush underdrains.
2. Trash and debris accumulation	Trash and debris accumulated in the bioretention area and around the inlet and outlet.			Trash and debris removed from bioretention area and disposed of properly.
3. Sediment	Evidence of sedimentation in bioretention area.			Material removed so that there is no clogging or blockage. Material is disposed of properly.
4. Erosion	Channels have formed around inlets, there are areas of bare soil, or other evidence of erosion.			Obstructions and sediment removed so that water flows freely and disperses over a wide area. Obstructions and sediment are disposed of properly.
5. Vegetation	Vegetation is dead, diseased or overgrown.			Vegetation is healthy and attractive.
6. Mulch	Mulch is missing or patchy. Areas of bare earth are exposed or mulch layer is less than 3 inches deep.			All bare earth is covered, except mulch is kept 6 inches away from trunks of trees and shrubs. Mulch is even, at a depth of 3 inches.
7. Sod (for sodden bioretention)	Sod is dead or requires mowing			Sod is healthy and maintained at least 3 inches in height.
8. Inlet/outlet	Sediment accumulations			Inlet/outlet is clear of sediment and allows water to flow freely
9. Miscellaneous	Any condition not covered above that needs attention for the bioretention area to function as designed.			Meet the design specifications.

a Describe the maintenance completed; if the needed maintenance was not conducted, note when it will be done.

Inspection and Maintenance Checklist for a Bioswale

Property Address: ______________________ Property Owner: ______________________

Treatment Measure No.: __________ Date of Inspection: __________ Type of Inspection: ☐ Monthly ☐ Pre-Wet Season ☐ End of Wet Season ☐ After heavy runoff ☐ Other: __________

Inspector(s): ______________________

Defect	Conditions when Maintenance is Needed	Maintenance Needed? (Y/N)	Comments[a]	Results Expected when Maintenance is Performed
1. Standing water	When water stands in the bioswale between storms and does not drain within 24 hours after rainfall			There should be no areas of standing water once inflow has ceased. Any of the following may apply: sediment or trash blockages removed, improve grade, scarify media surface, flush underdrains.
2. Trash and debris accumulation	Trash and debris accumulated in the bioswale and around the inlet and outlet			Trash and debris removed from the bioswale and disposed of properly.
3. Sediment	Evidence of sedimentation in the bioswale			Material removed so that there is no clogging or blockage. Material is disposed of properly.
4. Erosion	Channels have formed around inlets, there are areas of bare soil, or other evidence of erosion			Obstructions and sediment removed so that water flows freely and disperses throughout the bioswale. Obstructions and sediment are disposed of properly.
5. Vegetation	Vegetation is dead, diseased, or overgrown			Vegetation is healthy and attractive.
6. Mulch (for mulched bioswales)	Mulch is missing or patchy. Areas of bare earth are exposed, or mulch layer is less than 3 inches in depth			All bare earth is covered, except mulch is kept 6 inches away from trunks of trees and shrubs. Mulch is even, at a depth of 3 inches.
7. Sod (for sodden bioswales)	Sod is dead or requires mowing			Sod is healthy and maintained at least 3 inches in height.
8. Inlet/outlet	Sediment accumulations			Inlet/outlet is clear of sediment and allows water to flow freely
9. Miscellaneous	Any condition not covered above that needs attention for the bioswale to function as designed			Meet the design specifications.

a Describe the maintenance completed; if the needed maintenance was not conducted, note when it will be done.

Inspection and Maintenance Checklist for Permeable Pavement

Property Address: ______________________ Property Owner: ______________________

Treatment Measure No.: __________ Date of Inspection: __________ Type of Inspection: ☐ Monthly ☐ Pre-Wet Season ☐ End of Wet Season

☐ After heavy runoff

Inspector(s): ______________________ ☐ Other: ______________________

Defect	Conditions when Maintenance is Needed	Maintenance Needed? (Y/N)	Comments[a]	Results Expected when Maintenance is Performed
1. Ponded/standing water	When water is evident on the surface of the permeable pavement and 48 hours has passed since the last rainfall			There should be no areas of ponded/standing water more than 48 hours after a rain event. Any of the following can apply: surface needs to be swept or vacuumed; underdrains added; or underdrains cleaned.
2. Trash and debris accumulation	Leaves, grass clippings, trash, etc., are preventing water from draining into the permeable pavement and is unsightly			Area is free of all debris, and the permeable pavement is draining properly.
3. Bare soil around perimeter of permeable pavement	Evidence of bare soil and erosion around pavement area			Area adjacent to pavement is well-maintained, and no bare/exposed areas exist; grass is between 3 and 6 inches
4. Weeds	Weeds are growing on the surface of the permeable pavement			No weeds are in the pavement area.
5. Deteriorating surface	The pavement is cracked; paver blocks are misaligned or have settled			The surface area is stabilized, exhibiting no signs of cracks or uneven areas in the pavement area.
6. Miscellaneous	Any condition not covered above that needs attention for the permeable pavement area to function as designed			Meet the design specifications.

a Describe the maintenance completed; if the needed maintenance was not conducted, note when it will be done.

Inspection and Maintenance Checklist for an Infiltration Trench

Property Address: ______________________ Property Owner: ______________________

Treatment Measure No.: ________ Date of Inspection: ________ Type of Inspection: ☐ Monthly ☐ Pre-Wet Season ☐ End of Wet Season

☐ After heavy runoff

Inspector(s): ______________________ ☐ Other: ______________________

Defect	Conditions when Maintenance is Needed	Maintenance Needed? (Y/N)	Comments[a]	Results Expected when Maintenance is Performed
1. Standing water	When water stands in the infiltration trench between storms and does not drain within 24 hours after rainfall			There should be no areas of standing water once inflow has ceased. Any of the following can apply: sediment or trash blockages removed, improved grade, scarify media surface, flush underdrains.
2. Trash and debris accumulation	Trash and debris accumulated in the infiltration trench and around the inlet and outlet			Trash and debris removed and disposed of properly.
3. Sediment	Evidence of sedimentation accumulation			Material removed so that there is no clogging or blockage. Material is disposed of properly.
4. Erosion	Channels have formed around inlets, there are areas of bare soil, or other evidence of erosion			Obstructions and sediment removed so that water flows freely and disperses throughout the infiltration trench. Obstructions and sediment are disposed of properly.
5. Surface materials	Material is missing or patchy; areas of bare earth are exposed			All bare earth is covered, except mulch is kept 6 inches away from trunks of trees and shrubs. Mulch is even, at a depth of 3 inches.
6. Inlet/outlet	Sediment accumulations			Inlet/outlet is clear of sediment and allows water to flow freely
7. Miscellaneous	Any condition not covered above that needs attention for the infiltration trench to function as designed			Meet the design specifications.

a Describe the maintenance completed; if the needed maintenance was not conducted, note when it will be done.

Inspection and Maintenance Checklist for a Planter Box

Property Address: ______________________________ Property Owner: ______________________

Treatment Measure No.: __________ Date of Inspection: __________ Type of Inspection: ☐ Monthly ☐ Pre-Wet Season ☐ End of Wet Season ☐ After heavy runoff ☐ Other: ______________

Inspector(s): ______________________________

Defect	Conditions when Maintenance is Needed	Maintenance Needed? (Y/N)	Comments[a]	Results Expected when Maintenance is Performed
1. Standing Water	When water stands in the planter box between storms and does not drain within 24 hours after rainfall			There should be no areas of standing water after inflow has ceased. Any of the following could apply: sediment or trash blockages removed, replace mulch, scarify soil media surface, flush underdrains.
2. Trash and debris accumulation	Trash and debris accumulated in the planter box and around the inlet and outlet			Trash and debris removed and disposed of properly.
3. Sediment	Evidence of sedimentation in the planter box			Material removed so that there is no clogging or blockage. Material is disposed of properly.
4. Erosion	Channels have formed around inlets, there are areas of bare soil, or other evidence of erosion			Obstructions and sediment removed so that water flows freely and disperses over a wide area. Obstructions and sediment are disposed of properly.
5. Vegetation	Vegetation is dead, diseased, or overgrown			Vegetation is healthy and attractive.
6. Mulch	Mulch is missing or patchy; areas of bare earth are exposed, or mulch layer is less than 3 inches deep			All bare earth is covered, except mulch is kept 6 inches away from trunks of trees and shrubs. Mulch is even, at a depth of 3 inches.
7. Sod (for sodden planter boxes)	Sod is dead or requires mowing			Sod is healthy and maintained at least 3 inches in height.
8. Inlet/outlet	Sediment accumulations			Inlet/outlet is clear of sediment and allows water to flow freely
9. Affected impervious areas or structures	Obvious effects on surrounding impervious areas or structures			Hydraulic restriction layers prevent impacts from infiltration to surrounding structures.
10. Miscellaneous	Any condition not covered above that needs attention for the planter box to function as designed			Meet the design specifications.

a Describe the maintenance completed; if the needed maintenance was not conducted, note when it will be done.

Inspection and Maintenance Checklist for a Sand Filter

Property Address: ______________________ Property Owner: ______________________

Treatment Measure No.: __________ Date of Inspection: __________ Type of Inspection: ☐ Monthly ☐ Pre-Wet Season ☐ End of Wet Season ☐ After heavy runoff ☐ Other: __________

Inspector(s): ______________________

Defect	Conditions when Maintenance is Needed	Maintenance Needed? (Y/N)	Comments[a]	Results Expected when Maintenance is Performed
1. Standing water	When water stands over the sand filter media between storms and does not drain within 24 hours after rainfall			There should be no areas of standing water after inflow has ceased. Any of the following could apply: sediment or trash blockages removed, scarify filter media surface, flush underdrains, media replaced.
2. Trash and debris accumulation	Trash and debris accumulated in the sand filter and around the inlet and outlet			Trash and debris removed from and disposed of properly.
3. Sediment	Evidence of sedimentation accumulation			Material removed so that there is no clogging or blockage. Material is disposed of properly.
4. Erosion	Channels have formed around inlets, there are areas of bare soil, or there is other evidence of erosion			Obstructions and sediment removed so that water flows freely and disperses throughout the sand filter media. Obstructions and sediment are disposed of properly.
5. Inlet/outlet	Sediment accumulations			Inlet/outlet is clear of sediment and allows water to flow freely
6. Miscellaneous	Any condition not covered above that needs attention for the sand filter to function as designed			Meet the design specifications.

a Describe the maintenance completed; if the needed maintenance was not conducted, note when it will be done.

Inspection and Maintenance Checklist for Vegetated Filter Strips

Property Address: ____________________ Property Owner: ____________________

Treatment Measure No.: __________ Date of Inspection: __________ Type of Inspection: ☐ Monthly ☐ Pre-Wet Season ☐ End of Wet Season

☐ After heavy runoff

Inspector(s): ____________________ ☐ Other: ____________________

Defect	Conditions when Maintenance is Needed	Maintenance Needed? (Y/N)	Comments[a]	Results Expected when Maintenance is Performed
1. Sediment accumulation	Sediment depth exceeds 2 inches or covers vegetation			Sediment deposits removed and surface re-leveled to maintain sheet flow over the filter strip.
2. Erosion/scouring	Eroded or scoured areas due to flow channelization or high flows			No erosion or scouring evident. For ruts or bare areas less than 12 inches wide, damaged areas repaired by filling with crushed gravel. The grass will creep over the rock in time.
3. Flow spreader is clogged/uneven	Flow spreader uneven or clogged so that flows are not uniformly distributed through the entire filter width			No visual contaminants or pollutants present.
4. Visual contaminants and pollution	Any visual evidence of oil, gasoline contaminants, or other pollutants			No visual contaminants or pollutants present.
5. Aesthetics	Minor vegetation removal and thinning. Mowing berms and surroundings.			Facility is well kept.
6. Vegetation length, nuisance weeds	When grass becomes excessively tall (greater than 10 inches); when nuisance weeds and other vegetation starts to take over			Grass mowed, nuisance vegetation controlled such that flow is not impeded. Grass mowed to a height of between 2–5 inches and clippings removed.
7. Trash and debris accumulation	Trash and debris accumulated on the filter strip			Trash and debris is removed from filter strip and flow spreading devices.
8. Noxious weeds	Any evidence of noxious weeds			All noxious weeds eradicated and future establishment controlled with use of Integrated Pest Management (IPM) techniques if Applicable. For more information, see http://www.ipm.ucdavis.edu.

a Describe the maintenance completed; if the needed maintenance was not conducted, note when it will be done.

Inspection and Maintenance Checklist for a Vegetated Swale

Property Address: ______________________ Property Owner: ______________________

Treatment Measure No.: __________ Date of Inspection: __________ Type of Inspection: ☐ Monthly ☐ Pre-Wet Season ☐ End of Wet Season

☐ After heavy runoff

Inspector(s): ______________________ ☐ Other: ______________________

Defect	Conditions when Maintenance is Needed	Maintenance Needed? (Y/N)	Comments[a]	Results Expected when Maintenance is Performed
1. Sediment accumulation	Sediment depth exceeds 2 inches or covers vegetation			Sediment deposits should be removed without significant disturbance of the vegetation. When finished, swale should be level from side to side and drain freely toward outlet. There should be no areas of standing water after inflow has ceased.
2. Trash and debris accumulation	Any trash and debris that exceeds 5 cubic feet per 1,000 square feet (one standard garbage can)			Trash and debris are removed from the swale.
3. Standing water	When water stands in the swale between storms and does not drain freely			There should be no areas of standing water after inflow has ceased. Outlet structures and underdrain (if installed) should drain freely.
4. Flow spreader	Flow spreader uneven or clogged so that flows are not uniformly distributed through entire swale width			Spreader leveled and cleaned such that flows are distributed evenly over the entire swale width.
5. Excessive shading	Vegetation growth is poor because sunlight does not reach swale			Overhanging limbs and brushy vegetation on side slopes are trimmed back.
6. Erosion/scouring	Eroded or scoured swale bottom due to flow channelization or higher flows			No erosion or scouring in swale bottom. For ruts or bare areas less than 12 inches wide, damaged areas repaired by filling with crushed gravel. Over time the grass will have started to cover the rock.
7. Visual contaminants and pollution	Any visual evidence of oil, gasoline, contaminants, or other pollutants			No visual evidence of contaminants or pollutants present.
8. Vegetation length	When the grass becomes excessively tall (greater than 10 inches); when nuisance weeds and other vegetation starts to take over			Vegetation trimmed or mowed, and nuisance vegetation removed so that flow is not impeded. Vegetation/grass should not be trimmed shorter than 4 to 6 inches (depending on landscape requirements). Grass clippings removed.
9. Inlet/outlet blockage	Inlet/outlet areas clogged with sediment or debris			Inlet/outlet is clear of material and allows water to flow freely

Defect	Conditions when Maintenance is Needed	Maintenance Needed? (Y/N)	Comments[a]	Results Expected when Maintenance is Performed
10. Low-flow channel overflow	Nuisance flows are ponding, swale is continually wet			Low-flow channel media is renewed to adequately convey nuisance flows.
11. Constant baseflow	When small quantities of water continually flow through the swale, even when it has been dry for weeks, and an eroded muddy channel has formed in the swale bottom			A low-flow pea gravel drain can be added to the length of the swale, or an underdrain can be installed, to prevent an eroded or muddy channel.
12. Poor vegetation coverage	When grass is sparse or bare or eroded patches occur in more than 10% of the swale bottom			Vegetation coverage is in more than 90% of the swale bottom. Poorly vegetated areas of the swale bottom should be re-planted with plugs of grass from the upper slope and reseeded in locations where plugs were taken. Plugs should be planted in the swale bottom with no gaps, or reseeded into loosened, fertile soil.

a Describe the maintenance completed; if the needed maintenance was not conducted, note when it will be done.

Inspection and Maintenance Checklist for a Cistern

Property Address: ______________________ Property Owner: ______________________

Treatment Measure No.: __________ Date of Inspection: __________ Type of Inspection: ☐ Monthly ☐ Pre-Wet Season ☐ End of Wet Season ☐ After heavy runoff ☐ Other: __________

Inspector(s): ______________________

Defect	Conditions when Maintenance is Needed	Maintenance Needed? (Y/N)	Comments[a]	Results Expected when Maintenance is Performed
1. Low flow	Gutters are full of debris and overflowing			When gutters are cleaned appropriately and gutter guards or screens are installed, gutters should be clear and free-flowing.
2. Inlet	Filters are clogged or full			Filters are clean and free of trash and debris.
3. First flush diverter	First flush filter is full or clogged causing permanent flow to the cistern			When first flush diverter valve is removed and cleaned, the first flush will be diverted away from the cistern.
4. Cistern does not drain within 48 hours	Outlet is clogged			Cistern completely drains within 48 hours.
5. Cistern drains in less than 24 hours	Cistern leaks or outlet allows excessive flows			Cistern drains in 24 to 48 hours.
6. Miscellaneous	Any condition not covered above that needs attention for the infiltration trench to function as designed			Meet the design specifications.

a Describe the maintenance completed; if the needed maintenance was not conducted, note when it will be done.