City and County of Honolulu
Storm Water Best Management Practice Manual

NEW AND REDEVELOPMENT

FINAL

Prepared by
Department of Environmental Services
July 2014

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LIST OF ACRONYMS

API	American Petroleum Institute
ASCE	American Society of Engineers
BMPs	Best Management Practices
BOD	Biochemical Oxygen Demand
Caltrans	California Department of Transportation
CASQA	California Stormwater Quality Association
CCH or City	City and County of Honolulu
CFS	Cubic Feet per Second
CORP or COE	US Army Corporation of Engineers (USACE)
CSO	Combined Sewer Overflows
CWA	Clean Water Act (Federal Water Pollution Control Act of 1972 as amended in 1987)
CWB	Clean Water Branch, Environmental Management Division, Department of Health, State of Hawaii
CZMA	Coastal Zone Management
DCIA	Directly Connected Impervious Area
DLNR	Department of Land and Natural Resources, State of Hawaii
DOFAW	Division of Forestry and Wildlife, DLNR, State of Hawaii
DOH	Department of Health, State of Hawaii
Drainage Rules	Rules Relating to Storm Drainage Standards
EMC	Event Mean Concentration
ENV	Department of Environmental Services, City and County of Honolulu
HAR	State of Hawaii Administrative Rules
LID	Low Impact Development
MCTT	Multi-Chambered Treatment Train
MS4	Municipal Separate Storm Sewer Systems
NOC	Notice of Cessation
NOI	Notice of Intent
NPDES	National Pollutant Discharge Elimination System
NRCS	Natural Resources Conservation Service
NURP	Nationwide Urban Runoff Program
O&M	Operations and Maintenance
OWS	Oil Water Separator
POTW	Publicly Owned Treatment Works
PSD	Particle Size Distribution
SPCC	Spill Prevention Control and Countermeasure Plan

SSBMP	Site-Specific Best Management Practice Plan
State	State of Hawaii
SWMPP	Storm Water Management Program Plan
SWPCP	Storm Water Pollution Control Plan
SWQ	Storm Water Quality Branch, Department of Environmental Services, City and County of Honolulu
SWQC	Storm Water Quality Checklist
SWQR	Storm Water Quality Report
SWRCP	Southern Wisconsin Regional Planning Commission
TMDL	Total Maximum Daily Load
TOC	Total Organic Carbon
TSS	Total Suspended Solids
USDA	United States Department of Agriculture
USFWS	United States Fish and Wildlife Service
USEPA	United States Environmental Protection Agency
WQI	Water Quality Inlet
WQV	Water Quality Volume

SIGNIFICANT ADDITIONS AND REVISIONS MADE FROM 2003 CASQA NEW/REDEVELOPMENT BMP HANDBOOK

<table>
<tr><th>Item</th><th>Description</th></tr>
<tr><td>1</td><td>Acronyms have been updated with local definitions and terms.</td></tr>
<tr><td>2</td><td>Specific references to State of California, Regional Water Control Board, counties, and cities regulatory framework have been changed to applicable State of Hawaii and CCH references throughout the drafted document.</td></tr>
<tr><td>3</td><td>Added appropriate photos for the following sections:
• SD-32 Outdoor Trash Storage
• SD-36 Outdoor Process Equipment Operations
• TC-12 Retention/Irrigation
• TC-50 Water Quality Inlet
• TC-60 Multiple Systems
• MP-20 Wetland
• MP-40 Media Filter</td></tr>
<tr><td>4</td><td>Added design information for the following sections:
• TC-50 Water Quality Inlet
• MP-20 Wetland
• MP-40 Media Filter
• MP-50 Wet Vault
• MP-51 Vortex Separator
• MP-52 Drain Inlet
• SD-14 Green Roofs
• SD-20 Permeable Pavement
• TC-30 Vegetated Swale
• TC-32 Vegetated Biofilter</td></tr>
</table>

ACKNOWLEDGEMENTS

The Storm Water Best Management Practice (BMP) Manuals are adaptations of products of the California Stormwater Quality Association (CASQA) for the City and County of Honolulu (CCH or City). The handbooks were originally published in 1993 by the California Storm Water Quality Task Force, the predecessor of CASQA. As part of this project, the original handbooks have been updated to reflect the current state of storm water quality management practices and to make the handbook accessible via the Internet at www.cabmphandbooks.com.

The development of the City Storm Water BMP Manual - New Development and Redevelopment was guided by Technical Contributions from representatives of regulatory agencies (water quality and health), industry, transportation, and consulting. The quality of this manual is a result of the diverse expertise and experience of the committee and the workgroup.

Disclaimer

Information contained in CASQA products is to be considered general guidance and is not to be construed as specific recommendations or implied as compliance with other City Rules Related to Storm Drainage Standards for specific cases. Users of CASQA products assume all liability directly or indirectly arising from use of the products. The mention of commercial products, their source, or their use in connection with information in CASQA products is not to be construed as an actual or implied endorsement, recommendation, or warranty of such product. This disclaimer is applicable whether information from the CASQA products is obtained in hard copy form or downloaded from the Internet.

Technical Contributions

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1. INTRODUCTION

Note: Information contained in the City and County of Honolulu (CCH or City) Storm Water Best Management Practice (BMP) Manuals is considered to be general guidance and is not to be construed as specific recommendations for specific cases. Users of the manuals assume all liability directly or indirectly arising from use of the products. Please refer to the Disclaimer in Acknowledgements. Also please keep in mind that, as stated in the Acknowledgements, this manual is based on the CASQA 2003 New Development Handbook, and therefore may not reflect data, facts, or material that may have been developed since that time.

Storm water runoff is part of a natural hydrologic process. However, human activities particularly urbanization and agriculture, can alter natural drainage patterns and add pollutants to lakes, and streams as well as coastal bays and estuaries, and ultimately, the ocean. Numerous studies have shown urban runoff to be a significant source of water pollution, causing declines in fisheries, restrictions on swimming, and limiting our ability to enjoy many of the other benefits that water resources provide. Urban runoff in this context includes all flows discharged from urban land uses into storm water conveyance systems and receiving waters and includes both dry weather non-storm water sources (i.e., runoff from landscape irrigation, etc.) and wet weather storm water runoff. In this manual, urban runoff and storm water runoff are used interchangeably.

For many years the effort to control the discharge of storm water focused on quantity (i.e., drainage and flood control) and only to a limited extent on quality of the storm water (i.e., sediment and erosion control). However, in recent years awareness of the need to improve water quality has increased. With this awareness, Federal, State, and City programs have been established to pursue the ultimate goal of reducing pollutants contained in storm water discharges to our waterways. The emphasis of these programs is to promote the concept and the practice of preventing pollution at the source, before it can cause environmental problems (United States Environmental Protection Agency [USEPA], 1992). Other BMPs to reduce or eliminate post-project runoff should also be implemented. However, where further controls are needed, treatment of polluted runoff may be required.

1.1. Purpose and Scope

The purpose of this manual is to provide general guidance for selecting and implementing BMPs to reduce pollutants in runoff in newly developed areas and redeveloped areas to waters of the State of Hawaii (State). The City's "Rules Relating to Storm Drainage Standards," (Drainage Rules) adopted December 2012, also provides guidance on developing project-specific storm water management plans including selection and implementation of BMPs for a particular development or redevelopment project.

1.1.1. Users of the Manual

This manual provides guidance suitable for use by individuals involved in development or redevelopment site water pollution control and planning. Each user of the manual is responsible for working within their capabilities obtained through training and experience, and for seeking the advice and consultation of appropriate experts at all times.

The target audience for this manual includes:

- Developers (including their planners and engineers);
- Contractors and subcontractors (including their engineers, superintendents, foremen, and construction staff);
- City agencies involved in site development and redevelopment (including their engineers, planners, and construction staff);
- Regulatory agencies (including permit and planning staff); and
- General public with an interest in storm water pollution control.

1.1.2. Organization of the Manual

The manual is organized to assist the user in selecting and implementing BMPs to reduce impacts of storm water and non-storm water discharges on receiving waters. Sections of this manual are displayed in Figure 1.1.

Figure 1.1: Honolulu Storm Water BMP Manual - New/Redevelopment

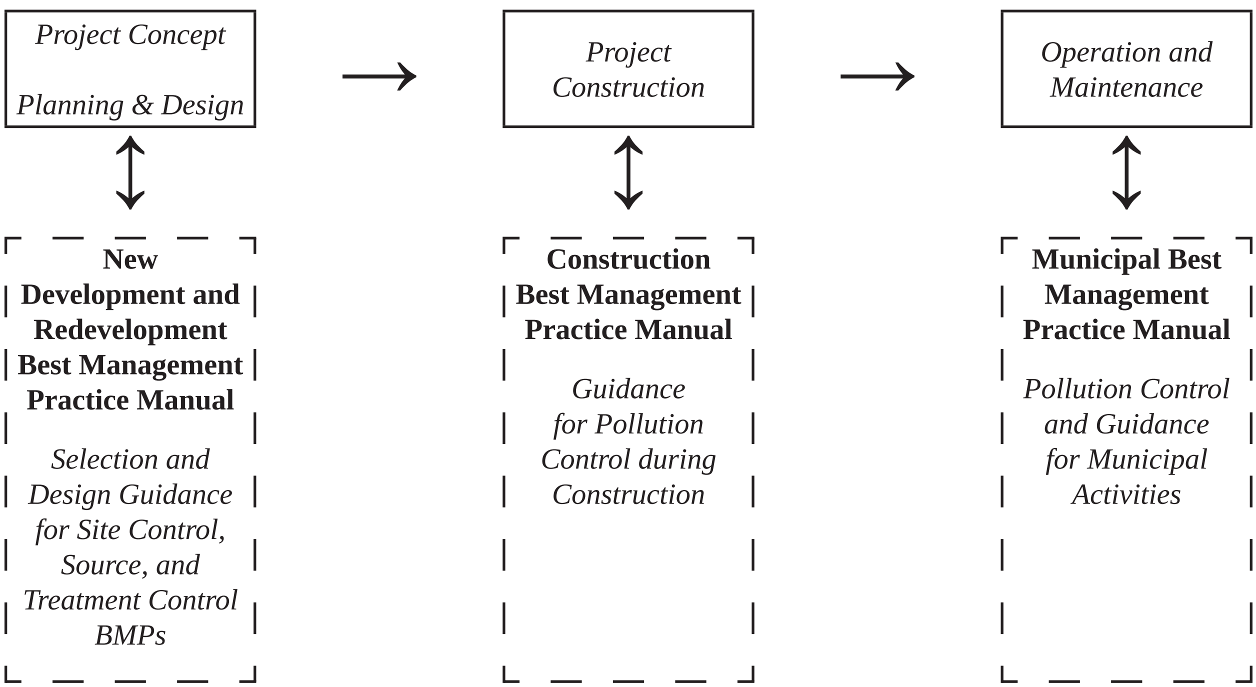
Section 1 **Introduction** *This section provides a general review of the sources and impacts of urban storm water discharges and provides an overview of the City Storm Water Management Plan.*	**Section 2** **Storm Water Quality Planning for New Development and Redevelopment** *This section describes typical permit principles, and site assessment. It also covers identifying BMPs, integrating BMPs into the project, and maintaining BMPs.*	**Section 3** **Site and Facility Design for Water Quality Protection** *This section describes planning approaches to reduce, eliminate, control and treat runoff from development and redevelopment, and integration of BMPs into common site, drainage, and building features.*
Section 4 **Source Control BMPs** *BMP fact sheets presented in this section address structural source control BMPs to be considered for development and redevelopment.*	**Section 5** **Treatment Control BMPs** *BMP fact sheets presented in this section address treatment control BMPs that may be used for development.*	**Section 6** **Long Term Maintenance of BMP** *This section outlines approaches to maintain BMPs, monitor BMP effectiveness, and evaluate additional BMP requirements.*
	Section 7 **Glossary** *This section identifies terms used in the manuals.*	

1.1.3. Relationship to Other Manuals

This manual is one (1) of three (3) manuals developed by the City to address BMP selection. Collectively, the three (3) manuals address BMP selection throughout the life of a project from planning and design, through construction, and into operation and maintenance (O&M) (shown in Figure 1.2). Individually, each manual is geared to a specific target audience during each stage of a project.

This New Development and Redevelopment Manual addresses selection and implementation of BMPs to eliminate or to reduce the discharge of pollutants associated with development and redevelopment activities.

Figure 1.2: Project Life Cycle



For a comprehensive understanding of storm water pollution control throughout the life cycle of the project, it is recommended that the reader obtain and become familiar with all three (3) manuals. Typically, storm water program managers, regulators, environmental organizations, and storm water quality professionals will have an interest in all three (3) manuals. For a focused understanding of storm water pollution control during a single phase of the project life cycle, a reader may obtain and become familiar with the manual associated with the appropriate phase. Typically, contractors, construction inspectors, industrial site operators, commercial site operators, some regulators and some staff may have an interest in a single manual.

1.2. Storm Water Pollutants and Impacts on Water Quality

Storm water runoff naturally contains numerous constituents, however, urbanization and urban activities including development and redevelopment typically increase constituent concentrations to levels that impact water quality. Pollutants associated with storm water include sediment, nutrients, bacteria and viruses, oil and grease, metals, organics, pesticides, and trash (floatables). In addition, nutrient-rich storm water runoff is an attractive medium for vector production when it accumulates and stands for more than 72 hours. Storm water pollutants are described in Table 1.1.

Table 1.1: Pollutants and Impacts on Water Quality

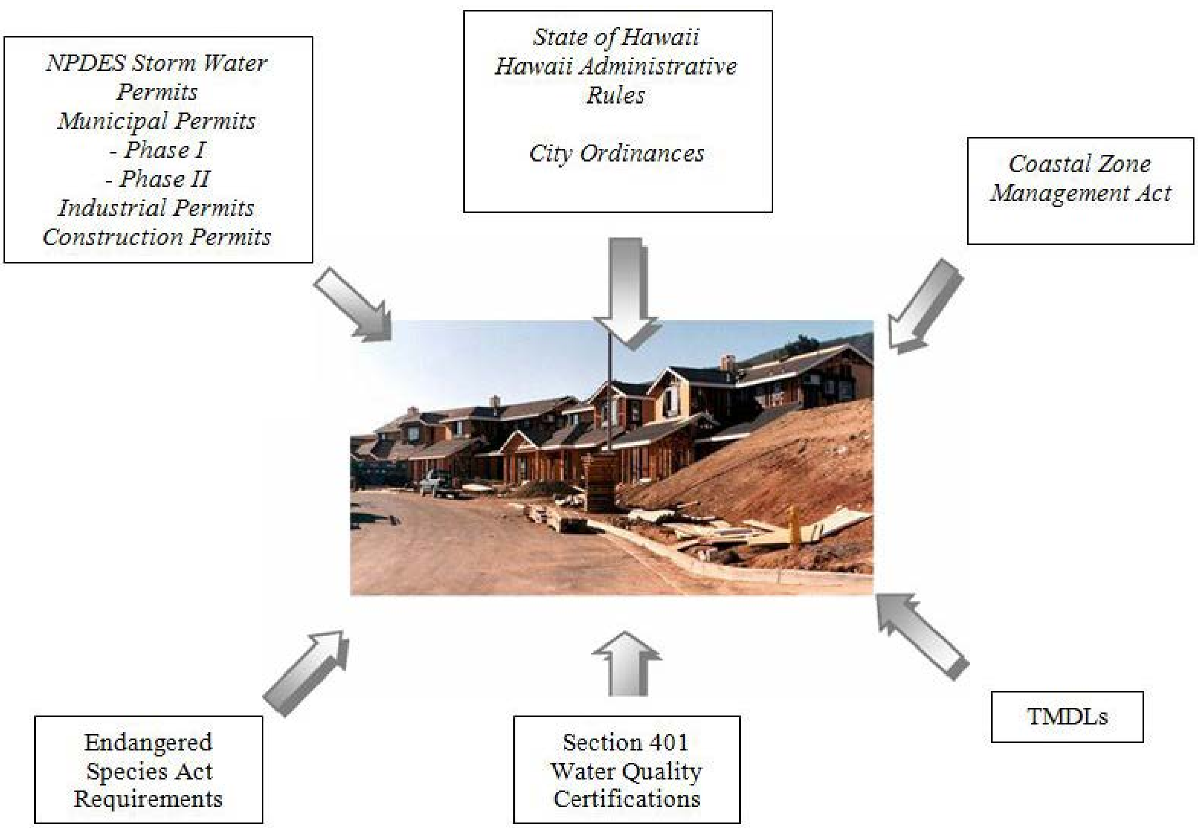
Sediment	Sediment is a common component of storm water, and can be a pollutant. Sediment can be detrimental to aquatic life (primary producers, benthic invertebrates, coral reefs and fish) by interfering with photosynthesis, respiration, growth, reproduction, and oxygen exchange in water bodies. Sediment can transport other pollutants that are attached to it including nutrients, trace metals, and hydrocarbons. Sediment is the primary component of total suspended solids (TSS), a common water quality analytical parameter
Nutrients	Nutrients including nitrogen and phosphorous are the major plant nutrients used for fertilizing landscapes, and are often found in storm water. These nutrients can result in excessive or accelerated growth of vegetation, such as algae, resulting in impaired use of water in lakes and other sources of water supply.
Bacteria and Viruses	Bacteria and viruses are common contaminants of storm water. For separate storm drain systems, sources of these contaminants include animal excrement and sanitary sewer overflow. High levels of indicator bacteria in storm water have led to the closure of beaches, lakes, and streams to contact recreation such as swimming.
Oil and Grease	Oil and grease includes a wide array of hydrocarbon compounds, some of which are toxic to aquatic organisms at low concentrations. Sources of oil and grease include leakage, spills, cleaning and sloughing associated with vehicle and equipment engines and suspensions, leaking and breaks in hydraulic systems, restaurants, and waste oil disposal.
Metals	Metals including lead, zinc, cadmium, copper, chromium, and nickel are commonly found in storm water. Many of the artificial surfaces of the urban environment (i.e., galvanized metal, paint, automobiles, or preserved wood) contain metals, which enter storm water as the surfaces corrode, flake, dissolve, decay, or leach. Over half the trace metal load carried in storm water is associated with sediments. Metals are of concern because they are toxic to aquatic organisms, can bioaccumulate (accumulate to toxic levels in aquatic animals such as fish), and have the potential to contaminate drinking water supplies.
Organics	Organics may be found in storm water in low concentrations. Often synthetic organic compounds (adhesives, cleaners, sealants, solvents, etc.) are widely applied and may be improperly stored and disposed. In addition, deliberate dumping of these chemicals into storm drains and inlets causes environmental harm to waterways.
Pesticides	Pesticides (including herbicides, fungicides, rodenticides, and insecticides) have been repeatedly detected in storm water at toxic levels, even when pesticides have been applied in accordance with label instructions. As pesticide use has increased, so too have concerns about adverse effects of pesticides on the environment and human health. Accumulation of these compounds in simple aquatic organisms, such as plankton, provides an avenue for biomagnification through the food web, potentially resulting in elevated levels of toxins in organisms that feed on them, such as fish and birds.
Gross Pollutants	Gross Pollutants (trash, debris, and floatables) may include heavy metals, pesticides, and bacteria in storm water. Typically resulting from an urban environment, industrial sites and construction sites, trash and floatables may create an aesthetic “eye sore” in waterways. Gross pollutants also include plant debris (such as leaves and lawn-clippings from landscape maintenance), animal excrement, street litter, and other organic matter. Such substances may harbor bacteria, viruses, vectors, and depress the dissolved oxygen levels in streams, lakes, and estuaries sometimes causing fish kills.

Development and redevelopment activities can result in two (2) types of water quality impacts: erosion and sedimentation and discharge of other pollutants during construction; and long-term impacts from runoff from the completed development and associated land uses. Control of water quality impacts during construction is covered in the Construction edition of the Storm Water BMP Manual. This manual addresses potential water quality impacts from completed development that can include the following:

- Urban activities can result in the generation of new dry-weather runoff that may contain many of the pollutants listed in Table 1.1.
- Impervious surfaces associated with development, such as streets, rooftops, and parking lots, prevent runoff infiltration and increase the rate and volume of storm water runoff that may increase downstream erosion potential and associated potential water quality impairment.
- Urban activities and increased impervious surfaces which can increase the concentration and/or total load of many of the pollutants listed above in wet weather storm water runoff.

1.3. Regulatory Requirements

The Federal Water Pollution Control Act of 1972 also known as the Clean Water Act (CWA), as amended in 1987, is the principal legislation for establishing requirements for the control of storm water pollutants from urbanization and related activities. However, other Federal, State, and City requirements deal directly or indirectly with controlling storm water discharges. Requirements for storm water under some of these programs are evolving: Coastal Zone Management Act (CZMA), State of Hawaii Administrative Rules (HAR), City Ordinances, Total Maximum Daily Loads (TMDLs), 401 Water Quality Certifications and Endangered Species Act. The user is advised to contact local regulatory and/or City officials for further information.



1.3.1. Federal Programs

In 1972, provisions of the CWA were amended so that discharge of pollutants to waters of the United States from any point source is effectively prohibited, unless the discharge is in compliance with a National Pollutant Discharge Elimination System (NPDES) permit. The 1987 amendments to the CWA added Section 402(p), which established a framework for regulating municipal, industrial, and construction storm water discharges under the NPDES program. On November 16, 1990, USEPA published final regulations that established application requirements for storm water permits for municipal separate storm sewer systems (MS4s) serving a population of over 100,000 (Phase I communities) and certain industrial facilities, including construction sites greater than five (5) acres.

On December 8, 1999, USEPA published the final regulations for communities under 100,000 (Phase II MS4s) and operators of construction sites between one (1) and five (5) acres.

1.3.2. State Programs

The statutory framework for the NPDES program requires that all point sources that discharge pollutants in the waters of the United States must obtain an NPDES permit from the USEPA or an authorized State (Hawaii is a delegated state). Storm water is regulated under the NPDES program. There has been a phased approach to regulation of storm water. Phase I, in 1990, regulated discharges from Medium and Large MS4s, industrial activity, and construction sites greater than or equal to five (5) acres. Phase II became effective March 10, 2003 and regulated discharges from Small MS4s and construction sites from one (1) acre to five (5) acres. Large, Medium, and Small MS4s were defined by the size of the population that the system serves. The regulations required the issuance of permits to regulated dischargers.

In Hawaii, Small MS4s, industrial facilities, and construction activities greater than or equal to one acre are normally covered by general permits. However if such facilities discharge storm water into sensitive water bodies designated as Class AA marine, or Class 1 inland State waters, or areas restricted in accordance with the State's "No Discharge" policy, then those facilities must be covered by an individual permit. Also, Small MS4s and industrial facilities could be covered under an individual permit issued to a Large MS4.

Regulatory emphasis is placed on pollution prevention by regulating "end of pipe" discharges in lieu of setting effluent limits. Prevention is accomplished through the development and implementation of plans such as the MS4 Storm Water Management Program Plan (SWMPP), Industrial Storm Water Pollution Control Plans (SWPCPs), and erosion control plans and Site-Specific BMP Plans (SSBMPs) for construction sites.

Projects designated by the City as "Priority Projects" have been identified to have a greater potential for activities which may contribute sources for pollutants. These projects are described in Table 1.2. Post-construction BMPs have been developed to reduce the risk of pollutant sources exposure to storm water runoff.

Table 1.2: Priority Project Categories

Priority	Description
A1	All projects that disturb at least five (5) acres during construction.
A2	All projects that disturb between one (1) and five (5) acres during construction.
B	Retail Gasoline Outlets, Automotive Repair Shops, Restaurants, and Parking Lots, all with at least 10,000 square feet of total impervious surface area.

1.3.3. Other Relevant Regulatory Programs

In addition to meeting City storm water program requirements under CWA section 402(p), municipalities are increasingly subject to other regulatory drivers that relate to the protection of surface water quality and beneficial uses of water bodies in their communities. Several other regulatory programs that can significantly affect new development and redevelopment planning and design are:

- TMDLs
- Endangered Species Act
- CWA Section 404 Dredge and Fill Permits
- Section 401 Water Quality Certification (regulated under HAR, Chapter 11-54)

In the coming years, these regulatory drivers will likely have at least as much impact on the design and implementation of municipal storm water programs and BMP selection and maintenance as current storm water regulations.

TMDLs

TMDLs are a regulatory mechanism to identify and implement additional controls on both point and non-point source discharges in water bodies that are impaired from one or more pollutants and are not expected to be restored through normal point source controls. States identify impairments and pollutants by putting impaired water bodies on a list as required under Section 303(d) of the CWA.

Storm water or urban runoff is listed as a suspected source for many of the water body pollutant combinations in the current 303(d) list. Storm water programs must be designed not only to be in compliance with the storm water NPDES permit regulations, but they must also be designed to implement TMDLs in which storm water or urban runoff is named as a source.

Endangered Species Act

Like TMDLs, Endangered Species Act (Hawaii Revised Statutes Title 12) issues are becoming increasingly important to storm water program design and implementation. The presence or potential presence of an endangered species impacts storm water management programs and the selection and maintenance of BMPs. The Department of Land and Natural Resources (DLNR) Division of Forestry and Wildlife (DOFAW) and the US Fish & Wildlife Service (USFWS) provides information on the designation of critical habitat in Hawaii.

The developers or public agency intending to conduct activities in or discharge to an area that serves as a critical habitat must contact resource agencies such as DLNR, DOFAW, and the USFWS to learn about specific compliance requirements and actions.

CWA Section 404 Dredge and Fill Permits

In 1972, Section 404 of the CWA was passed prohibiting the discharge of dredged or filled material into U.S. waters without a permit from the Army Corps of Engineers (USACE or CORP or COE). Subsequent court rulings and litigation further defined “Waters of the U.S.” to include virtually all surface waters, including wetlands. Activities in waters of the United States that are regulated under this Act include fills for development, water resource projects (such as dams and levees), infrastructure development (such as highways and airports), and conversion of wetlands to uplands for farming and forestry.

The basic premise of the CWA is that no discharge of dredged or fill material is permitted if a practicable alternative exists that is less damaging to the aquatic environment or if the nation's waters would be significantly degraded. When applying for a permit, it must be shown that:

- Steps have been taken to avoid wetland impacts where practicable.
- Potential impacts to wetlands have been minimized.
- Compensation for any remaining, unavoidable impacts through activities has been provided to restore or create wetlands.

An individual permit is usually required for potentially significant impacts. However, for most discharges that will have only minimal adverse effects, the USACE often grants up-front general permits. These may be issued on a nationwide or state basis for particular categories of activities (for example, minor road crossings, utility line backfill, and bedding) as a means to expedite the permitting process.

CWA Section 401 Water Quality Certification

Anyone proposing to conduct a project that requires a Federal permit (404) or involves dredge or fill activities that may result in a discharge to U.S. surface waters and/or "Waters of the State" is required to obtain a CWA Section 401 Water Quality Certification and/or Waste Discharge Requirements (Dredge/Fill Projects) from the Department of Health (DOH) Clean Water Branch (CWB), verifying that the project activities will comply with state water quality standards (HAR CH11-54). The rules and regulations apply to all "Waters of the State," including isolated wetlands and stream channels that may be dry during much of the year, have been modified in the past, look like a depression or drainage ditch, have no riparian corridor, or are on private land.

Section 401 of the CWA grants each state the right to ensure that the state's interests are protected on any federally permitted activity occurring in or adjacent to "Waters of the State." In Hawaii, the CWB is the agency mandated to ensure protection of the State's waters. If a proposed project requires a USACE, CWA Section 404 permit and has the potential to impact Waters of the State, the CWB through HAR Chapter 11-54 will regulate the project and associated activities through a Water Quality Certification determination (Section 401), as part of the 404 process.

1.4. Definitions

Many of the common definitions for storm water control are found in the Glossary (see Section 7). Throughout the manual the user will find references to the following terms:

MS4 is a municipal owned separate storm sewer system. Operators of MS4s are permitted under Phase I or Phase II of the NPDES program. NPDES is an acronym for National Pollutant Discharge Elimination System. NPDES is the national program for administering and regulating Sections 307, 318, 402 and 405 of the CWA.

A **BMP** is defined as any program, technology, process, siting criteria, operating method, measure, or device, which controls, prevents, removes, or reduces pollution to protect water quality while maintaining a healthy environment.

Source Control (SC) BMPs are operational practices that prevent pollution by reducing potential pollutants at the source.

Source Control BMPs for design (SD) are planning methods and concepts that should be taken into consideration by developers during project design.

Treatment Control (TC) BMPs are methods of treatment to remove pollutants from storm water.

1.5. References

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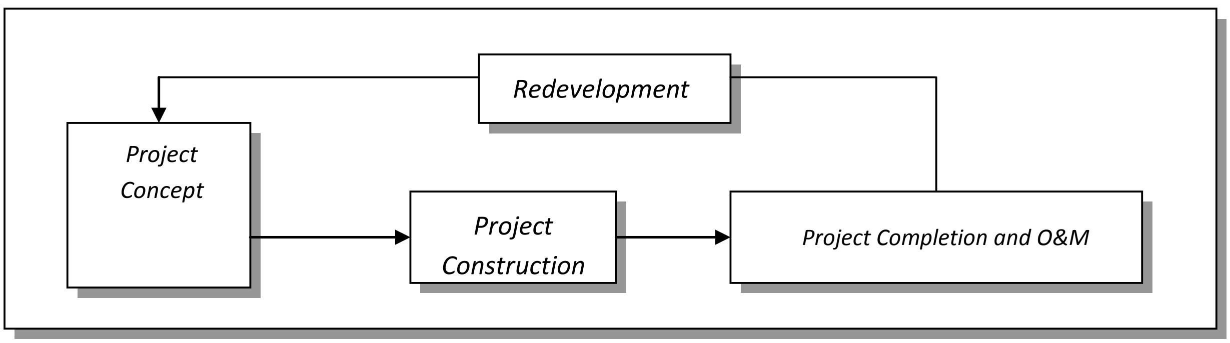
2. STORM WATER QUALITY PLANNING FOR NEW DEVELOPMENT AND REDEVELOPMENT

2.1. Introduction

The City's program requires/recommends BMPs to be implemented by developers, property owners, and public agencies engaged in new development or redevelopment activities. Understanding new development and redevelopment in the context of the project life cycle is important for proper selection and implementation of BMPs as shown in Figure 2.1. The concept, planning, and design phases of a project may be spread over a period of months to many years. BMPs incorporated into the concept, planning, and design phase are much more cost-effective than the retrofit of developed projects with BMPs.

Figure 2.1: Project Life Cycle



2.2. Permit Requirements

New development BMPs are required under NPDES permits shown in Figure 2.2. The intent of incorporating BMPs in new private development and public capital projects is to prevent any net detrimental change in runoff quantity or quality resulting from new development and redevelopment.

Figure 2.2: NPDES Storm Water Permit Requirements

NPDES Storm Water Permit Requirements

Phase I areas (large urban areas and major industries):

- Under permits since early 1990s; and
- Individual municipal permits all include a program element for new development or "post-construction" BMPs.

Phase II areas (small urban areas and additional industries):

- Under General Permit since early 2003; and
- Permit includes new development requirements similar to Phase I.

Permit requirements in the City's Phase I general permit include:

- Identification of specific thresholds for "Priority Projects" that must incorporate Low Impact Development (LID) in the completed projects (typical project thresholds are shown in the City Drainage Rules).
- Identification of a specific water quality design volume and/or water quality design flow rate for treatment control BMPs.

An effective mechanism for documenting the incorporation of storm water quality controls into new development and redevelopment projects on a site or watershed basis is to develop a written plan known as a Storm Water Quality Report (SWQR) or Storm Water Quality Checklist (SWQC). An effective SWQR or SWQC clearly sets forth the means and methods for long-term storm water quality protection. The SWQR or SWQC is a valuable document and can be used as part of the construction Storm Water Pollution Prevention Plan to describe post-construction storm water management, and will also prove to be useful during ownership transitions to convey critical storm water quality control information to subsequent owners. Section 2.3 of this manual describes general steps required to develop a SWQR or SWQC. Section 2.4 of this manual describes planning principles appropriate for consideration during new development and redevelopment storm water quality planning.

2.3. Developing a BMP Plan

A critical element of the SWQR or SWQC is developing an effective BMP plan. This section describes the basic steps and process one would go through to develop a plan with appropriate BMPs. Such a plan would include reviewing the full suite of BMPs that are available and identifying the dominant site factors that should go into the decision making process. Assessment of specific site conditions, site constraints, site hydrology, and project type, are central to successful planning to minimize pollutants during development as well as during the life of the project. The basic steps in the storm water management plan process are to:

- Assess site and watershed conditions.
- Understand hydrologic conditions of concern.
- Evaluate pollutants of concern.
- Identify candidate BMPs (Reference: Table 2.1).
- Develop plan for BMP maintenance.

Table 2.1: Summary of Post Construction BMPs for New Development/Redevelopment Projects

BMP Category	Applicable Projects	Pollution Prevention Objective
LID Site Design	Required for all Priority A1 and A2 projects; recommended for all others. See Section 3.	Strategies integrated into the facility design to maintain or restore the natural hydrologic functions of a site to reduce the rate of runoff, filter out its pollutants, and facilitate the infiltration of water into the ground.
Source Control	Required for all Priority A1, A2, and B projects; recommended for all others. See SC BMPs in Section 4.	Low-technology practices designed to prevent pollutants from contacting storm water runoff or to prevent discharge of contaminated runoff to the storm drainage system.
LID Retention	Required for all Priority A1 projects if feasible; recommended for all others if feasible. See TC BMPs in Section 5.	Engineered technologies designed to retain runoff on-site by infiltration, evapotranspiration, or reuse.
LID Biofiltration	Required for all Priority A1 and A2 projects if LID Retention is infeasible; recommended for all others if feasible. See TC BMPs in Section 5.	Engineered technologies designed to remove pollutants from runoff by filtration, adsorption, and biological uptake.
Other Treatment Control	Alternative compliance for Priority A1 and A2 projects when retention and biofiltration are infeasible. See TC BMPs in Section 5.	Engineered technologies designed to remove pollutants from runoff by detention, filtration, settling, or vortex separation.

The specific requirements of a SWQR and SWQC are specified in the Department of Planning and Permitting's Storm Water Quality Report Preparation Manual and Storm Water Quality Checklist Preparation Manual, respectively.

2.3.1. Assess Site Conditions

Site and watershed assessment includes assessing and describing the pre- and post-development site conditions and how the site fits into the overall watershed or drainage area. The assessment should include sufficient detail to allow for assessment of the need for and application of storm water BMPs. Information typically required is listed below.

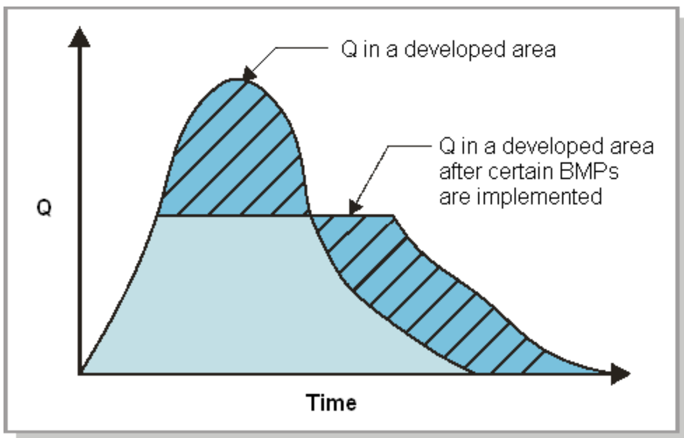
- Site information:
    - Historic features
    - Existing features
    - Planned features
    - Drainage patterns
    - Discharge locations
- Vicinity information
    - Major roadways
    - Geographic features or landmarks

    - Area surrounding the site
    - General topography
    - Area drainage
- Watershed or drainage area information:
    - Receiving waters
    - Watershed drainage

2.3.2. *Understand Hydrologic Conditions of Concern*

Development of impervious areas changes the landform and therefore the runoff hydrograph. Modifications to the runoff hydrograph change downstream hydrology. New development typically results in more runoff volume and higher rates of runoff. Many BMPs, such as detention basins, which detain volume, effectively remove the top part of the hydrograph, but extend the duration of flow. See Figure 2.3.

Figure 2.3: Hydraulic Alteration after Certain BMPs are Implemented



Recent findings indicate that while such actions mitigate peak flows, the increased duration associated with these actions has impacts as well. Problems include washing out habitat, eroding streambed and banks, and changing downstream ecosystems. In addition to volume, rate, and duration, other factors such as the amount of energy in the water and peak flow impact downstream conditions.

A comprehensive understanding of these factors is necessary to develop meaningful storm water management plans. To be effective, these solutions must be done on an individual watershed basis.

Ideally, the runoff hydrograph that exists after construction would parallel the pre-construction hydrograph. It is difficult to ask upstream developers to be concerned about what is happening several miles below them in a watershed. On the other hand, storm water planners and policy makers must ask what can be done to make the watershed more stable, and what enhancements are needed to balance impacts to the watershed from development. Storm water quality planning for new development and redevelopment can be used to make qualitative predictions concerning channel impacts due to changes in runoff or sediment loads from the watershed.

The best way to resolve the watershed stability and balance issues is through a comprehensive drainage water master plan. A formal drainage study considers the project area’s location in the larger watershed, topography, soil and vegetation conditions, percent impervious area, natural and infrastructure drainage features, and any other relevant hydrologic and environmental factors. A drainage study is typically prepared by a licensed civil engineer. As part of the study, the drainage report includes:

- Field reconnaissance to observe downstream conditions.
- Computed rainfall and runoff characteristics including a minimum of peak flow rate, flow velocity, runoff volume, time of concentration and retention volume.
- Establishment of site design, source control and treatment control measures to be incorporated and maintained to address downstream conditions of concern.

2.3.3. Evaluate Pollutants of Concern

The BMP plan should identify anticipated pollutants of concern. Pollutants identified in the USEPA 303(d) list for specific water bodies in Hawaii include metals, nitrogen, nutrients (but often nutrients without specifying nitrogen or phosphorus), indicator bacteria (i.e., fecal coliform), pesticides, and trash. Less commonly cited pollutants include suspended solids, PCBs, and ammonium. With respect to metals, typically, only the general term is used. In some cases, lead is identified.

The BMP plan development process typically includes consideration of:

- Receiving water quality (including pollutants for which receiving waters are listed as impaired under CWA section 303(d)).
- Land use type of the development project and pollutants associated with that land use type;
- Pollutants expected to be present on site.
- Changes in storm water discharge flow rates, velocities, durations, and volumes resulting from the development project.
- Sensitivity of receiving waters to changes in storm water discharge flow rates, velocities, durations, and volumes.

It is important to realize that pollutants of concern for a water body can extend beyond those pollutants listed in the 303(d) list as causing impairment. For example, trash is a pollutant of concern in most communities, yet only a few water bodies are presently listed as impaired by trash. The key to remember is that a pollutant need not be causing an immediate impairment to be considered when developing a BMP Plan.

2.3.4. Identify Candidate BMPs

Selecting BMPs based on pollutants of concern is a function of site constraints, constituents 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 BMP performance. BMP performance is discussed further in Section 5.

When no specific pollutant has been targeted for removal, developers may address pollutant removal through LID Retention and/or LID Biofiltration requirements. Under these circumstances, cost can become an important differentiator in BMP selection. BMP specific cost information is included in Section 5.

Large reductions in treatment BMP size and investment can be made by:

- Reducing runoff that needs to be captured, infiltrated, or treated.
- Controlling sources of pollutants.

These two strategies are the most effective in managing storm water. A third strategy includes implementation of treatment BMPs. The principles and methodologies for incorporating these strategies into site facility planning and design are discussed in Section 2.4 and Section 3, respectively. Fact Sheets for source control BMPs and treatment control BMPs are included in Section 4 and Section 5, respectively.

2.3.5. Determine BMP Size/Capacity

Based on the selected BMPs, the capacity and primary design sizing criteria must be established using a combination of local hydrology, project drainage characteristics (i.e., percent imperviousness or runoff coefficient), and numerical sizing requirements. BMPs will be volume-based, flow-based, area-based, or demand-based, as discussed in more detail later in this manual and must be able to effectively treat the design quantity. Peak storm event flows must also be taken into account if the BMP is a flow-based BMP, or a volume-based BMP that must also safely pass the design storm (i.e., an in-line detention basin). The volume-based BMP can safely pass the design peak event while maintaining its water quality functions up to the water quality design volume.

2.3.6. Develop Plan for BMP Maintenance

BMP maintenance arrangements take place during the planning phase of development and redevelopment projects. CCH is committed to providing for water quality protection by requiring that a mechanism for ongoing, long-term maintenance of BMPs is in place. To ensure that BMP maintenance will take place, evidence that project proponents have executed an approved method of BMP maintenance, repair, and replacement must be provided before project completion. Mechanisms used to assign responsibility for maintenance to public and private sector project proponents include:

- Covenants
- Maintenance agreements
- Conditional use permits
- Deed restrictions
- Other legal agreements

An O&M plan should be prepared by the project proponents. These plans are normally attached to approved maintenance agreements and describe a designated party to manage:

- BMPs
- Employee training programs and duties
- Operating schedules
- Maintenance frequencies
- Routine service schedules
- Specific maintenance activities
- Copies of resource agency permits

- Funding
- Other necessary activities

CCH requires annual inspection and servicing of all BMPs within maintenance agreements, and O&M forms documenting all required maintenance activities. The party responsible for the O&M plan is required to retain O&M forms for at least five (5) years.

A BMP maintenance plan is particularly valuable during ownership transitions; for example, when a developer transitions maintenance to a homeowners association, or when a developer turns over maintenance to a new owner. The BMP maintenance plan is also important when evaluating properties for acquisition, allowing long-term costs associated with BMPs to be factored into the property purchase agreement.

A more extensive discussion of long-term BMP maintenance is included in Section 6.

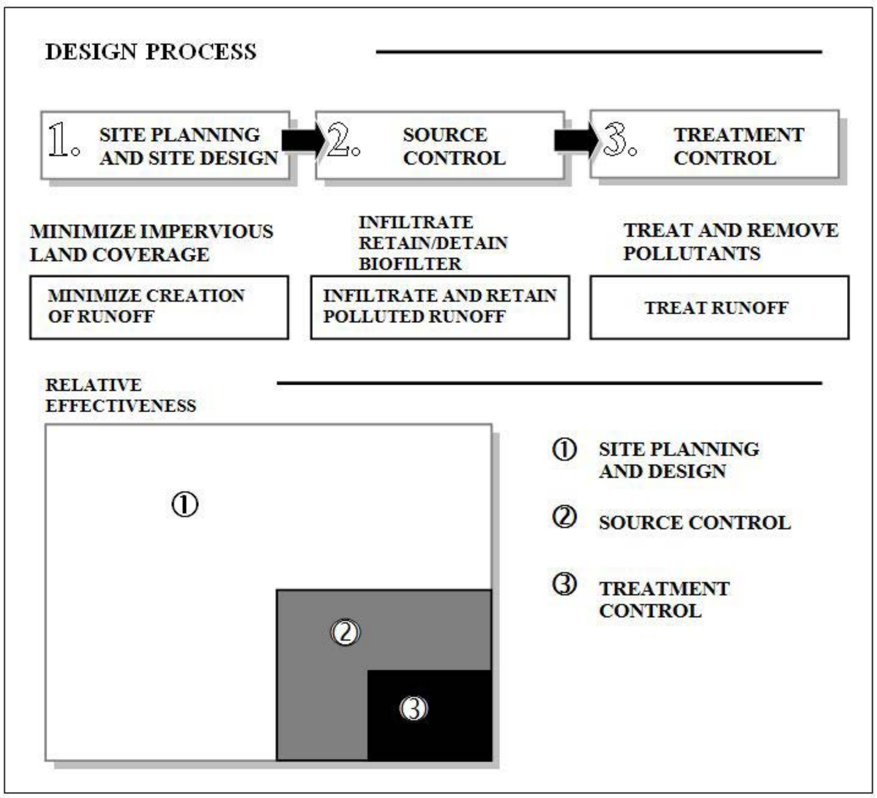
2.4. Planning Principles

Planning and design for water quality protection employs three basic strategies in the following order of relative effectiveness:

1. Reduce or eliminate post-project runoff.
2. Control sources of pollutants.
3. Treat contaminated storm water runoff before discharging it to natural water bodies.

A schematic of the design process and planning principles is illustrated in Figure 2.4.

Figure 2.4: Planning Principles



These principles are consistent with the permit and the program requirements for Priority Projects that require a consideration of a combination of site design, source control BMPs (that reduce or eliminate runoff and control pollutant sources) and treatment control BMPs with specific quantitative standards. The extent to which projects can incorporate site design strategies that reduce or eliminate post project runoff will depend upon the land use and local site characteristics of each project. Reduction in post project runoff offers a direct benefit by reducing the required size of treatment controls to meet the numeric standard included in the City Drainage Rules. Therefore, project developers can evaluate tradeoffs between the incorporation of alternative site design and source control techniques that reduce runoff and pollutants, and the size of required treatment controls.

2.4.1. Reduce Runoff

The principle of runoff reduction starts by recognizing that developing or redeveloping land within a watershed inherently increases the imperviousness of the areas and therefore the volume and rate of runoff and the associated pollutant load; and outlines various approaches to reduce or minimize this impact through planning and design techniques.

The extent of impervious land covering the landscape is an important indicator of storm water quantity and quality and the health of urban watersheds. Impervious land coverage is a fundamental characteristic of the urban and suburban environment -- rooftops, roadways, parking areas and other impenetrable surfaces cover soils that, before development, allowed rainwater to infiltrate.

Without these impervious coverings, inherent watershed functions would naturally filter rainwater and prevent receiving water degradation. Impervious surfaces associated with urbanization can cause adverse receiving water impacts in four (4) ways:

1. Rainwater is prevented from filtering into the soil, adversely affecting groundwater recharge and reducing base stream flows.
2. Because it cannot filter into the soil, more rainwater runs off, and runs off more quickly, causing increased flow volumes, accelerating erosion in natural channels, and reducing habitat and other stream values. Flooding and channel destabilization often require further intervention. As a result, riparian corridors are lost to channelization, further reducing habitat values.
3. Pollutants that settle on the impervious pavements and rooftops are washed untreated into storm sewers and nearby stream channels, increasing pollution in receiving water bodies.
4. Impervious surfaces retain and reflect heat, increasing ambient air and water temperatures. Increased water temperature negatively impacts aquatic life and reduces the oxygen content of nearby water bodies.

Techniques for reducing runoff range from land use planning on a regional scale by CCH or other local planning agencies, to methods that can be incorporated into specific projects. These techniques include actions to:

- Manage watershed impervious area.
- Minimize directly connected impervious areas.
- Incorporate zero discharge areas.
- Include self-treatment areas.
- Consider runoff reduction areas.

Brief summaries of the following techniques are presented:

Manage Watershed Impervious Area

Land use planning on the watershed scale is a powerful tool to manage the extent of impervious land coverage. This planning has two elements. First, identify open space and sensitive resource areas and target growth to areas that are best suited to development, and second, plan development that is compact to reduce overall land conversion to impervious surfaces and reliance on land-intensive streets and parking systems.

Impervious land coverage is a practical measure of environmental quality because:

- It is quantifiable, meaning that it can be easily recognized and calculated.
- It is integrative, meaning that it can estimate or predict cumulative water resource impacts independent of specific factors, helping to simplify the intimidating complexity surrounding non-point source pollution.
- It is conceptual, meaning that water resource scientists, city planners, landscape architects, developers, policy makers and citizens can easily understand it.

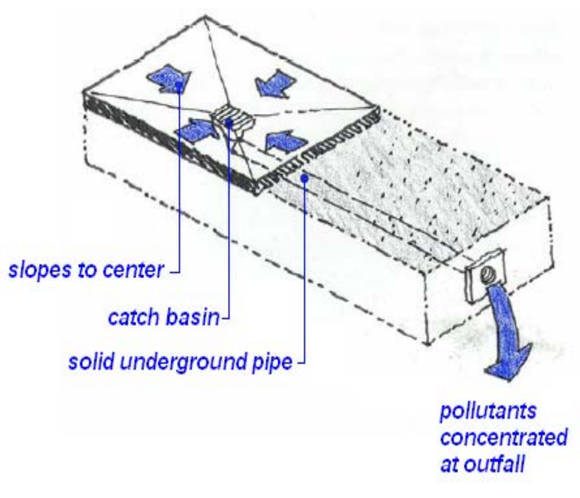
Water resource protection is becoming more complex. A wide variety of regulatory agencies, diverse sources of non-point source pollution, and a multitude of stakeholders make it difficult to achieve a consistent, easily understandable strategy for watershed protection. Impervious land coverage is a scientifically sound, easily communicated, and practical way to measure the impacts of new development on water quality.

Impervious area reductions also provide additional benefits such as reduced urban heat island effect, resulting in less energy use to cool structures and more efficient irrigation use by plants. Reductions have also been attributed to more human-scale landscaper and higher property values.

Minimize Directly Connected Impervious Areas (DCIA)

Impervious areas directly connected to the storm drain system are the greatest contributor to non-point source pollution. The first effort in site planning and design for storm water quality protection is to minimize the "directly connected impervious area (DCIA)" as shown in Figure 2.5.

Figure 2.5: Directly Connected Imperious Area



Any impervious surface that drains into a catch basin, area drain, or other conveyance structure is a DCIA. As storm water runoff flows across parking lots, roadways, and paved areas, the oils, sediments, metals and other pollutants are collected and concentrated. If this runoff is collected by a drainage system and carried directly along impervious gutters or in closed underground pipes, it has no opportunity for filtering by plant material or infiltration into the soil. It also increases in speed and volume, which may cause higher peak flows downstream, and may require larger capacity storm drain systems, increasing flood and erosion potential.

Minimizing directly connected impervious areas can be achieved in two (2) ways:

1. Limiting overall impervious land coverage.
2. Directing runoff from impervious areas to pervious areas for infiltration, retention/detention, or filtration.

Strategies for reducing impervious land coverage include:

- Cluster rather than sprawl development.
- Taller narrower buildings rather than lower spreading ones.
- Sod or vegetative “green roofs” rather than conventional roofing materials.
- Narrower streets rather than wider ones.
- Pervious pavement for light duty roads, parking lots, and pathways.

Example strategies for infiltration, retention/detention, and biofiltration include:

- Vegetated swales
- Vegetated basins (ephemeral - seasonally wet)
- Constructed ponds (permanent - always wet)
- Crushed stone reservoir base rock under pavements or in sumps
- Cisterns and tanks
- Infiltration basins
- Drainage trenches
- Dry wells
- Others

Unlike conveyance storm drain systems that convey water beneath the surface and work independently of surface topography, a drainage system for storm water infiltration can work with natural landforms and land uses to become a major design element of a site plan. Solutions that reduce DCIA prevent runoff, detain or retain surface water, attenuate peak runoff rates, benefit water quality and convey storm water. Site plans that apply storm water management techniques use the natural topography to suggest the drainage system, pathway alignments, optimum locations for parks and play areas, and the most advantageous locations for building sites. In this way, the natural landforms help to generate an aesthetically pleasing urban form integrated with the natural features of the site.

Incorporate No Discharge Areas

An area within a development project can be designed to infiltrate, retain, or detain the volume of runoff requiring treatment from that area.

The term “No Discharge” in this philosophy applies at storm water treatment design storm volumes.

BMP site design techniques available for designing areas that produce no treatment-required runoff include:

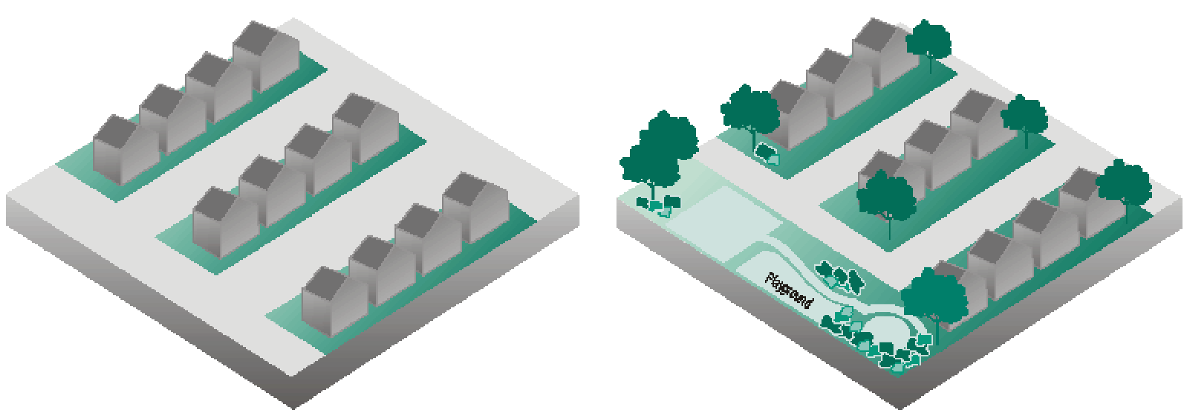
- Retention/Detention ponds
- Wet ponds
- Infiltration areas
- Large fountains
- Retention rooftops
- Green roofs (roofs that incorporate vegetation) and blue roofs (roofs that incorporate detention or retention of rain)

Infiltration areas, ponds, fountains, and green/blue roofs can provide “dual use” functionality as storm water retention measures and development amenities. Detention ponds and infiltration areas can double as playing fields or parks. Wet ponds and infiltration areas can serve dual roles when meeting landscaping requirements.

When several “No Discharge” areas are incorporated into a development design, significant reductions in volumes requiring treatment may be realized.

“No Discharge” areas such as wet ponds, detention ponds, and infiltration areas can be designed to provide treatment over and above the storm volume captured and infiltrated. For example, after a wet pond area has captured its required storm volume, additional storm volume may be treated via settling prior to discharge from the pond. In this case, the “No discharge” area converts automatically into a treatment device for runoff from other areas, providing settling for storm volumes beyond treatment requirements. Another example is a grassy infiltration area that converts into a treatment swale after infiltrating its area-required treatment volume. The grassy infiltration area in this example becomes a treatment swale for another area within the development. See Figure 2.6.

Figure 2.6: No Discharge Area Usage



Include Self-Treatment Areas

Developed areas may provide "self-treatment" of runoff if properly designed and drained.

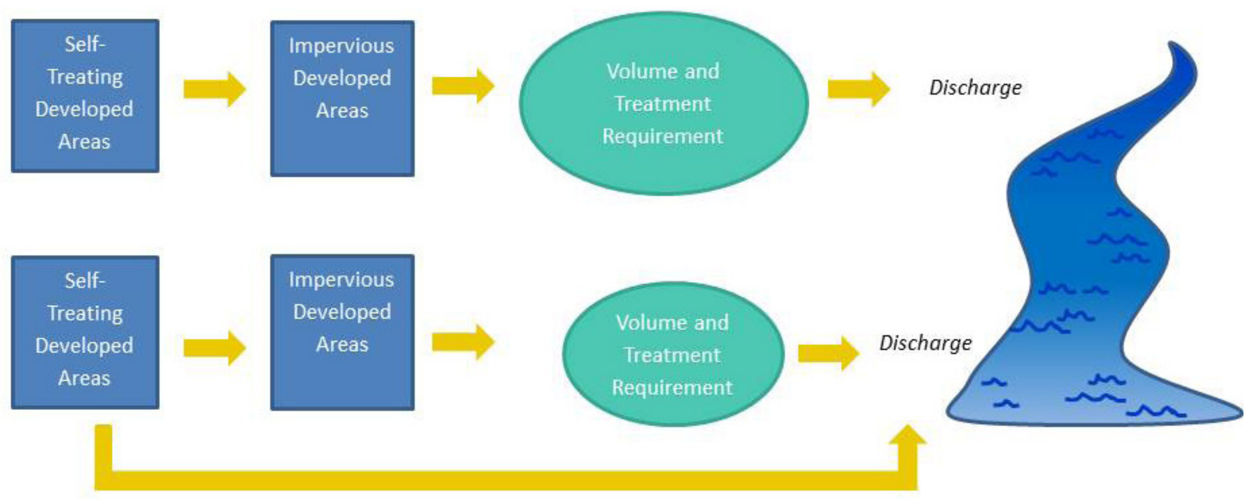
Self-treating site design techniques include:

- Conserved natural spaces
- Large landscaped areas (including parks and lawns)
- Grass/vegetated swales
- Turf block paving areas

The infiltration and biotreatment inherent to such areas provides the treatment control necessary. These areas therefore act as their own BMP, and no additional BMPs to treat runoff should be required.

As illustrated in Figure 2.7, site drainage designs must direct runoff from self-treating areas away from other areas of the site that require treatment of runoff. Otherwise, the volume from the self-treating area will only add to the volume requiring treatment from the impervious area.

Figure 2.7: Self-Treating Usage Areas



Likewise, under this philosophy, self-treating areas receiving runoff from treatment-required areas would no longer be considered self-treating, but rather would be considered as the BMPs in place to treat that runoff. These areas could remain as self-treating, or partially self-treating areas, if adequately sized to handle the excess runoff addition.

Consider Runoff Reduction Areas

Using alternative surfaces with a lower coefficient of runoff or "C-Factor" may reduce runoff from developed areas. The C-Factor is a representation of the surface's ability to produce runoff. Surfaces that produce higher volumes of runoff are represented by higher C-Factors, such as impervious surfaces. Surfaces that produce smaller volumes of runoff are represented by lower C-Factors, such as more pervious surfaces. See Table 2.2 for typical C-Factor values for various surfaces during small storms.

Table 2.2: Estimated C-Factors for Various Surfaces during Small Storms

Paving Surfaces	C-Factor
Concrete	0.80
Asphalt	0.70
Pervious Concrete	0.60
Cobbles	0.60
Pervious Asphalt	0.55
Natural Stone without Grout	0.25
Turf Block	0.15
Brick without Grout	0.13
Unit Pavers on Sand	0.10
Crushed Aggregate	0.10
Grass	0.10
Grass Over Porous Plastic	0.05
Gravel Over Porous Plastic	0.05

Note: C-Factors for small storms are likely to differ (be lower) than C-Factors developed for large, flood control volume size storms. The above C-Factors were produced by selecting the lower end of the best available C-Factor range for each paving surface. These C-Factors are only appropriate for small storm treatment design, and should not be used for flood control sizing.

Site design techniques that incorporate pervious materials may be used to reduce the C-Factor of a developed area, reducing the amount of runoff requiring treatment. These materials include:

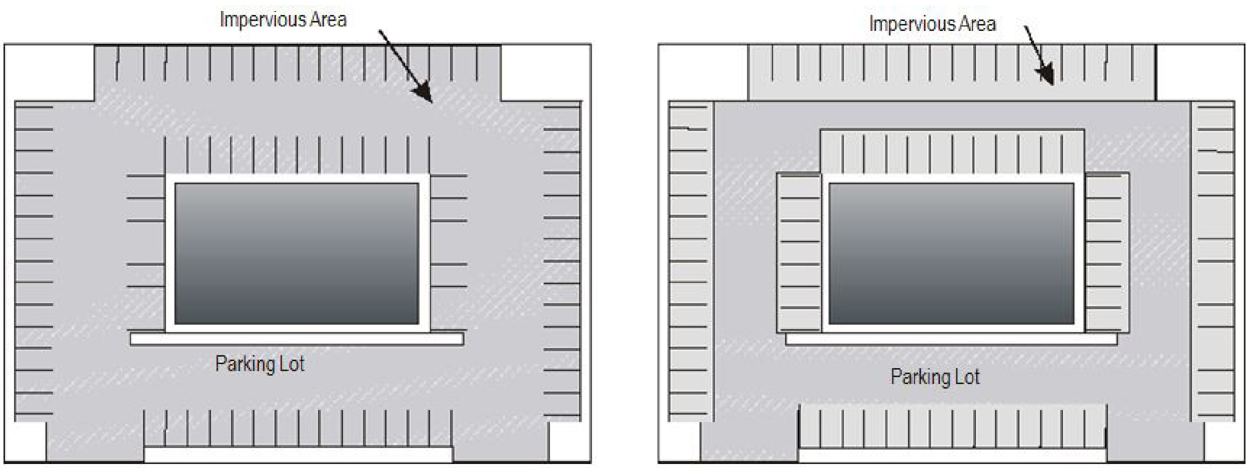
- Pervious concrete
- Pervious asphalt
- Turf block
- Brick (un-grouted)
- Natural stone
- Concrete unit pavers
- Crushed aggregate
- Cobbles
- Wood mulch

Table 2.3 compares the C-Factors of conventional paving surfaces to alternative; lower C-Factor paving surfaces. By incorporating more pervious, lower C-Factor surfaces into a development (see Figure 2.8); lower volumes of runoff may be produced. Lower volumes and rates of runoff translate directly to lower treatment requirements.

Table 2.3: Conventional Paving Surface Small Storm C-Factor versus Alternative Paving C-Factors

Conventional Paving Surface C-Factors	Reduce C-Factor Paving Alternatives
• Concrete Patio/Plaza (0.80) • Asphalt Parking Area (0.70)	• Decorative unit Pavers on Sand (0.10) • Turf Block Overflow Parking Area (0.15) • Pervious Concrete (0.60) • Pervious Asphalt (0.55) • Crushed Aggregate (0.10)

Figure 2.8: Impervious Parking Lot Versus Parking lot with Some Pervious Surfaces



Other site design techniques such as disconnecting impervious areas, preservation of natural areas, and designing concave medians may be used to reduce the overall C-Factor of development areas.

Table 2.4 presents a list of site design and landscaping techniques and indicates whether they are applicable for use in No Discharge Areas, Self-Treating Areas, and Runoff Reduction Areas. Several different techniques may be implemented within the same design philosophy. Some techniques may be used to implement more than one design philosophy. Where feasible, combinations of multiple techniques may be incorporated into new development and redevelopment projects to minimize the amount of treatment required.

Table 2.4: Site Design and Landscaping Technique

Site Design and Landscape Techniques	Design Criteria			Design Philosophy		
	Volume-based Design	Flow-based Design	Demand-Based Design	No Discharge	Self Treating	Runoff Reduction
Permeable pavements	X					
Pervious concrete	X					X
Pervious asphalt	X					X
Turf block	X				X	X
Un-grouted brick	X					X
Un-grouted natural stone	X					X
Un-grouted concrete unit pavers	X					X
Unit pavers on sand	X					X
Crush aggregate	X					X
Cobbles	X					X
Wood Mulch	X					X
Streets						
Urban curb/swale system	X	X				X
Rural swale system	X	X				X

Table 2.4: Site Design and Landscaping Technique (Continued)

Site Design and Landscape Techniques	Design Criteria			Design Philosophy		
	Volume-based Design	Flow-based Design	Demand-Based Design	No Discharge	Self Treating	Runoff Reduction
Dual drainage system	X	X				X
Concave median	X	X		X		X
Pervious island	X	X				X
Parking lot						
Hybrid surface parking lot	X					X
Pervious parking grove	X					X
Pervious overflow parking	X				X	X
Driveways						
Not directly connected impervious driveways		X				X
Paving only under wheels	X				X	X
Flared driveways	X					X
Buildings						
Dry-well	X			X		X
Cistern			X	X		X
Foundation planting	X	X				X
Pop-up drainage emitters		X				
Landscape						
Grass/vegetated swale		X			X	X
Extended detention (dry) ponds	X			X	X	X
Wet ponds	X			X	X	X
Bioretention areas	X			X	X	X

2.4.2. Control Sources of Pollutants

There are a number of items that can be routinely designed into a project that function as source controls once a project is completed. They include such items as marking new drain inlets and posting informational signs; improving landscape planning and efficient irrigation methods; using water quality friendly building materials; implementing roof runoff controls; properly designing outdoor material and trash storage areas; and permanently protecting slopes and channels from erosion. They also include design features for specific workplace or other activity areas such as vehicle washing areas, outdoor processing areas, maintenance bays and docks, and fueling areas.

Design of BMPs to control workplace exposure to pollutants is guided by two (2) general principles:

1. Prevent water from contacting work areas. Work and storage areas should be designed to prevent storm water runoff from passing through shipping areas, vehicle maintenance yards, and other work places before it reaches storm drains. The objective is to prevent the discharge of water laden with grease, oil, heavy metals and process fluids to surface waters or sensitive resource areas.

2. Prevent pollutants from contacting surfaces that come into contact with storm water runoff. Precautionary measures should be employed to keep pollutants from contacting surfaces that come into contact with runoff. This means controlling spills and reviewing operational practices and equipment to prevent pollutants from coming into contact with storm or wash water runoff.

Once BMPs are designed into a project, they must be appropriately operated and maintained throughout the life cycle of the project in order to accomplish the BMPs' pollution control objectives.

2.4.3. Treat Runoff

Until recently, storm water and street design systems were designed to achieve a single objective—to convey water off-site as quickly as possible. The primary concern of conveyance systems was to protect property from flooding during large, infrequent storms. Drainage systems designed to meet this single volume control objective fail to address the environmental effects of non-point source pollution and increases in runoff volume and velocity caused by development.

Today's drainage systems must meet multiple purposes: protect property from flooding, control stream bank erosion, and protect water quality. To achieve this, designers must integrate conventional flood control strategies for large, infrequent storms with storm water quality control strategies.

There are several basic water quality strategies for treating runoff:

- Infiltrate runoff into the soil.
- Retain/detain runoff for later release with the detention providing treatment.
- Convey runoff slowly through vegetation.
- Treat runoff on a flow-through basis using various treatment technologies.

Solutions should be based on an understanding of the water quality and economic benefits inherent in construction of systems that utilize or mimic natural drainage patterns. Site designs should be based on site conditions and use these as the basis for selecting appropriate storm water quality controls. The drainage system design process considers variables such as local climate, the infiltration rate and erosivity of the soils, and slope. Many of the negative impacts associated with urban development can be alleviated if policy alternatives encourage developers to protect and restore habitat quality and quantity, include measures to improve water quality, and provide buffers between development and stream corridors.

Unlike conveyance models, which are assessed by simple quantitative measures (flood control volumes and economics), water quality designs must optimize a complex array of both quantitative and qualitative standards, including engineering worthiness, environmental benefit, horticultural sustainability, aesthetics, functionality, maintainability, economics and safety.

2.4.4. Planning Development Strategies in Practice

The importance of site planning in storm water quality protection is illustrated in the following examples of development strategies: conventional residential subdivision (Figure 2.9, Alternative 1), conventional subdivision employing BMPs (Figure 2.10, Alternative 2), and a mixed-use transit-oriented development (Figure 2.11, Alternative 3). All three (3) examples are intended to accommodate approximately 660 housing units on a 220-acre site adjacent to a stream.

The conventional residential subdivision (Alternative 1) accommodates 660 single-family homes on individual lots. One-sixth acre lots are accessed by a network of 40 feet wide cul-de-sac streets, with 5 feet sidewalks adjacent to the curb on each side of the street. The street and sidewalks are located within a 60 feet right-of-way, which is covered with a 40 feet wide street and two (2)- 5 feet sidewalks, or 50 feet of pavement, 100% impervious land coverage (streets only), and no room for street trees. No variation exists in housing types (all single-family).

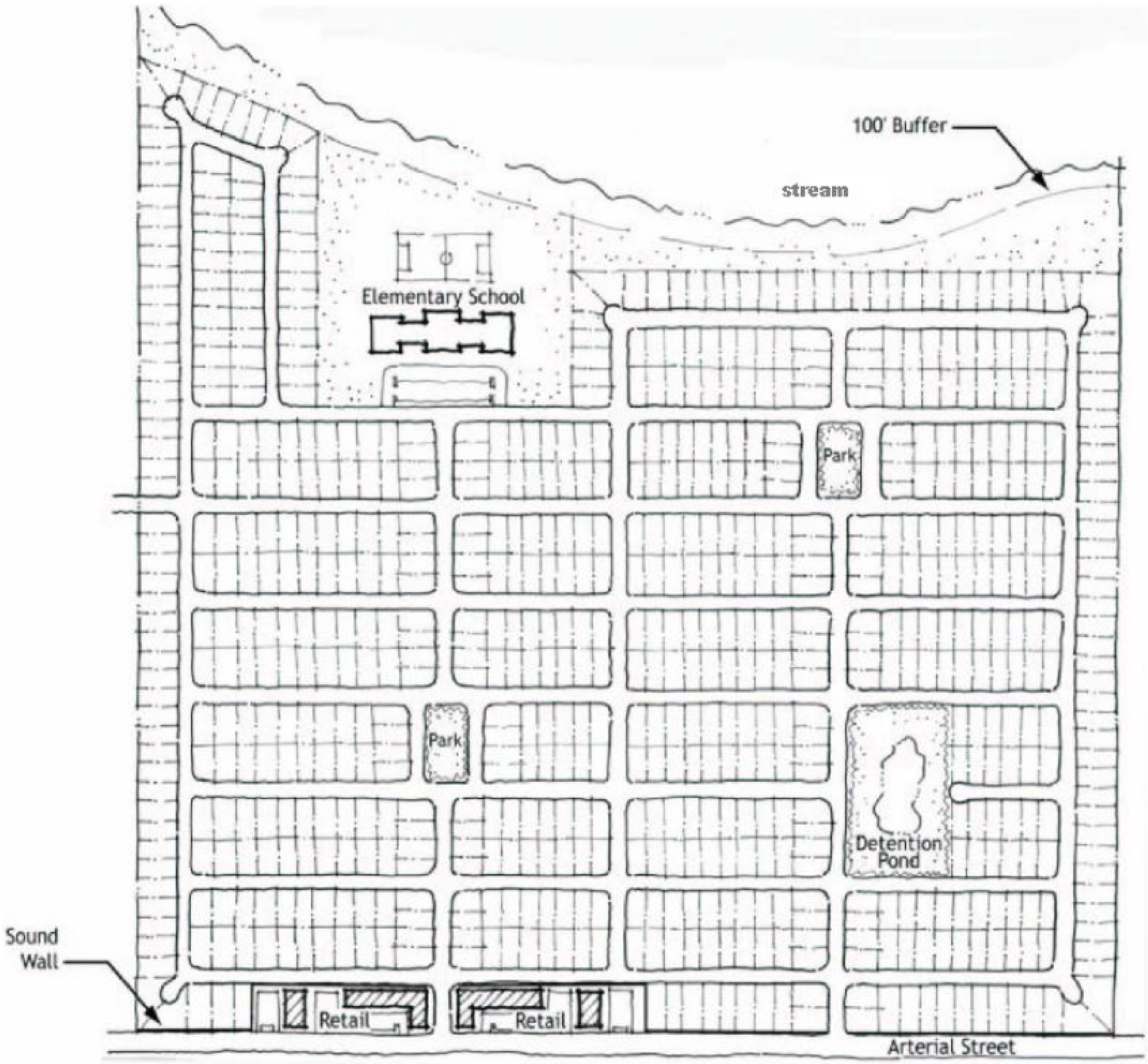
Figure 2.9: Alternative 1- Conventional

Both the streets and the open space features lack structure or hierarchy. The few direct connections through the neighborhood result in long stretches of overly wide streets that discourage walking.

Conventional development design does not use the recreational or storm water benefits of the available open space and does not respond to natural and topographic features. Preservation of open space is a low priority, and the setback between the development and the stream is minimal. The remaining open space character is remnant space offering residents no stream access or parks. Storm water travels through a 15,000 feet network of drainpipes and in the absence of current permit requirements would discharge untreated runoff directly into the stream. However, applying typical permit requirements, the development would still be required to incorporate runoff treatment for the water quality design volume defined in the local permit or MS4 new development program. For example, if the permit required treatment of the runoff from 0.75 inches of rainfall, the development as planned had an overall percent impervious value of 45%, and the designer was considering the use of an extended detention basin for treatment, this would require a treatment volume of approximately 6.2 acre-feet. Based on typical detention basin design practices, this could result in the need to dedicate approximately 2 to 3 acres of land, or the equivalent of approximately 12 to 18 lots to incorporate the basin into the development near the point where drainage enters the stream. Alternatively, if a watershed master plan for water quality had been adopted in which the development could participate financially, the project would contribute financially based on its required treatment volume and the cost allocation plan for the watershed program.

The hybrid/best practices subdivision (Alternative 2) illustrates a conventional neighborhood that applies some storm water management practices. This attempt accommodates 660 single-family homes on individual lots. Streets are narrower, with the interior access streets at 28 feet wide, while internal neighborhood collectors are 32 feet wide. All streets have detached sidewalks that accommodate street trees planted between the sidewalk and the curb. This development sets the houses 100 feet back from the stream and offers residents 12 acres of access to open space and parks. The overall imperviousness has been reduced to about 41%, thereby reducing the volume to be treated to approximately 5.6 acre-feet. A detention basin has been created in open space within the development. Nearly 1/4 of the 13,000 feet network of piped storm water drains to a detention pond.

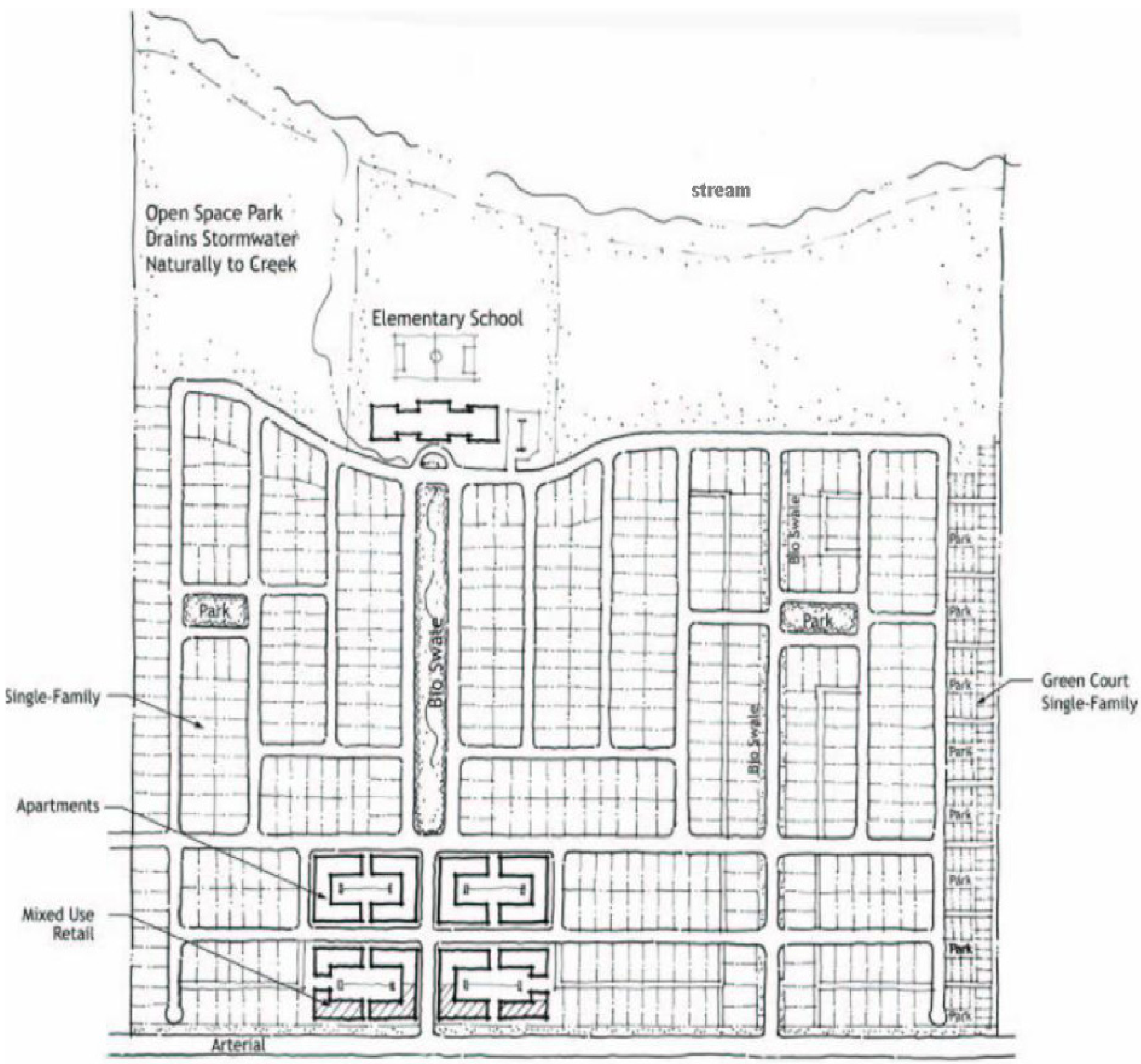
Figure 2.10: Alternative 2- Hybrid/Best Practices



By employing a hierarchy of narrower streets this neighborhood requires 1,475 feet^2 of street per housing unit, a reduction of 19% relative to the conventional sub-division.

The neo-traditional mixed-use neighborhood is illustrated as Alternative 3. This neighborhood includes 660 housing units, but also introduces other uses: retail, office, and live-work, within a network of tree-lined streets and open space. The neighborhood drains to an open space park adjacent to the stream, naturally and efficiently filtering storm water before it enters the stream. Bioswales along key streets capture and treat storm water en-route to the stream, providing aesthetic appeal and recreational opportunities. Alternative 3 requires 965 feet^2 of street per housing unit, a reduction of 47% relative to the conventional sub-division. A strategically located transit system stops near shops and higher density housing makes transit feasible. Every dwelling unit in the neighborhood is within a 5-minute walk from shops or transit. The overall imperviousness of this site has been reduced to approximately 36%, further reducing the treatment volume. In addition, there are a variety of opportunities to incorporate treatment for all of the remaining runoff within the open space park without the need to dedicate any additional developable land.

Figure 2.11: Alternative 3 – Neo-Traditional



A comparison of the three (3) alternatives is shown in Table 2.5

Table 2.5: Comparison of Three Alternatives

	Alternative 1	Alternative 2	Alternative 3
Total Site (acre)	220	220	220
# of Housing Units	660	660	660
Parks & Open Space (acre)	0	12	12
Stream Setback (feet)	0	100	500
Impervious Land Coverage - Streets (acre)	28	22	15
% of Site that is Impervious - Streets Only	13%	10%	7%
% of Site that is Impervious - Streets Only (Relative to Conventional)	100%	81%	53%
Linear Feet of Pipe	15,000	13,000	10,000
Linear Feet of Swale	0	0	4,700
Width of Major Streets (ft)	40	32	32
Width of Minor Streets (ft)	None	28	28

Typical lots in Alternatives 2 and 3 are illustrated in three (3) forms: street loaded, alley fed and rural. In the street-loaded form, lot size is still approximately 1/6 acre, but the lot is narrower and deeper, thus reducing the amount of street frontage per household. The two-car garage is accessed from a front driveway. This front-loaded street accounts for 63% impervious land coverage in the 60 feet right-of-way.

Looking at a typical street, the traditional residential neighborhood reduces the number of feet of street and sidewalk per housing unit by nearly 40% compared to the conventional subdivision. This is accomplished by two means: a narrower street width (28 feet versus 40 feet), and narrower, deeper lots (60 feet versus 65 feet wide). Narrower lots mean less street frontage per lot.

In the alley-loaded form, the street right-of-way is narrowed to 50 feet, leaving 4 feet for trees between the sidewalk and curb. This form also employs the narrower street, achieving a 40% reduction in pavement dedicated to street and sidewalk. A 16 feet wide alley is provided in the back to access a garage at the rear of each lot. Additional pavement for the alley is balanced by elimination of pavement for the front driveway. This model assumes an impervious asphalt or concrete alley. Gravel alleys are feasible, and improve permeability. In this form, narrower, deeper lots are employed to accommodate the depth required for the alley.

The rural street form dramatically reduces impervious land coverage. The street is 19 feet wide with gravel shoulders for trees and parking. Pedestrians walk on the gravel shoulder or share the street with slow-moving cars.

Looking at a typical street, the rural form provides the greatest reduction in impervious land coverage. Only 570 $feet^2$ of pavement of street is required per housing unit, a reduction of 62% compared to the conventional sub-division.

3. SITE AND FACILITY DESIGN FOR WATER QUALITY PROTECTION

3.1. Introduction

Development and significant redevelopment usually creates impervious surfaces which prevents rainwater from soaking into the ground, allowing it to run across parking lots, streets, and roofs, picking up contaminants and pollutants along the way. Historically, the goal of storm water planning has been to prevent localized flooding by moving large amounts of water off-site as quickly as possible, but fast moving storm water presents some problems. High velocity discharges causes downstream flooding, erode stream banks, and contribute to water quality violations. Bacteria and other pathogens carried in storm water contaminate coastal waters, often requiring the closure of beaches. Rainwater diverted or unable to soak into the soil cannot recharge aquifers. This reduces stream base flows, which can cause streams to dry up for extended periods of time. Storm water that collects in detention basins or flows over impervious surfaces is often much warmer than the receiving water, causing stress to fish and other aquatic life.

Site and facility design for storm water quality protection employs a multi-level strategy. The strategy consists of: 1) reducing or eliminating post-project runoff; 2) controlling sources of pollutants; and 3), if still needed after deploying 1) and 2), treating contaminated storm water runoff before discharging it to the storm drain system or to receiving waters.

This section describes how elements 1), 2), and 3) of the strategy can be incorporated into the site and facility planning and design process, and by doing so, eliminating or reducing the amount of storm water runoff that may require treatment at the point where storm water runoff ultimately leaves the site. Element 1) is referred to as “site design strategies” because it utilizes strategies during site design to reduce or eliminate runoff. Element 2) may be referred to as “source controls” because they emphasize reducing or eliminating pollutants in storm water runoff at their source through runoff reduction and by keeping pollutants and storm water segregated. Section 4 provides detailed descriptions of the BMPs related to element 2) of the strategy. Element 3) of the strategy is referred to as “treatment control” because it utilizes treatment mechanisms to remove pollutants that have entered storm water runoff. Section 5 provides detailed descriptions of BMPs related to element 3) of the strategy. Treatment controls integrated into and throughout the site usually provide enhanced benefits over the same or similar controls deployed only at the “end of the pipe” where runoff leaves the project site.

Low Impact Development (LID)

LID is a strategy seeking to control storm water quality at its source, incorporating such elements as infiltration, retention, and biofiltration. An emphasis on LID is mandatory for Priority A1 and A2 projects if the site allows. Rather than moving storm water off-site through a conveyance system, the goal of LID is to restore the natural ability of an urban site to absorb storm water, resulting in an area more closely resembling pre-development hydrology. LID employs such principles as preserving and recreating natural landscape features and minimizing effective imperviousness to create functional and aesthetically appealing drainage that treats storm water as a resource rather than a waste product. LID reduces peak runoff by allowing rainwater to infiltrate into the ground, allowing rainwater to evaporate and transpire, and collecting rainwater as a resource for irrigation and other methods of reuse. LID addresses pollutant removal, maintains or restores pre-development hydrological and ecological functions, minimizes impervious surfaces, and ultimately reduces runoff volume.

LID integrates a range of small-scale, economical devices that control runoff at the source, such as green roofs (see TC-33), vegetated biofilters or rain gardens employing native landscaping (see TC-32), constructed green spaces such as vegetated swales (see TC-30), and infiltration through permeable pavement (see TC-13). By implementing LID principles and practices, water can be managed in such a way that reduces the impact of built areas and promotes the natural movement of water within an ecosystem.

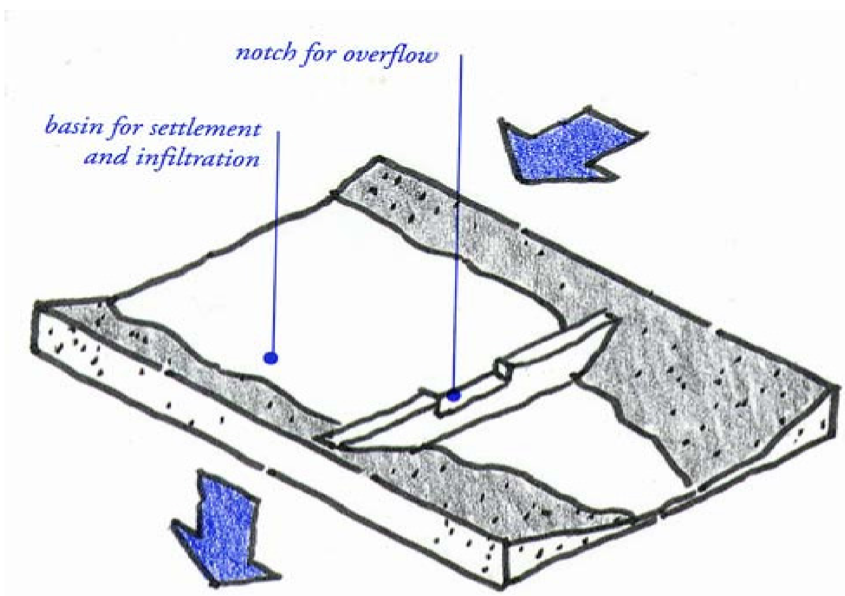
3.2. Integration of BMPs into Common Site Features

Many common site features can achieve storm water management goals by incorporating one or more basic elements, either alone or in combination, depending on site and other conditions. The basic elements include infiltration, retention/detention, biofilters, and structural controls. This section first describes these basic elements, and then describes how these elements can be incorporated into common site features.

Infiltration

Infiltration is the process where water enters the ground and moves downward through the unsaturated soil zone. Infiltration is ideal for management and conservation of runoff because it filters pollutants through the soil and restores natural flows to groundwater and downstream water bodies. See Figure 3.1.

Figure 3.1: Infiltration Basin



The infiltration approach to storm water management seeks to “preserve and restore the hydrologic cycle.” An infiltration storm water system seeks to infiltrate runoff into the soil by allowing it to flow slowly over permeable surfaces.

The slow flow of runoff allows pollutants to settle into the soil where they are naturally mitigated. The reduced volume of runoff that remains takes a long time to reach the outfall, and when it empties into a natural water body or storm sewer, its pollutant load is greatly reduced.

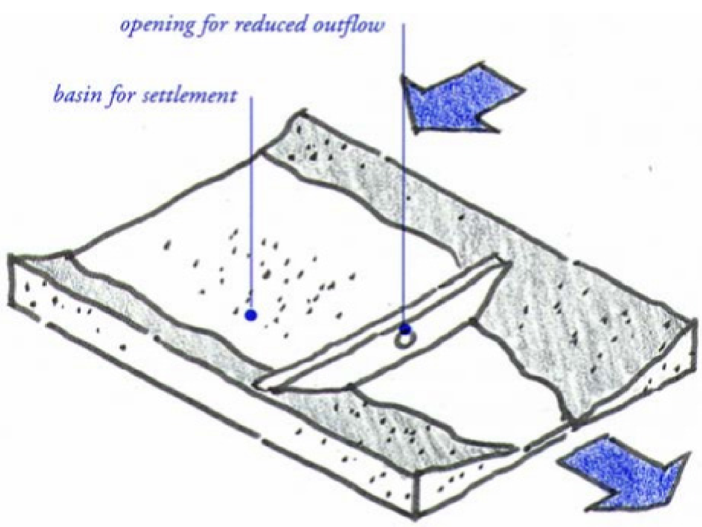
Infiltration basins can be either open or closed. Open infiltration basins, include ponds, swales and other landscape features, are usually vegetated to maintain the porosity of the soil structure and to reduce erosion. Closed infiltration basins can be constructed under the land surface with open graded crushed stone, leaving the surface to be used for parking or other uses. Subsurface closed basins are generally more difficult to maintain and more expensive than open filtration systems, and are used primarily where high land costs demand that the land surface be reclaimed for economic use.

Infiltration systems are often designed to capture the "first flush" storm event and used in combination with a detention basin to control peak hydraulic flows. They effectively remove suspended solids, particulates, bacteria, organics and soluble metals and nutrients through the vehicle of filtration, absorption and microbial decomposition. Groundwater contamination should be considered as a potential adverse effect and should be considered where shallow groundwater is a source of drinking water. In cases where groundwater sources are deep, there is a very low chance of contamination from normal concentrations of typical urban runoff.

Retention and Detention

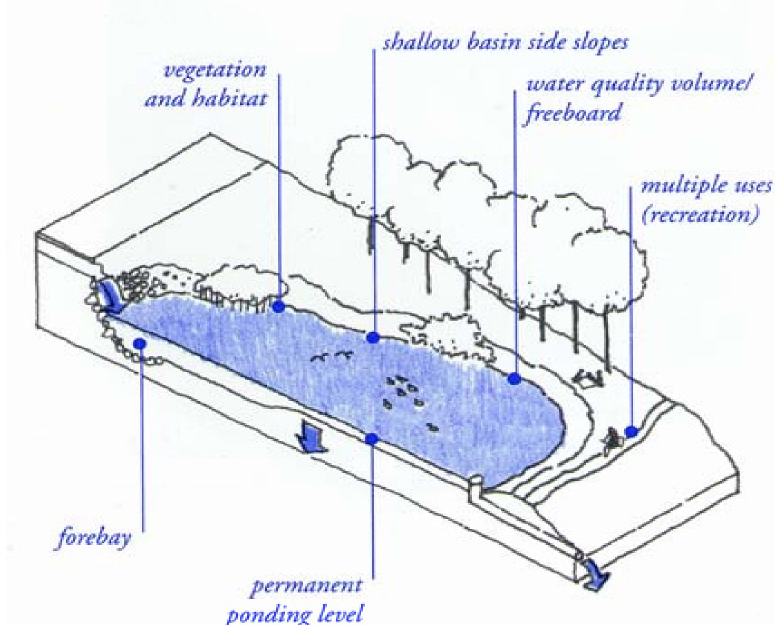
Retention and detention systems differ from infiltration systems primarily in intent. Detention systems are designed to capture and retain runoff temporarily and release it to receiving waters at predevelopment flow rates. Permanent pools of water are not held between storm events. Pollutants settle out and are removed from the water column through physical processes. See Figure 3.2.

Figure 3.2: Simple Detention System



Retention systems capture runoff and retain it between storms as shown in Figure 3.3. Water held in the system is displaced by the next significant rainfall event. Pollutants settle out and are thereby removed from the water column. Because the water remains in the system for a period of time, retention system benefits from biological and biochemical removal mechanisms provided by aquatic plants and microorganisms. See Figure 3.3.

Figure 3.3: Retention System



Retention/detention systems may release runoff slowly enough to reduce downstream peak flows to their pre-development levels, allow fine sediments to settle, and uptake dissolved nutrients in the runoff where wetland vegetation is included.

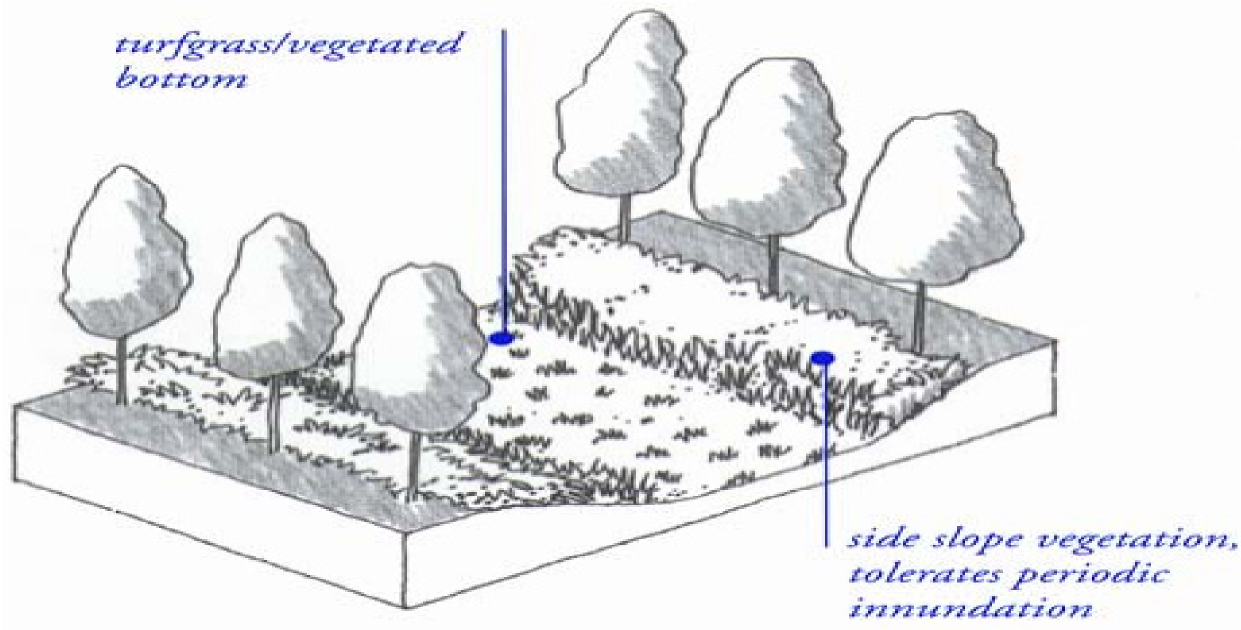
Bioretention facilities have the added benefit of aesthetic appeal. These systems can be placed in parking lot islands, landscaped areas surrounding buildings, perimeter parking lots, and other open space sections. Placing bioretention facilities on land that city regulations require developers to devote to open space efficiently uses the land. An experienced landscape architect can choose plant species and planting materials that are easy to maintain, aesthetically pleasing, and capable of effectively reducing pollutants in runoff from the site.

Constructed wetland systems retain and release storm water in a manner that is similar to retention or detention basins. The design mimics natural ecological functions and uses wetland vegetation to filter pollutants. The system needs a permanent water source to function properly and must be engineered to remove coarse sediment, especially construction related sediments, from entering the pond. Storm water has the potential to negatively affect natural wetland functions and constructed wetlands can be used to buffer sensitive resources.

Biofilters

Biofilters, also known as vegetated swales and filter strips, are vegetated slopes and channels designed and maintained to transport shallow depths of runoff slowly over vegetation. Biofilters are effective if flows are slow (1 feet per second maximum) and depths are shallow (4 inch maximum). The slow movement of runoff through the vegetation provides an opportunity for sediments and particulates to be filtered and degraded through biological activity. In most soils, the biofilter also provides an opportunity for storm water infiltration, which further removes pollutants and reduces runoff volumes. See Figure 3.4.

Figure 3.4: Vegetated Swale



Swales intercept both sheet and concentrated flows and convey these flows in a concentrated, vegetation-lined channel. Grass filter strips intercept sheet runoff from the impervious network of streets, parking lots, and rooftops and divert storm water to a uniformly graded meadow, buffer zone, or small forest. Typically, the vegetated swale and grass strip-planting palette can comprise a wide range of possibilities from dense vegetation to turf grass. Grass strips and vegetated swales can function as pretreatment systems for water entering bioretention systems or other BMPs. If biofilters are to succeed in filtering pollutants from the water column, the planting design must consider the hydrology, soils, and maintenance requirements of the site.

Appropriate plantings not only improve water quality, they provide habitat and aesthetic benefits. Selected plant materials must be able to adapt to variable moisture regimes. Turf grass is acceptable if it can be watered in the dry season, and if it is not inundated for long periods.

Structural Controls

Structural controls in the context of this section include a range of measures that prevent pollutants from coming into contact with storm water. In this context, these measures may be referred to as “structural source controls” meaning that they utilize structural features to prevent pollutant sources and storm water from coming into contact with one another, thus reducing the opportunity for storm water to become contaminated. Examples of structural source controls include covers, impermeable surfaces, secondary containment facilities, runoff diversion berms, and diversions to wastewater treatment plants.

3.2.1. Streets

More than any other single element, street design has a powerful impact on storm water quality. Street and other transportation-related structures typically can comprise between 60 to 70% of the total impervious coverage in urban areas and, unlike rooftops, streets are almost always directly connected to an underground storm water system.

Recognizing that street design can be the greatest factor in development's impact on storm water quality, it is important that designers and developers employ street standards that reduce impervious land coverage. Directing runoff to biofilters or swales rather than underground storm drains produces a street system that conveys storm water efficiently while providing both water quality and aesthetic benefits.

On streets where a more urban character is desired, or where a rigid pavement edge is required, curb and gutter systems can be designed to empty into drainage swales. These swales can run parallel to the street, in the parkway between the curb and the sidewalk, or can intersect the street at cross-angles, and run between residences, depending on topography or site planning. Runoff travels along the gutter, but instead of being emptied into a catch basin and underground pipe, multiple openings in the curb direct runoff into surface swales or infiltration/detention basins.

In recent years, new street standards have been gaining acceptance that meets the access requirements of local residential streets while reducing impervious land coverage. These standards create a new class of street that is narrower and more interconnected than the current local street standard, called an "access" street. An access street is at the lowest end of the street hierarchy and is intended only to provide access to a limited number of residences.

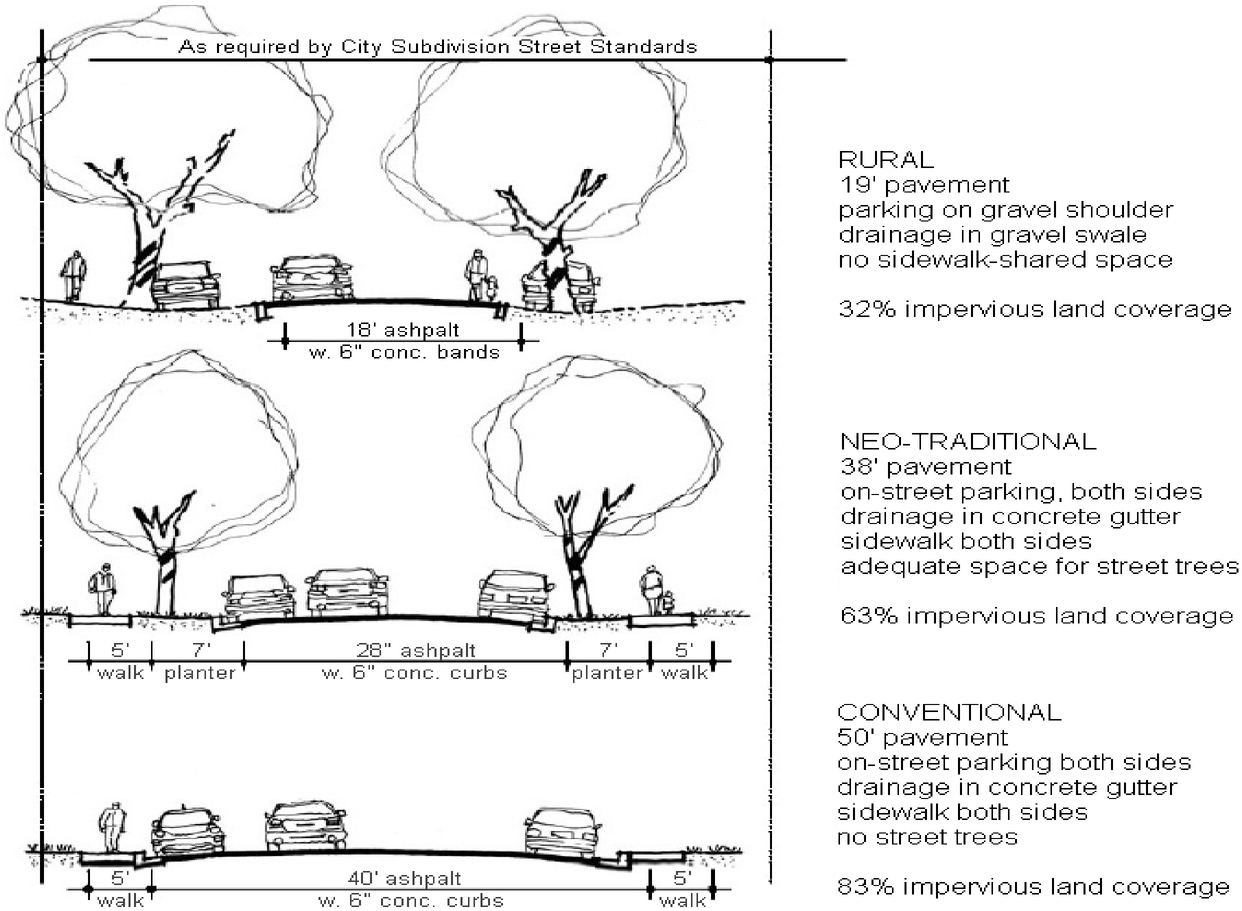
Street design is mandated by City standards. Officials must consider the scale of the land use as they select storm water and water quality design solutions. Traffic volume and speeds, bicycle lane design criteria, and residential and business densities influence the willingness of decision makers to permit the narrow streets that include curb less design alternatives.

Emergency service providers often raise objections to reduced street widths. Street designs illustrated here meet national Fire Code standards for emergency access. An interconnected grid system of narrow streets also allows emergency service providers with multiple access routes to compensate for the unlikely possibility that a street may be blocked.

A street standard that allows an interconnected system of narrow access streets for residential neighborhoods has the potential to achieve several complimentary environmental and social benefits. A hierarchy of streets sized according to average daily traffic volumes yields a wide variety of benefits: improved safety from lower speeds and volumes, improved aesthetics from street trees and green parkways, reduced impervious land coverage, less heat island effect, and lower development costs. If the reduction in street width is accompanied by a drainage system that allows for infiltration of runoff, the impact of streets on storm water quality can be greatly mitigated.

A comparison of street cross-sections is shown in Figure 3.5.

Figure 3.5: Comparison of Street Cross-Section (Two-way, Residential Access Streets)



3.2.2. Parking Lots

In any development, storage space for stationary vehicles can consume many acres of land area, often greater than the area covered by streets or rooftops. In a neighborhood of single-family homes, this parking area is generally located on private driveways or along the street. In higher density residential developments, parking is often consolidated in parking lots.

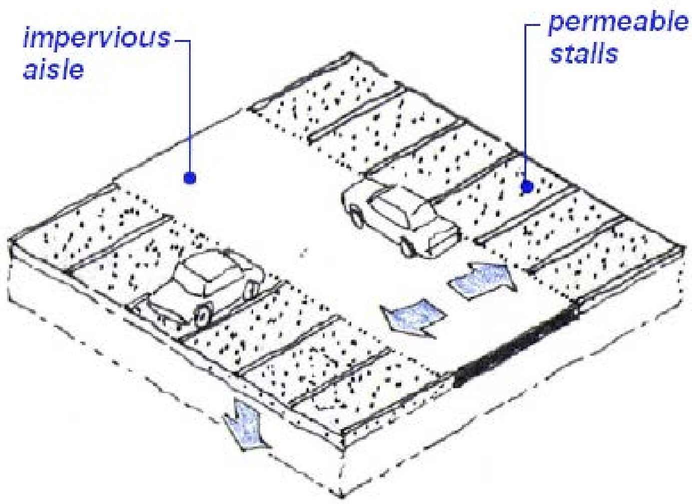
The space for storage of the automobile, the standard parking stall, occupies only 160 ft^2, but when combined with aisles, driveways, curbs, overhang space, and median islands, a parking lot can require up to 400 ft^2 per vehicle, or nearly one acre per 100 cars. Since parking is usually accommodated on an asphalt or concrete surface with conventional underground storm drain systems, parking lots typically generate a great deal of DCIA.

There are many ways to both reduce the impervious land coverage of parking areas and to filter runoff before it reaches the storm drain system.

Hybrid Parking Lot

Hybrid lots work on the principle that pavement use differs between aisles and stalls. Aisles must be designed for speeds between 10 and 20 miles per hour (mph), and durable enough to support the concentrated traffic of all vehicles using the lot. The stalls, on the other hand, need only be designed for the 2 or 3 mph speed of vehicles maneuvering into place. Most of the time the stalls are in use, vehicles are stationary. Hybrid lots reduce impervious surface coverage in parking areas by differentiating the paving between aisles and stalls, and combining impervious aisles with permeable stalls, as shown in Figure 3.6.

Figure 3.6: Hybrid Parking Lot



If aisles are constructed of a more conventional, impermeable material suitable for heavier vehicle use, such as asphalt, stalls can be constructed of permeable pavement. This can reduce the overall impervious surface coverage of a typical double loaded parking lot by 60% and avoid the need for an underground drainage system.

Permeable stalls can be constructed of a number of materials including pervious concrete, unit pavers such as brick or stone spaced to expose a permeable joint and set on a permeable base, crushed aggregate, porous asphalt, turf block, and cobbles in low traffic areas. Turf blocks and permeable joints are shown in Figures 3.7 and 3.8.

Figure 3.7: Turf Blocks

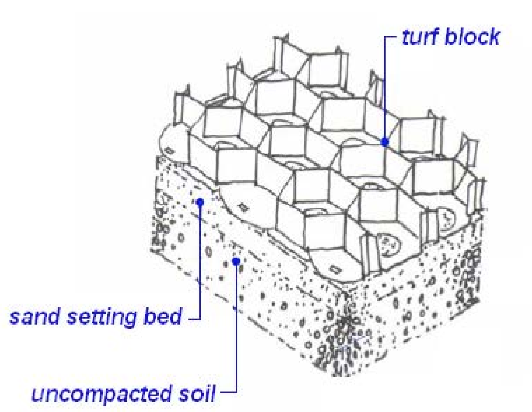
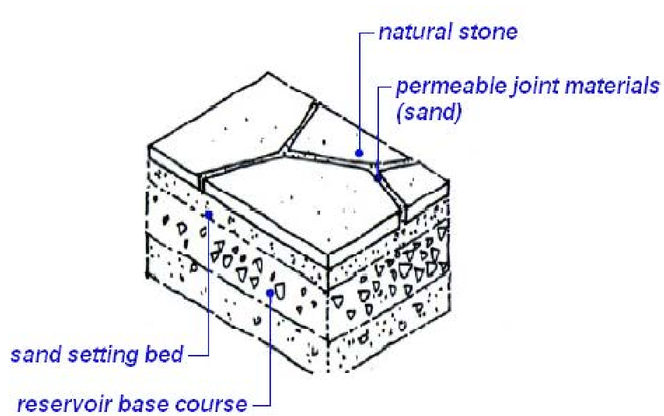


Figure 3.8 Permeable Joints



Parking Grove

A variation on the permeable stall design, a grid of trees and bollards can be used to delineate parking stalls and create a "parking grove." If the bollard and tree grids are spaced approximately 19 feet apart, two vehicles can park between each row of the grid. This 9.5 feet stall spacing is slightly more generous than the standard 8.5 to 9 feet stall, and allows for the added width of the tree trunks and bollards. A benefit of this design is that the parking grove not only shades parked cars, but also presents an attractive open space when cars are absent. Examples of parking groves are shown in Figures 3.9 and 3.10.

Figure 3.9: Parking Grove

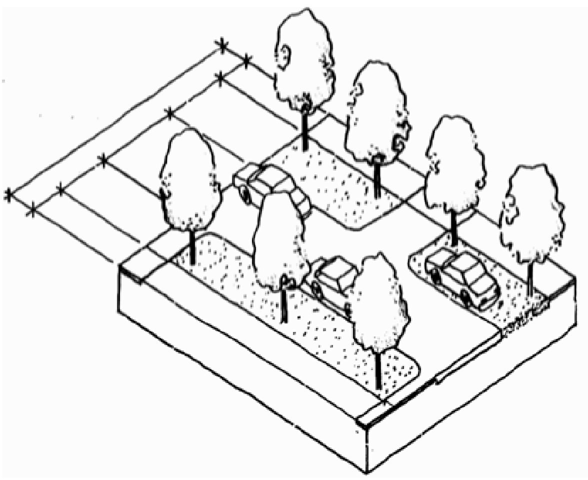
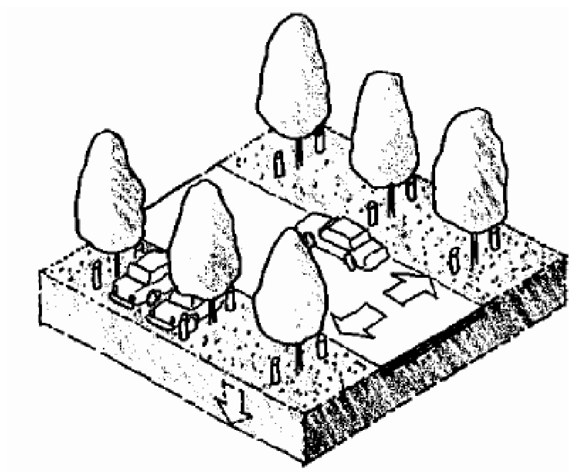


Figure 3.10: Parking Grove



Overflow Parking

Parking lot design is often required to accommodate peak demand, generating a high proportion of impervious land coverage of very limited usefulness. An alternative is to differentiate between regular and peak parking demands, and to construct the peak parking stalls of a different, more permeable, material. This "overflow parking" area can be made of a turf block, which appears as a green lawn when not occupied by vehicles, or crushed stone or other materials. See Figure 3.11. The same concept can be applied to areas with temporary parking needs, such as emergency access routes, or in residential applications, RV, or trailer parking.

Porous Pavement Recharge Bed

In some cases, parking lots can be designed to perform more complex storm water management functions. Constructing a stone-filled reservoir below the pavement surface and directing runoff underground by means of perforated distribution pipes can achieve subsurface storm water storage and infiltration as shown in Figure 3.12. Subsurface infiltration basins eliminate the possibilities of mud, mosquitoes and safety hazards sometimes perceived to be associated with ephemeral surface drainage. They also can provide for storage of large volumes of runoff, and can be incorporated with roof runoff collection systems.

Figure 3.11: Overflow Parking

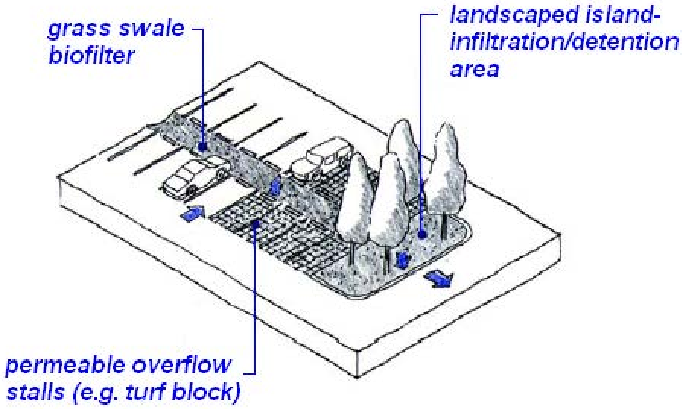
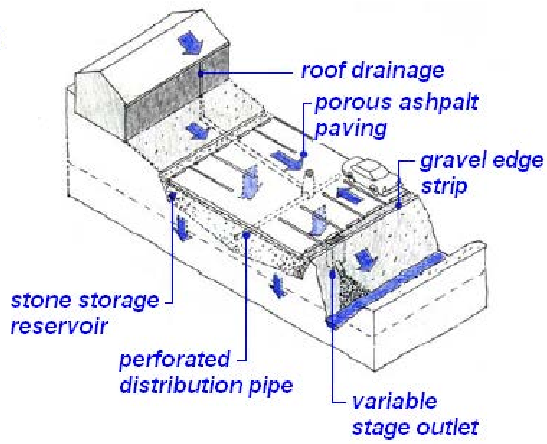


Figure 3.12: Porous Pavement Recharge Bed



3.2.3. Driveways

Driveways can comprise up to 40% of the total transportation network in a conventional development, with streets, turn-arounds, and sidewalks comprising the remaining 60%.

Driveway length is generally determined by garage setback requirements and width by city codes and land use ordinances. If garages are setback from the street, long driveways are required, unless a rear alley system is included to provide garage access. If parking for two vehicles side by side is required, a 20 feet minimum width is required. Thus, if a 20 feet setback and a two-car-wide driveway are required, a minimum of 400 ft^2 of driveway will result, or 4% of a typical 10,000 ft^2 residential lot. If the house itself is compact, and the driveway is long, wide, and paved with an impervious material such as asphalt or concrete, it can become the largest component of impervious land coverage on the lot. Driveways to City streets shall have a minimum width of 12 feet excluding flares (reference: City Standard Details for Public Works Construction).

An option to reduce the area dedicated to driveways is to allow for tandem parking (one vehicle in front of another on a narrow driveway). In addition, if shared driveways are permitted, then two (2) or more garages can be accessed by a single driveway, further reducing required land area. Rear alley access to the garage can reduce driveway length, but overall impervious surface coverage may not be reduced if the alleys are paved with impervious materials and the access streets remain designed to conventional city standards.

Alternative solutions that work to reduce the impact of water quality problems associated with impervious land coverage on city streets also work on driveways. Sloping the driveway so that it drains onto an adjacent turf or groundcover area prevents driveways from draining directly to storm drain systems. This concept is shown in Figures 3.13 and 3.14. Use of turf-block or unit pavers on sand creates attractive, low maintenance, permeable driveways that filter storm water. (See Figure 3.15.) Crushed aggregate can serve as a relatively smooth pavement with minimal maintenance as shown in Figure 3.16. Paving only under wheels (Figure 3.17) is a viable, inexpensive design if the driveway is straight between the garage and the street, and repaving temporary parking areas with permeable unit pavers such as brick or stone can significantly reduce the percentage of impervious area devoted to the driveway.

Figure 3.13: Traditional Design Drain Flow Directly to Storm Drain

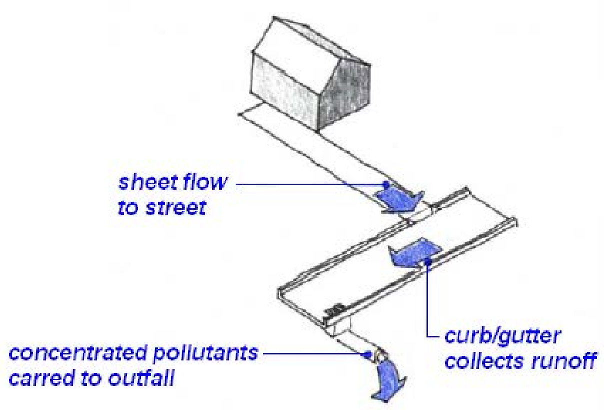


Figure 3.14: Alternative Solution Slope Flow to Groundcover

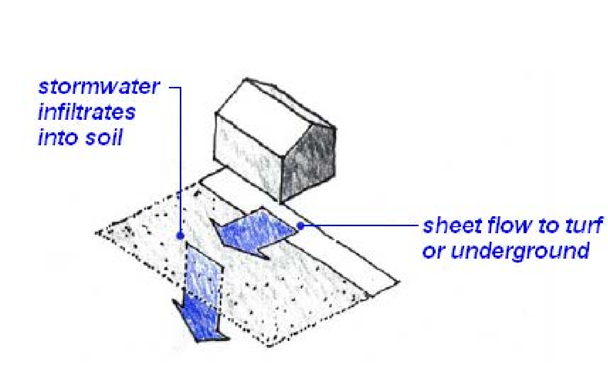


Figure 3.15: Unit Pavers

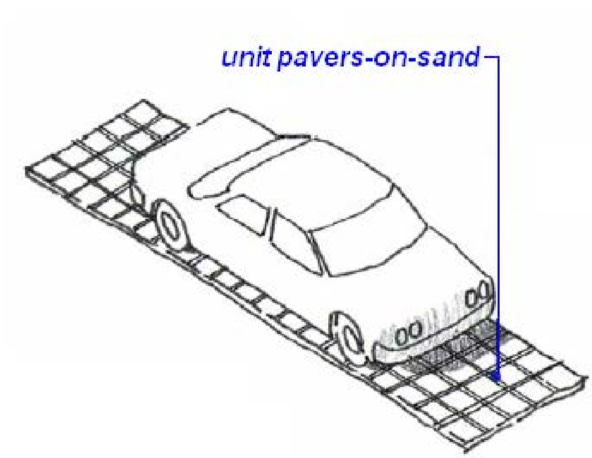


Figure 3.16: Crush Aggregate

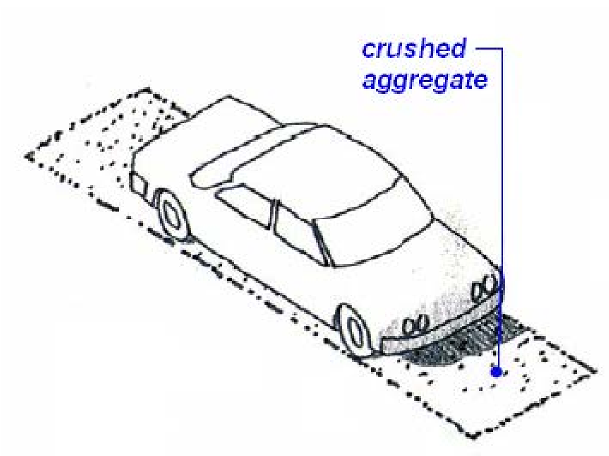
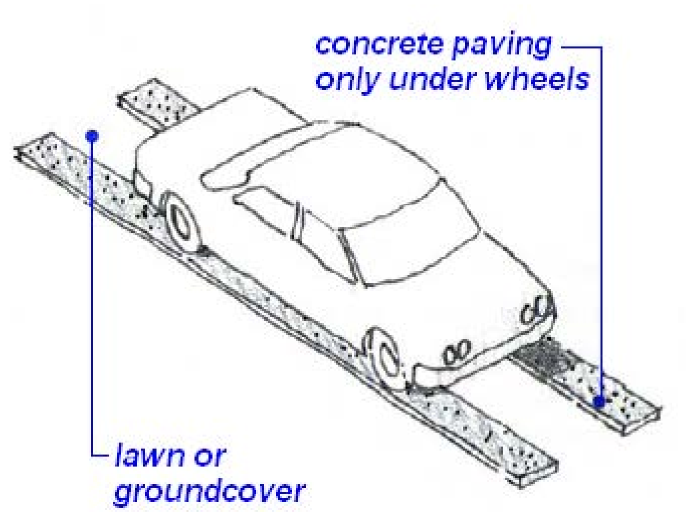


Figure 3.17: Paving Only under Wheels



3.2.4. Landscape and Open Space

In the natural landscape, most soils infiltrate a high percentage of rainwater through a complex web of organic and biological activities that build soil porosity and permeability. Roots reach into the soil and separate particles of clay, insects excavate voids in the soil mass, roots decay leaving networks of macro pores, leaves fall and form a mulch over the soil surface, and earthworms burrow and ingest organic detritus to create richer, more porous soil. These are just a few examples of the natural processes that occur within the soil.

Maintenance of a healthy soil structure through the practice of retaining or restoring native soils where possible and using soil amendments where appropriate can improve the land’s ability to filter and slowly release storm water into drainage networks. Construction practices such as decreasing soil compaction, storing topsoil on-site for use after construction, and chipping wood for mulch as it is cleared for the land can improve soil quality and help maintain healthy watersheds. Practices that reduce erosion and help retain water on-site include incorporating organic amendments into disturbed soils after construction, retaining native vegetation, and covering soil during revegetation.

Subtle changes in grading can also improve infiltration. Landscape surfaces are conventionally graded to have a slight convex slope. This causes water to run off a central high point into a surrounding drainage system, creating increased runoff. If a landscape surface is graded to have a slightly concave slope, it will hold water. The infiltration value of concave vegetated surfaces is greater in permeable soils. Soils of heavy clay or underlain with hardpan provide less infiltration value. In these cases, concave vegetated surfaces must be designed as retention/detention basins, with proper outlets or under drains to an interconnected system.

Multiple Small Basins

Biofilters, infiltration, retention/detention basins are the basic elements of a landscape designed for storm water management. The challenge for designers is to integrate these elements creatively and attractively in the landscape – either within a conventional landscape aesthetic or by presenting a different landscape image that emphasizes the role of water and drainage.

Multiple small basins can provide a great deal of water storage and infiltration capacity. These small basins can fit into the parkway planting strip or shoulders of street rights-of-way. If connected by culverts under walks and driveways, they can create a continuous linear infiltration system. Infiltration and retention/detention basins can be placed under wood decks, in parking lot planter islands, and at roof downspouts. Outdoor patios or seating areas can be sunken a few steps, paved with a permeable pavement such as flagstone or gravel, and designed to hold a few inches of water collected from surrounding rooftops or paved areas for a few hours after a rain.

All of these are examples of small basins that can store water for a brief period, allowing it to infiltrate into the soil, slowing its release into the drainage network, and filtering pollutants. An ordinary lawn can be designed to hold a few inches of water for a few hours after a storm, attracting birds and creating a landscape of diversity. Grass/vegetated swales can be integrated with landscaping, providing an attractive, low maintenance, linear biofilter. Extended detention (dry ponds) store water during storms, holding runoff to predevelopment levels. Pollutants settle and are removed from the water column before discharging to streams. Wet ponds serve a similar purpose and can increase property values by providing a significant aesthetic, and passive recreation opportunity.

Plant species selection is critical for proper functioning of infiltration areas. Proper selection of plant materials can improve the infiltration potential of landscape areas. Deep-rooted plants help to build soil porosity. Plant leaf-surface area helps to collect rainwater before it lands on the soil, especially in light rains, increasing the overall water-holding potential of the landscape.

A large number of plant species will survive moist soils or periodic inundation. These plants provide a wide range of choices for planted infiltration/detention basins and drainage swales. Most inundated plants have a higher survival potential on well-drained alluvial soils than on fine textured shallow soils or clays.

Maintenance Needs for Storm Water Systems

All landscape treatments require maintenance. Landscapes designed to perform storm water management functions are not necessarily more maintenance intensive than highly manicured conventional landscapes. A concave lawn requires the same mowing, fertilizing, and weeding as a convex one and often less irrigation because more rain is filtered into the underlying soil. Sometimes infiltration basins may require a different kind of maintenance than conventionally practiced.

Typical maintenance activities include periodic inspection of surface drainage systems to ensure clear flow lines, repair of eroded surfaces, adjustment or repair of drainage structures, soil cultivation or aeration, care of plant materials, replacement of dead plants, replenishment of mulch cover, irrigation, fertilizing, pruning and mowing. In addition, dead or stressed vegetation may indicate chemical dumping. Careful observation should be made of these areas to determine if such a problem exists.

Landscape maintenance can have a significant impact on soil permeability and its ability to support plant growth. Most plants concentrate the majority of their small absorbing roots in the upper 6 inches of the soil surface if a mulch or forest litter protects the surface. If the soil is exposed or bare, it can become so hot that surface roots will not grow in the upper 8 to 10 inches The common practice of removing all leaf litter and detritus with leaf blowers creates a hard-crusted soil surface of low permeability and high heat conduction. Proper mulching of the soil surface improves water retention and infiltration, while protecting the surface root zone from temperature extremes.

In addition to impacting permeability, landscape maintenance practices can have adverse effects on water quality. Because commonly used fertilizers and herbicides are a source of organic compounds, it is important to keep these practices to a minimum, and prevent over-watering.

When well maintained and designed, landscaped concave surfaces, infiltration basins, swales and bioretention areas can add aesthetic value while providing the framework for environmentally sound, comprehensive storm water management systems.

Street Trees

Trees improve water quality by intercepting and storing rainfall on leaves and branch surfaces, thereby reducing runoff volumes and delaying the onset of peak flows. A single street tree can have a total leaf surface area of several hundred to several thousand ft^2, depending on species and size. This aboveground surface area created by trees and other plants greatly contributes to the water holding capacity of the land. They attenuate conveyance by increasing the soil's capacity to filter rainwater and reduce overland flow rates. By diminishing the impact of raindrops on un-vegetated soil, trees reduce soil erosion. Street trees also have the ability to reduce ambient temperature of storm water runoff and absorb surface water pollutants.

3.2.5. Outdoor Work Areas

The site design and landscape details listed in previous sections are appropriate for uses where low concentrations of pollutants can be mitigated through infiltration, retention, and detention. Often in commercial and industrial sites, there are outdoor work areas in which a higher concentration of pollutants exists, and thus a higher potential of pollutants infiltrating the soil. These work areas often involve automobiles, equipment machinery, or other commercial and industrial uses, and require special consideration.

Outdoor work areas are usually isolated elements in a larger development. Infiltration and detention strategies are still appropriate for and can be applied to other areas of the site, such as parking lots, landscape areas, employee use areas, and bicycle path. It is only the outdoor work area within the development – such as the loading dock, fueling area, or equipment wash area that requires a different drainage approach. This drainage approach is often precisely the opposite from the infiltration/detention strategy – in other words, collect and convey.

In these outdoor work areas, infiltration is discouraged and runoff is often routed directly to the sanitary sewer, not the storm drain. Because this runoff is being added to the loads normally received by the water treatment plants (publicly owned treatment works – POTWs), it raises several concerns that must be addressed in the planning and design stage. These include:

- Higher flows that could exceed the sewer system capacity.
- Catastrophic spills that may cause harm to POTW operation.
- Potential increase in pollutants.

These concerns can be addressed at policy, management, and site planning levels.

Management

Commercial and industrial sites that host special activities need to implement a pollution prevention control plan minimizing hazardous material use and waste. For example, if restaurant grease traps are directly connected to the sanitary sewer, proper management programs can mitigate the amount of grease that escapes from the trap, clogging sewer systems and causing overflows or damage to downstream systems.

Site Planning

Outdoor work areas can be designed in particular ways to reduce their impacts on both storm water quality and sewage treatment plants.

- Create an impermeable surface such as concrete or asphalt, or a prefabricated metal drip pan, depending on the use.
- Cover the area with a roof. This prevents rain from falling on the work area and becoming polluted runoff.
- Berm or mound around the perimeter of the area to prevent water from adjacent areas to flow on to the surface of the work area.
- Directly connect runoff. Unlike other areas, runoff from these work areas is directly connected to the sanitary sewer or other specialized containment systems. This allows the more highly concentrated pollutants from these areas to receive special treatment that removes particular

constituents. Approval for this connection must be obtained from the City's Department of Environmental Services (ENV).

- Locate the work area away from storm drains or catch basins. If the work area is adjacent to, or directly upstream from a storm drain or landscape drainage feature (i.e., bioswales), debris or liquids from the work area can migrate into the storm water system.
- Plan the work area to prevent run-on. This can be accomplished by raising the work area or by diverting run-on around the work area.

These design elements are general considerations for work areas. In designing any outdoor work area, evaluate local ordinances affecting the type of work area, as many local jurisdictions have specific requirements.

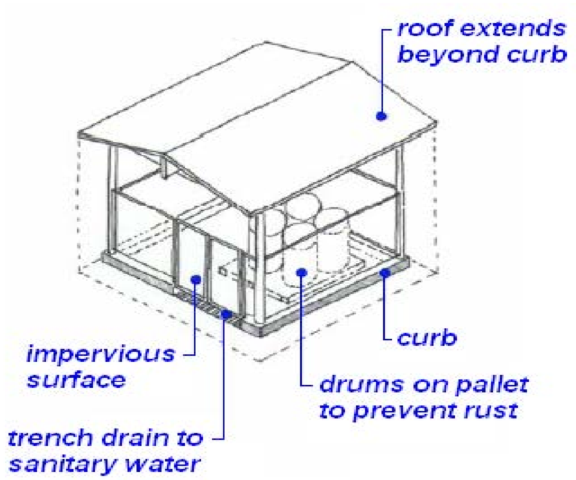
Some activities are common to many commercial and industrial sites. These include garbage and recycling, maintenance and storage, and loading. These activities can have a significant negative impact on storm water quality, and require special attention to the siting and design of the activity area.

3.2.6. Maintenance and Storage Areas

To reduce the possibility of contact with storm water runoff, maintenance and storage areas can be sited away from drainage paths and waterways, and covered. Implementing a regular maintenance plan for sweeping, litter control, and spill cleanup also helps prevent storm water pollution.

Specifying impermeable surfaces for vehicle and equipment maintenance areas will reduce the chance of pollutant infiltration. A concrete surface will usually last much longer than an asphalt one, as vehicle fluids can either dissolve asphalt or be absorbed by the asphalt and released later. See Figure 3.18.

Figure 3.18: Material Storage



3.2.7. Vehicle and Equipment Washing Area

It is generally advisable to cover areas used for regular washing of vehicles, trucks, or equipment, surround them with a perimeter berm, and clearly mark them as a designated washing area. Sumps or drain lines can be installed to collect wash water, which may be treated for reuse or recycling, or for discharge to the sanitary sewer. The POTW may require some form of pretreatment, such as a strainer, filter or trap, for these areas.

Fueling and maintenance activities must be isolated from the vehicle washing facilities. These activities have specific requirements, described later in this section.

Storage of bulk materials, fuels, oils, solvents, other chemicals, and process equipment should be accommodated on an impervious surface covered with a roof. To reduce the chances of corrosion, materials should not be stored directly on the ground, but supported by a wire mesh or other flooring above the impervious pavement. In uncovered areas, drums or other containers can be stored at a slight angle to prevent ponding of rainwater from rusting the lids. Liquid containers should be stored in a designated impervious area that is roofed, fenced within a berm, to prevent spills from flowing into the storm drain.

If hazardous materials are being used or stored, additional requirements may apply.

3.2.8. Loading Area

Loading areas and docks can be designed with a roof or overhang, and a surrounding curb or berm. The area should be graded to direct flow toward an inlet with a shutoff valve or dead-end sump. The sump must be designed with enough capacity to hold a spill while the valve is closed. If the sump has a valve, it must be kept in the closed position and require an action to open it. All sumps must have a sealed bottom so they cannot infiltrate water. Contaminated accumulated waste and liquid must not be discharged to a storm drain and may be discharged to the sanitary sewer only with the POTW's permission. If the waste is not approved for discharge to the sanitary sewer, it must be conveyed to a hazardous waste (or other offsite disposal) facility, and may require pretreatment. Some specific uses have unique requirements.

3.2.9. Trash Storage Areas

Areas designated for trash storage can be covered to protect containers from rainfall. Where covering the trash storage area is not feasible, the area can be protected from run on using grading and berms, and connected to the sanitary sewer to prevent leaks from leaving the designated trash storage area enclosure.

3.2.10. Wash Areas

Areas designated for washing of floor mats, containers, exhaust filters, and similar items can be covered and enclosed to protect the area from rainfall and from overspray leaving the area. These areas can also be connected to the sanitary sewer to prevent wash waters from leaving the designated enclosures. A benefit of covering and enclosing these areas is that vectors may be reduced and aesthetics of the area improved.

3.2.11. Fueling Areas

In all vehicle and equipment fueling areas, plans must be developed for cleaning near fuel dispensers, emergency spill cleanup, and routine inspections to prevent leaks and ensure properly functioning equipment.

If the fueling activities are minor, fueling can be performed in a designated, covered, and bermed area that will not allow run-on of storm water or runoff of spills.

Fuel dispensing areas are defined as extending 6.5 feet from the corner of each fuel dispenser or the length at which the hose and nozzle assembly may be operated plus 1 foot, whichever is less. These areas must be paved with smooth impervious surfaces, such as Portland cement concrete, with a 2 to 4% slope to prevent ponding, and must be covered. The cover must not drain onto the work area. The rest of the site must separate the fuel dispensing area by a grade break that prevents run-on of storm water.

Within the gas station, the outdoor trash receptacle area (garbage and recycling), and the air/water supply area must be paved and graded to prevent storm water run-on. Trash receptacles should be covered.

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4. SOURCE CONTROL BMPS

4.1. Introduction

This section describes specific Source Control (SC) BMPs to be considered for incorporation into newly developed public and private infrastructure, as well as retrofit into existing facilities to meet storm water management objectives.

4.2. Source Control BMPs

Source control fact sheets for design are listed in Table 4.1. The fact sheets detail planning methods and concepts that should be taken into consideration by developers during project design. The fact sheets are arranged in three (3) categories that pertain to the following:

1. Design
2. Use of particular materials
3. Design of particular areas

Table 4.1: Source Control BMPs for Design

Design	
SD-10	Landscaped Areas
SD-11	Roof Runoff Controls
SD-12	Automatic Irrigation System
SD-13	Storm Drain Inlets
Materials	
SD-21	Alternative Building Materials
Areas	
SD-30	Vehicle/Equipment Fueling
SD-31	Loading Docks
SD-32	Outdoor Trash Storage
SD-33	Vehicle/Equipment Washing & Cleaning
SD-34	Outdoor Material Storage
SD-35	Outdoor Work Areas
SD-36	Outdoor Process Equipment Operations

4.3. Fact Sheet Format

A BMP fact sheet is a short document that provides information about a particular BMP. Typically, each fact sheet contains the information outlined in Figure 4.1. Supplemental information is provided if it is available. The fact sheets also contain side bar presentations with information on BMP design objectives. Completed fact sheets for each of the above activities are provided in Section 4.4.

Figure 4.1 Example Sheet

SDxx Example Fact Sheet

Description of the BMP

Approach

Suitable Applications

- Design Consideration
- Designing New Installations

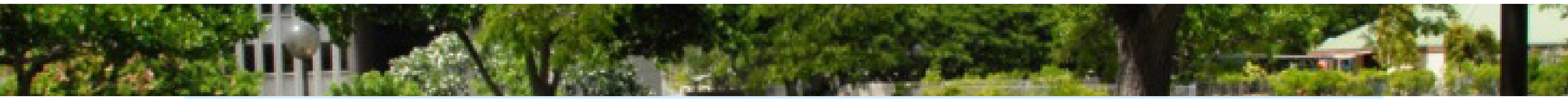
Supplemental Information

- Examples
- Other Resources

4.4. Source Control BMPs for Design (SD) Fact Sheets

The Source Control BMPs for Design fact sheets are presented in the following pages. Each fact sheet is individually page numbered and suitable for photocopying.

Source Control for Design (SD) Fact Sheets



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Design Objectives	
✓	Maximize Infiltration
✓	Provide On-site Retention
✓	Slow Runoff
✓	Minimize Impervious Land Coverage
✓	Implement LID
	Prohibit Dumping of Improper Materials
	Contain Pollutants
	Collect and Convey

Description

Each project site possesses unique topographic, hydrologic, and vegetative features, some of which are more suitable for development than others. Integrating and incorporating appropriate landscape planning methodologies into the project design is the most effective action that can be done to minimize surface and groundwater contamination from storm water.

Approach

Landscape planning should couple consideration of land suitability for urban uses with consideration of community goals and projected growth. Project plan designs should conserve natural areas to the extent possible, maximize natural water storage and infiltration opportunities, and protect slopes and channels.

Suitable Applications

Appropriate applications include residential, commercial and industrial areas planned for development or redevelopment.

Design Considerations

Design requirements for site design and landscapes planning should conform to applicable standards and specifications of agencies with jurisdiction and be consistent with applicable General Plan and Local Area Plan policies.

Designing New Installations

Begin the development of a plan for the landscape unit with attention to the following general principles:

- Formulate the plan on the basis of clearly articulated community goals. Carefully identify conflicts and choices between retaining and protecting desired resources and community growth.
- Map and assess land suitability for urban uses. Include the following landscape features in the assessment: wooded land, open un-wooded land, steep slopes, erosion-prone soils, foundation suitability, soil suitability for waste disposal, aquifers, aquifer recharge areas, wetlands, floodplains, surface waters, agricultural lands, and various categories of urban land use. When appropriate, the assessment can highlight outstanding local or regional resources that the community determines should be protected (i.e., a scenic area, recreational area, threatened species habitat, farmland, fish run). Mapping and assessment should recognize not only these resources but also additional areas needed for their sustenance.

Project plan designs should conserve natural areas to the extent possible, maximize natural water storage and infiltration opportunities, and protect slopes and channels.

Conserve Natural Areas during Landscape Planning

If applicable, the following items are required and must be implemented in the site layout during the subdivision design and approval process, consistent with applicable General Plan and Local Area Plan policies:

- Cluster development on least-sensitive portions of a site while leaving the remaining land in a natural undisturbed condition.
- Limit clearing and grading of native vegetation at a site to the minimum amount needed to build lots, allow access, and provide fire protection.
- Maximize trees and other vegetation at each site by planting additional vegetation, clustering tree areas, and promoting the use of native and/or drought tolerant plants.
- Promote natural vegetation by using parking lot islands and other landscaped areas.
- Preserve riparian areas and wetlands.

Maximize Natural Water Storage and Infiltration Opportunities within the Landscape Unit

- Promote the conservation of forest cover. Building on land that is already deforested affects basin hydrology to a lesser extent than converting forested land. Loss of forest cover reduces interception storage, detention in the organic forest floor layer, and water losses by evapotranspiration, resulting in large peak runoff increases and either their negative effects or the expense of countering them with structural solutions.
- Maintain natural storage reservoirs and drainage corridors, including depressions, areas of permeable soils, swales, and intermittent streams. Develop and implement policies and regulations to discourage the clearing, filling, and channelization of these features. Utilize them in drainage networks in preference to pipes, culverts, and engineered ditches.
- Evaluating infiltration opportunities by referring to the storm water management manual for the jurisdiction and pay particular attention to the selection criteria for avoiding groundwater contamination, poor soils, and hydro-geological conditions that cause these facilities to fail. If necessary, locate developments with large amounts of impervious surfaces or a potential to produce relatively contaminated runoff away from groundwater recharge areas.

Protection of Slopes and Channels during Landscape Design

- Convey runoff safely from the tops of slopes.
- Avoid disturbing steep or unstable slopes.
- Avoid disturbing natural channels.
- Stabilize disturbed slopes as quickly as possible.
- Vegetated slopes with native or drought tolerant vegetation.
- Control and treat flows in landscaping and/or other controls prior to reaching existing natural drainage systems.
- Stabilize temporary and permanent channel crossings as quickly as possible, and ensure that increases in run-off velocity and frequency caused by the project do not erode the channel.

- Install energy dissipaters, such as riprap, at the outlets of new storm drains, culverts, conduits, or channels that enter unlined channels in accordance with applicable specifications to minimize erosion. Energy dissipaters shall be installed in such a way as to minimize impacts to receiving waters.
- Line on-site conveyance channels where appropriate, to reduce erosion caused by increased flow velocity due to increases in tributary impervious area. The first choice for linings should be grass or some other vegetative surface, since these materials not only reduce runoff velocities, but also provide water quality benefits from filtration and infiltration. If velocities in the channel are high enough to erode grass or other vegetative linings, riprap, concrete, soil cement, or geo-grid stabilization are other alternatives.
- Consider other design principles that are comparable and equally effective.

Redeveloping Existing Installations

The City's SWMPP defines "redevelopment" as development that would create or add impervious surface area on an already developed site. Redevelopment includes, but is not limited to:

- Expansion of a building footprint.
- Addition to or replacement of a structure.
- Replacement of an impervious surface that is not part of a routine maintenance activity.
- Land disturbing activities related to structural or impervious surfaces.

Redevelopment may present significant opportunity to add features which had not previously been implemented. Examples include incorporation of depressions, areas of permeable soils, and swales in newly redeveloped areas. While some site constraints may exist due to the status of already existing infrastructure, opportunities should not be missed to maximize infiltration, slow runoff, reduce impervious areas, and disconnect directly connected impervious areas.

References

California Stormwater Quality Association (CASQA) Best Management Practices Handbook New Development and Redevelopment, 2003.

A Manual for the Standard Urban Stormwater Mitigation Plan (SUSMP), Los Angeles County, Department of Public Works, May 2002.

Stormwater Management Manual for Western Washington, Washington State Department of Ecology, August 2001.

Model Standard Urban Storm Water Mitigation Plan (SUSMP) for San Diego County, Port of San Diego, and Cities in San Diego County, February 14, 2002.

Model Water Quality Management Plan (WQMP) for County of Orange, Orange County Flood Control District, and the Incorporated Cities of Orange County, Draft February 2003.

Ventura Countywide Technical Guidance Manual for Stormwater Quality Control Measures, July 2002.

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Roof Runoff Controls SD-11

Design Objectives	
✓	Maximize Infiltration
✓	Provide On-site Retention
✓	Slow Runoff
	Minimize Impervious Land Coverage
✓	Implement LID
	Prohibit Dumping of Improper Materials
✓	Contain Pollutants
	Collect and Convey

Description

Various roof runoff controls are available to address storm water that drains off rooftops. The objective is to reduce the total volume and rate of runoff from individual lots, and retain the pollutants on site that may be picked up from roofing materials and atmospheric deposition. Roof runoff controls consist of directing the roof runoff away from paved areas and mitigating flow to the storm drain system through one of several general approaches: cisterns or rain barrels; dry wells or infiltration trenches; green roofs (LID, see TC-33), pop-up emitters, and foundation planting. The first three (3) approaches require the roof runoff to be contained in a gutter and downspout system. Foundation planting provides a vegetated strip under the drip line of the roof.

Approach

Design of individual lots for single-family homes as well as lots for higher density residential and commercial structures should consider site design provisions for containing and infiltrating roof runoff or directing roof runoff to vegetative swales or buffer areas. Retained water can be reused for watering gardens, lawns, and trees. Benefits to the environment include reduced demand for potable water used for irrigation, improved storm water quality, increased groundwater recharge, decreased runoff volume and peak flows, and decreased flooding potential.

Suitable Applications

Appropriate applications include residential, commercial and industrial areas planned for development or redevelopment.

Design Considerations

Designing New Installations

Cisterns or Rain Barrels

One method of addressing roof runoff is to direct roof downspouts to cisterns or rain barrels. A cistern is an above ground storage vessel with either a manually operated valve or a permanently open outlet. Roof runoff is temporarily stored and then released for irrigation or infiltration between storms. The number of rain barrels needed is a function of the rooftop area. Some low impact developers recommend that every house have at least two (2) rain barrels, with a minimum storage capacity of 1,000 liters. Roof barrels serve several purposes including mitigating the first flush from the roof which has a high volume, amount of contaminants, and thermal load. Several types of rain barrels are commercially available. Consideration must be given to selecting rain barrels that are vector proof and childproof. In addition, some barrels are designed with a bypass valve that filters out grit and other contaminants and routes overflow to a soak-away pit or rain garden.

If the cistern has an operable valve, the valve can be closed to store storm water for irrigation or infiltration between storms. This system requires continual monitoring by the resident or grounds crews, but provides greater flexibility in water storage and metering. If a cistern is provided with an operable valve and water is stored inside for long periods, the cistern must be covered to prevent mosquitoes from breeding.

A cistern system with a permanently open outlet can also provide for metering storm water runoff. If the cistern outlet is significantly smaller than the size of the downspout inlet (say ¼ to ½ inch diameter), runoff will build up inside the cistern during storms, and will empty out slowly after peak intensities subside. This is a feasible way to mitigate the peak flow increases caused by rooftop impervious land coverage, especially for the frequent, small storms.

Dry wells and Infiltration Trenches

Roof downspouts can be directed to dry wells or infiltration trenches. A dry well is constructed by excavating a hole in the ground and filling it with an open graded aggregate, and allowing the water to fill the dry well and infiltrate after the storm event. An underground connection from the downspout conveys water into the dry well, allowing it to be stored in the voids. To minimize sedimentation from lateral soil movement, the sides and top of the stone storage matrix can be wrapped in a permeable filter fabric, though the bottom may remain open. A perforated observation pipe can be inserted vertically into the dry well to allow for inspection and maintenance.

In practice, dry wells receiving runoff from single roof downspouts have been successful over long periods because they contain very little sediment. They should be sized according to the amount of rooftop runoff received, but are typically 4 to 5 $feet^2$, and 2 to 3 feet deep, with a minimum of 1-foot soil cover over the top (maximum depth of 10 feet).

To protect the foundation, dry wells must be set away from the building at least 10 feet The location of drywells should be determined by a licensed engineer. They must be installed in solids that accommodate infiltration. In poorly drained soils, dry wells have very limited feasibility. Overflow shall be directed away from the structure and surrounding buildings.

Infiltration trenches function in a similar manner and would be particularly effective for larger roof areas. An infiltration trench is a long, narrow, rock-filled trench with no outlet that receives storm water runoff. These are described under Treatment Controls.

Pop-up Drainage Emitter

Roof downspouts can be directed to an underground pipe that daylights some distance from the building foundation, releasing the roof runoff through a pop-up emitter. Similar to a pop-up irrigation head, the emitter only opens when there is flow from the roof. The emitter remains flush to the ground during dry periods, for ease of lawn or landscape maintenance.

Foundation Planting

Landscape planting can be provided around the base to allow increased opportunities for storm water infiltration and protect the soil from erosion caused by concentrated sheet flow coming off the roof. Foundation plantings can reduce the physical impact of water on the soil and provide a subsurface matrix of roots that encourage infiltration. These plantings must be sturdy enough to tolerate the heavy runoff sheet flows, and periodic soil saturation.

Redeveloping Existing Installations

The City's SWMPP defines "redevelopment" as development that would create or add impervious surface area on an already developed site. The definition of "redevelopment" must be consulted to determine whether or not the requirements for new development apply to areas intended for redevelopment. If the definition applies, the steps outlined under "designing new installations" above should be followed.

Supplemental Information

Examples

- City of Ottawa's Water Links Surface –Water Quality Protection Program
- City of Toronto Downspout Disconnection Program
- City of Boston, MA, Rain Barrel Demonstration Program

References

California Stormwater Quality Association (CASQA) Best Management Practices Handbook New Development and Redevelopment, 2003.

Hager, Marty Catherine, Stormwater, "Low-Impact Development," January/February 2003. http://www.stormh2o.com/SW/Articles/226.aspx

Low Impact Urban Design Tools, Low Impact Development Design Center, Beltsville, MD. www.lid-stormwater.net.

Start at the Source, Bay Area Stormwater Management Agencies Association, 1999 Edition.

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Automatic Irrigation System SD-12

Design Objectives	
✓	Maximize Infiltration
✓	Provide On-site Retention
✓	Slow Runoff
	Minimize Impervious Land Coverage
✓	Implement LID
	Prohibit Dumping of Improper Materials
	Contain Pollutants
	Collect and Convey

Description

Irrigation water provided to landscaped areas may result in excess irrigation water being conveyed into storm water drainage systems.

Approach

Project plan designs for development and redevelopment should include application methods of irrigation water that minimize runoff of excess irrigation water into the storm water conveyance system.

Suitable Applications

Appropriate applications include residential, commercial and industrial areas planned for development or redevelopment. (Detached residential single-family homes are typically excluded from this requirement.)

Design Considerations

Designing New Installations

The following methods to reduce excessive irrigation runoff should be considered, and incorporated and implemented where determined applicable and feasible:

- Employ rain-triggered shutoff devices to prevent irrigation after precipitation.
- Design irrigation systems to each landscape area's specific water requirements.
- Include design featuring flow reducers or shutoff valves triggered by a pressure drop to control water loss in the event of broken sprinkler heads or lines.
- Implement landscape plans consistent with City water conservation resolutions, which may include provision of water sensors, programmable irrigation times (for short cycles), etc.
- Design timing and application methods of irrigation water to minimize the runoff of excess irrigation water into the storm water drainage system.
- Group plants with similar water requirements in order to reduce excess irrigation runoff and promote surface filtration. Choose plants with low irrigation requirements (for example, native or drought tolerant species). Consider design features such as:
  - Using mulches (such as wood chips or bar) in planter areas without ground cover to minimize sediment in runoff.

  - Installing appropriate plant materials for the location, in accordance with amount of sunlight and climate, and use native plant materials where possible and/or as recommended by the landscape architect.
  - Leaving a vegetative barrier along the property boundary and interior watercourses, to act as a pollutant filter, where appropriate and feasible.
  - Choosing plants that minimize or eliminate the use of fertilizer or pesticides to sustain growth.
- Employ other comparable, equally effective methods to reduce irrigation water runoff.

Redeveloping Existing Installations

The City's SWMPP defines "redevelopment" as development that would create or add impervious surface area on an already developed site. The definition of "redevelopment" must be consulted to determine whether or not the requirements for new development apply to areas intended for redevelopment. If the definition applies, the steps outlined under "designing new installations" above should be followed.

References

California Stormwater Quality Association (CASQA) Best Management Practices Handbook New Development and Redevelopment, 2003.

A Manual for the Standard Urban Stormwater Mitigation Plan (SUSMP), Los Angeles County Department of Public Works, May 2002.

Model Standard Urban Storm Water Mitigation Plan (SUSMP) for San Diego County, Port of San Diego, and Cities in San Diego County, February 14, 2002.

Model Water Quality Management Plan (WQMP) for County of Orange, Orange County Flood Control District, and the Incorporated Cities of Orange County, Draft February 2003.

Ventura Countywide Technical Guidance Manual for Stormwater Quality Control Measures, July 2002.

Storm Drain Inlet SD-13

Design Objectives	
	Maximize Infiltration
	Provide On-site Retention
	Slow Runoff
	Minimize Impervious Land Coverage
	Implement LID
✓	Prohibit Dumping of Improper Materials
	Contain Pollutants
	Collect and Convey

Description

Waste materials dumped into storm drain inlets can have severe impacts on receiving and ground waters. Posting notices regarding discharge prohibitions at storm drain inlets can prevent waste dumping. Storm drain signs and stencils are highly visible source controls that are typically placed directly adjacent to storm drain inlets.

Approach

The stencil or affixed sign contains a brief statement that prohibits dumping of improper materials into the urban runoff conveyance system. Storm drain messages have become a popular method of alerting the public about the effects of and the prohibitions against waste disposal.

Suitable Applications

Stencils and signs alert the public to the destination of pollutants discharged to the storm drain. Signs are appropriate in residential, commercial, and industrial areas, as well as any other area where contributions or dumping to storm drains is likely.

Design Considerations

Storm drain message markers or placards are recommended at all storm drain inlets within the boundary of a development project. The marker should be placed in clear sight facing toward anyone approaching the inlet from either side. All storm drain inlet locations should be identified on the development site map.

Designing New Installations

The following methods should be considered for inclusion in the project design and shown on project plans:

- Provide stenciling or labeling of all storm drain inlets and catch basins, constructed or modified, within the project area with prohibitive language. Examples include "Dump No Waste" and/or other graphical icons to discourage illegal dumping.
- Post signs with prohibitive language and/or graphical icons, which prohibit illegal dumping at public access points along channels and creeks within the project area.

Note: ENV Storm Water Branch (SWQ) has approved specific signage and/or storm drain message placards for use. Consult local agency storm water staff to determine specific requirements for placard types and methods of application.

Redeveloping Existing Installations

The City's SWMPP defines "redevelopment" as development that would create or add impervious surface area on an already developed site. If the project meets the definition of "redevelopment," then the requirements stated under "designing new installations" above should be included in all project design plans.

Supplemental Information

Maintenance Considerations

- Legibility of markers and signs should be maintained. If required by the agency with jurisdiction over the project, the owner/operator or homeowner's association should enter into a maintenance agreement with the agency or record a deed restriction upon the property title to maintain the legibility of placards or signs.

Placement

- Signage on top of curbs tends to weather and fade.
- Signage on face of curbs tends to be worn by contact with vehicle tires and sweeper brooms.

References

California Stormwater Quality Association (CASQA) Best Management Practices Handbook New Development and Redevelopment, 2003.

A Manual for the Standard Urban Stormwater Mitigation Plan (SUSMP), Los Angeles County Department of Public Works, May 2002.

Model Standard Urban Storm Water Mitigation Plan (SUSMP) for San Diego County, Port of San Diego, and Cities in San Diego County, February 14, 2002.

Model Water Quality Management Plan (WQMP) for County of Orange, Orange County Flood Control District, and the Incorporated Cities of Orange County, Draft February 2003.

Ventura Countywide Technical Guidance Manual for Stormwater Quality Control Measures, July 2002.

Alternative Building Materials SD-21

Design Objectives	
✓	Maximize Infiltration
✓	Provide On-site Retention
✓	Slow Runoff
	Minimize Impervious Land Coverage
✓	Implement LID
	Prohibit Dumping of Improper Materials
	Contain Pollutants
	Collect and Convey

Description

Alternative building materials are selected instead of conventional materials for new construction and renovation. These materials reduce potential sources of pollutants in storm water runoff by eliminating compounds that can leach into runoff, reducing the need for pesticide application, reducing the need for painting and other maintenance, or by reducing the volume of runoff.

Approach

Alternative building materials are available for use as lumber for decking, roofing materials, home siding, and paving for driveways, decks, and sidewalks.

Suitable Applications

Appropriate applications include residential, commercial and industrial areas planned for development or redevelopment.

Design Considerations

Designing New Installations

Decking

One of the most common materials for construction of decks and other outdoor construction has traditionally been pressure treated wood, which is now being phased out. The standard treatment is called CCA, for chromated copper arsenate. The key ingredients are arsenic (which kills termites, carpenter ants and other insects), copper (which kills the fungi that cause wood to rot) and chromium (which reacts with the other ingredients to bind them to the wood). The amount of arsenic is far from trivial. A deck just 8 feet by 10 feet contains more than 1 1/3 pounds of this highly potent poison. Replacement materials include a new type of pressure treated wood, plastic and composite lumber.

There are currently over 20 products in the market consisting of plastic or plastic-wood composites. Plastic lumber is made from 100% recycled plastic, # 2 HDPE and polyethylene plastic milk jugs and soap bottles. Plastic-wood composites are a combination of plastic and wood fibers or sawdust. These materials are a long lasting exterior weather, insect, and chemical resistant wood lumber replacement for non-structural applications. Use it for decks, docks, raised garden beds and planter boxes, pallets, hand railings, outdoor furniture, animal pens, boat decks, etc.

New pressure treated wood uses a much safer recipe, ACQ, which stands for ammoniacal copper quartenary. It contains no arsenic and no chromium. Yet the American Wood Preservers Association has found it to be just as effective as the standard formula. ACQ is common in Japan and Europe.

Roofing

Several studies have indicated that metal used as roofing material, flashing, or gutters can leach metals into the environment. The leaching occurs because rainfall is slightly acidic and slowly dissolved the exposed metals. Common traditional applications include copper sheathing and galvanized (zinc) gutters.

Coated metal products are available for both roofing and gutter applications. These products eliminate contact of bare metal with rainfall, eliminating one source of metals in runoff. There are also roofing materials made of recycled rubber and plastic that resemble traditional materials.

A less traditional approach is the use of green roofs (See TC-33). These roofs are not just green, they're alive. Planted with grasses and succulents, low- profile green roofs reduce the urban heat island effect, storm water runoff, and cooling costs, while providing wildlife habitat and a connection to nature for building occupants. These roofs are widely used on industrial facilities in Europe and have been established as experimental installations in several locations in the US, including Portland, Oregon.

Paved Areas

Traditionally, concrete is used for construction of patios, sidewalks, and driveways. Although it is non-toxic, these paved areas reduce storm water infiltration and increase the volume and rate of runoff. This increase in the amount of runoff is the leading cause of stream channel degradation in urban areas.

There are a number of alternative materials that can be used in these applications, including porous concrete and asphalt, modular blocks, and crushed granite. These materials, especially modular paving blocks, are widely available and a well established method to reduce storm water runoff.

Building Siding

Wood siding is commonly used on the exterior of residential construction. This material weathers fairly rapidly and requires repeated painting to prevent rotting. Alternative "new" products for this application include cement-fiber and vinyl. Cement-fiber siding is a masonry product made from Portland cement, sand, and cellulose and will not burn, cup, swell, or shrink.

Pesticide Reduction

A common use of powerful pesticides is for the control of termites. Chlordane was used for many years for this purpose and is now found in urban streams and lakes nationwide. There are a number of physical barriers that can be installed during construction to help reduce the use of pesticides.

Sand barriers for subterranean termites are a physical deterrent because the termites cannot tunnel through it. Sand barriers can be applied in crawl spaces under pier and beam foundations, under slab foundations, and between the foundation and concrete porches, terraces, patios and steps. Other possible locations include under fence posts, underground electrical cables, water and gas lines, telephone and electrical poles, inside hollow tile cells and against retaining walls.

Metal termite shields are physical barriers to termites which prevent them from building invisible tunnels. In reality, metal shields function as a helpful termite detection device, forcing them to build tunnels on the outside of the shields which are easily seen. Metal termite shields also help prevent dampness from wicking to adjoining wood members which can result in rot, thus making the material more attractive to termites and other pests. Metal flashing and metal plates can also be used as a barrier between piers and beams of structures such as decks, which are particularly vulnerable to termite attack.

Redeveloping Existing Installations

The City's SWMPP defines "redevelopment" as development that would create or add impervious surface area on an already developed site. The definition of "redevelopment" must be consulted to determine whether or not the requirements for new development apply to areas intended for redevelopment. If the definition applies, the steps outlined under "designing new installations" above should be followed.

Other Resources

There are no good, independent, comprehensive sources of information on alternative building materials for use in minimizing the impacts of storm water runoff. Most websites or other references to "green" or "alternative" building materials focus on indoor applications, such as formaldehyde free plywood and low VOC paints, carpets, and pads. Some supplemental information on alternative materials is available from the manufacturers.

Other Resources

California Stormwater Quality Association (CASQA) Best Management Practices Handbook New Development and Redevelopment, 2003.

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Vehicle/Equipment Fueling SD-30

Design Objectives	
	Maximize Infiltration
	Provide On-site Retention
	Slow Runoff
	Minimize Impervious Land Coverage
	Implement LID
	Prohibit Dumping of Improper Materials
✓	Contain Pollutants
✓	Collect and Convey

Description

Fueling areas have the potential to contribute oil and grease, solvents, car battery acid, coolant and gasoline to the storm water conveyance system. Spills at vehicle and equipment fueling areas can be a significant source of pollution because fuels contain toxic materials and heavy metals that are not easily removed by storm water treatment devices.

Approach

Project plans must be developed for cleaning near fuel dispensers, emergency spill cleanup, containment, and leak prevention.

Suitable Applications

Appropriate applications include commercial, industrial, and any other areas planned to have fuel dispensing equipment, including retail gasoline outlets, automotive repair shops, and major non-retail dispensing areas.

Design Considerations

Design requirements for fueling areas are governed by Building and Fire Codes and by current local agency ordinances and zoning requirements. Design requirements described in this fact sheet are meant to enhance and be consistent with these code and ordinance requirements.

Designing New Installations

Covering

Fuel dispensing areas should provide an overhanging roof structure or canopy. The cover's minimum dimensions must be equal to or greater than the area within the grade break. The cover must not drain onto the fuel dispensing area and the downspouts must be routed to prevent drainage across the fueling area. The fueling area should drain to the project's treatment control BMP(s) prior to discharging to the storm water conveyance system. Note: If fueling large equipment or vehicles that would prohibit the use of covers or roofs, the fueling island should be designed to sufficiently accommodate the larger vehicles and equipment and to prevent storm water run-on and runoff. Grade to direct storm water to a dead-end sump.

Surfacing

Fuel dispensing areas should be paved with Portland cement concrete (or equivalent smooth impervious surface). The use of asphalt concrete should be minimized. Use asphalt sealant to protect asphalt paved areas surrounding the fueling area. This provision may be made to sites that have pre-existing asphalt surfaces.

The concrete fuel dispensing area should be extended a minimum of 6.5 feet from the corner of each fuel dispenser, or the length at which the hose and nozzle assembly may be operated plus 1 foot, whichever is less.

Grading/Contouring

Dispensing areas should have an appropriate slope to prevent ponding, and be separated from the rest of the site by a grade break that prevents run-on of urban runoff (slope is required to be 2 to 4% in some jurisdictions' storm water management and mitigation plans).

Fueling areas should be graded to drain toward a dead-end sump. Runoff from downspouts/roofs should be directed away from fueling areas. Do not locate storm drains in the immediate vicinity of the fueling area.

Redeveloping Existing Installations

The City's SWMPP defines "redevelopment" as development that would create or add impervious surface area on an already developed site. The definition of "redevelopment" must be consulted to determine whether or not the requirements for new development apply to areas intended for redevelopment. If the definition applies, the steps outlined under "designing new installations" above should be followed.

Supplemental Information

In the case of an emergency, provide storm drain seals, such as isolation valves, drain plugs, or drain covers, to prevent spills or contaminated storm water from entering the storm water conveyance system.

References

California Stormwater Quality Association (CASQA) Best Management Practices Handbook New Development and Redevelopment, 2003.

A Manual for the Standard Urban Stormwater Mitigation Plan (SUSMP), Los Angeles County Department of Public Works, May 2002.

Model Standard Urban Storm Water Mitigation Plan (SUSMP) for San Diego County, Port of San Diego, and Cities in San Diego County, February 14, 2002.

Model Water Quality Management Plan (WQMP) for County of Orange, Orange County Flood Control District, and the Incorporated Cities of Orange County, Draft February 2003.

Ventura Countywide Technical Guidance Manual for Stormwater Quality Control Measures, July 2002.

Loading Docks SD-31

Design Objectives	
	Maximize Infiltration
	Provide On-site Retention
	Slow Runoff
	Minimize Impervious Land Coverage
	Implement LID
✓	Prohibit Dumping of Improper Materials
✓	Contain Pollutants
	Collect and Convey

Description

Several measures can be taken to prevent operations at maintenance bays and loading docks from contributing a variety of toxic compounds, oil and grease, heavy metals, nutrients, suspended solids, and other pollutants to the storm water conveyance system.

Approach

In designs for maintenance bays and loading docks, containment is encouraged. Preventative measures include overflow containment structures and dead-end sumps. However, in the case of loading docks from grocery stores and warehouse/distribution centers, engineered infiltration systems may be considered.

Suitable Applications

Appropriate applications include commercial and industrial areas planned for development or redevelopment.

Design Considerations

Design requirements for vehicle maintenance and repair are governed by Building and Fire Codes, and by current local agency ordinances, and zoning requirements. The design criteria described in this fact sheet are meant to enhance and be consistent with these code requirements.

Designing New Installations

Designs of maintenance bays should consider the following:

- Repair/maintenance bays and vehicle parts with fluids should be indoors; or designed to preclude urban run-on and runoff.
- Repair/maintenance floor areas should be paved with Portland cement concrete (or equivalent smooth impervious surface).
- Repair/maintenance bays should be designed to capture all wash water leaks and spills. Provide impermeable berms, drop inlets, trench catch basins, or overflow containment structures around repair bays to prevent spilled materials and wash-down waters from entering the storm drain system. Connect drains to a sump for collection and disposal. Direct connection of the repair/ maintenance bays to the storm drain system is prohibited. If required by local jurisdiction, obtain an Industrial Waste Discharge Permit.
- Other features may be comparable and equally effective.

The following designs of loading/unloading dock areas should be considered:

- Loading dock areas should be covered, or drainage should be designed to preclude urban run-on and runoff.
- Direct connections into storm drains from depressed loading docks (truck wells) are prohibited.
- Below-grade loading docks from grocery stores and warehouse/distribution centers of fresh food items should drain through water quality inlets, or to an engineered infiltration system, or an equally effective alternative. Pre-treatment may also be required.
- Other features may be comparable and equally effective.

Redeveloping Existing Installations

The City's SWMPP defines "redevelopment" as development that would create or add impervious surface area on an already developed site. The definition of "redevelopment" must be consulted to determine whether or not the requirements for new development apply to areas intended for redevelopment. If the definition applies, the steps outlined under "designing new installations" above should be followed.

Supplemental Information

Storm water and non-storm water will accumulate in containment areas and sumps with impervious surfaces. Contaminated accumulated water must be disposed of in accordance with applicable laws and cannot be discharged directly to the storm drain or sanitary sewer system without the appropriate permit.

References

California Stormwater Quality Association (CASQA) Best Management Practices Handbook New Development and Redevelopment, 2003.

A Manual for the Standard Urban Stormwater Mitigation Plan (SUSMP), Los Angeles County Department of Public Works, May 2002.

Model Standard Urban Storm Water Mitigation Plan (SUSMP) for San Diego County, Port of San Diego, and Cities in San Diego County, February 14, 2002.

Model Water Quality Management Plan (WQMP) for County of Orange, Orange County Flood Control District, and the Incorporated Cities of Orange County, Draft February 2003.

Ventura Countywide Technical Guidance Manual for Stormwater Quality Control Measures, July 2002.

Design Objectives	
	Maximize Infiltration
	Provide On-site Retention
	Slow Runoff
	Minimize Impervious Land Coverage
	Implement LID
	Prohibit Dumping of Improper Materials
✓	Contain Pollutants
	Collect and Convey

Description

Trash storage areas are areas where a trash receptacle(s) is located for use as a repository for solid wastes. Storm water runoff from areas where trash is stored or disposed of can be polluted. In addition, loose trash and debris can be easily transported by water or wind into nearby storm drain inlets, channels, and/or streams. Waste handling operations that may be sources of storm water pollution include dumpsters, litter control, and waste piles.

Approach

This fact sheet contains details on the specific measures required to prevent or reduce pollutants in storm water runoff associated with trash storage and handling. Preventative measures including enclosures, containment structures, and impervious pavements to mitigate spills, should be used to reduce the likelihood of contamination.

Suitable Applications

Appropriate applications include residential, commercial, and industrial areas planned for development or redevelopment. (Detached residential single-family homes are typically excluded from this requirement.)

Design Considerations

Design requirements for waste handling areas are governed by Building and Fire Codes, and by current local agency ordinances and zoning requirements. The design criteria described in this fact sheet are meant to enhance and be consistent with these code and ordinance requirements. Hazardous waste should be handled in accordance with legal requirements established in Hawaii Administrative Rules Title 11 Chapter 58.1 Solid Waste Management Control, and enforcement by the State of Hawaii Department of Health Solid and Hazardous Waste Branch.

Wastes from commercial and industrial sites are typically hauled by either public or commercial carriers that may have design or access requirements for waste storage areas. The design criteria in this fact sheet are recommendations and are not intended to be in conflict with requirements established by the waste hauler. The waste hauler should be contacted prior to the design of your site trash collection areas. Conflicts or issues should be discussed with the local agency.

Designing New Installations

Trash storage areas should be designed to consider the following structural or treatment control BMPs:

- Design trash container areas so that drainage from adjoining roofs and pavement is diverted around the area(s) to avoid run-on. This might include berming or grading the waste handling area to prevent run-on of storm water.
- Make sure trash container areas are screened or walled to prevent off-site transport of trash.
- Use lined bins or dumpsters to reduce leaking of liquid waste.
- Provide roofs, awnings, or attached lids on all trash containers to minimize direct precipitation and prevent rainfall from entering containers.
- Pave trash storage areas with an impervious surface to mitigate spills.
- Do not locate storm drains in immediate vicinity of the trash storage area.
- Post signs on all dumpsters informing users that hazardous material are not to be disposed of therein.

Redeveloping Existing Installations

The City's SWMPP defines "redevelopment" as development that would create or add impervious surface area on an already developed site. The definition of "redevelopment" must be consulted to determine whether or not the requirements for new development apply to areas intended for redevelopment. If the definition applies, the steps outlined under "designing new installations" above should be followed.

Supplemental Information

Maintenance Considerations

The integrity of structural elements that are subject to damage (i.e., screens, covers, and signs) must be maintained by the owner/operator. Maintenance agreements between the local agency and the owner/operator may be required. Some agencies will require maintenance deed restrictions to be recorded of the property title. If required by the local agency, maintenance agreements or deed restrictions must be executed by the owner/operator before improvement plans are approved.

References

California Stormwater Quality Association (CASQA) Best Management Practices Handbook New Development and Redevelopment, 2003.

Hawaii Administrative Rules Title 11 Chapter 58.1 Solid Waste Management Control, Honolulu Hawaii Department of Health, 2003: http://health.hawaii.gov/shwb/files/2013/06/11-5811.pdf

A Manual for the Standard Urban Stormwater Mitigation Plan (SUSMP), Los Angeles County Department of Public Works, May 2002.

Model Standard Urban Storm Water Mitigation Plan (SUSMP) for San Diego County, Port of San Diego, and Cities in San Diego County, February 14, 2002.

Model Water Quality Management Plan (WQMP) for County of Orange, Orange County Flood Control District, and the Incorporated Cities of Orange County, Draft February 2003.

Ventura Countywide Technical Guidance Manual for Stormwater Quality Control Measures, July 2002.

Vehicle/Equipment Washing & Cleaning SD-33

Design Objectives	
✓	Maximize Infiltration
	Provide On-site Retention
	Slow Runoff
	Minimize Impervious Land Coverage
	Implement LID
	Prohibit Dumping of Improper Materials
✓	Contain Pollutants
✓	Collect and Convey

Description

Vehicle washing, equipment washing, and steam cleaning may contribute high concentrations of metals, oil and grease, solvents, phosphates, and suspended solids to wash waters that drain to storm water conveyance systems.

Approach

Project plans should include appropriately designed area(s) for washing-steam cleaning of vehicles and equipment. Depending on the size and other parameters of the wastewater facility, wash water may be conveyed to a sewer, an infiltration system, recycling system or other alternative. Pretreatment may be required for conveyance to a sanitary sewer.

Suitable Applications

Appropriate applications include commercial developments, restaurants, retail gasoline outlets, automotive repair shops and others.

Design Considerations

Design requirements for vehicle maintenance are governed by Building and Fire Codes, and by current local agency ordinances, and zoning requirements. Design criteria described in this fact sheet are meant to enhance and be consistent with these code requirements.

Designing New Installations

Areas for washing/steam cleaning should incorporate one of the following features:

- Be self-contained and/or covered with a roof or overhang.
- Be equipped with a clarifier or other pretreatment facility.
- Have a proper connection to a sanitary sewer.
- Include other features which are comparable and equally effective.

Car Wash Areas

Wash water from the areas may be directed to the sanitary sewer, to an engineered infiltration system, or to an equally effective alternative. Pre-treatment may also be required.

Developers are to direct and divert surface water runoff away from the exposed area around the wash pad (parking lot, storage areas), and wash pad itself to alternatives other than the sanitary sewer. Roofing may be required for exposed wash pads.

It is generally advisable to cover areas used for regular washing of vehicles, trucks, or equipment, surround them with a perimeter berm, and clearly mark them as a designated washing area. Sumps or drain lines can be installed to collect wash water, which may be treated for reuse or recycling, or for discharge to the sanitary sewer. Some areas may require some form of pretreatment, such as a trap, for these areas.

Redeveloping Existing Installations

The City's SWMPP defines "redevelopment" as development that would create or add impervious surface area on an already developed site. The definition of "redevelopment" must be consulted to determine whether or not the requirements for new development apply to areas intended for redevelopment. If the definition applies, the steps outlined under "designing new installations" above should be followed.

Supplemental Information

Maintenance Considerations

Storm water and non-storm water will accumulate in containment areas and sumps with impervious surfaces. Contaminated accumulated water must be disposed of in accordance with applicable laws and cannot be discharged directly to the storm drain or sanitary sewer system without the appropriate permit.

References

California Stormwater Quality Association (CASQA) Best Management Practices Handbook New Development and Redevelopment, 2003.

A Manual for the Standard Urban Stormwater Mitigation Plan (SUSMP), Los Angeles County Department of Public Works, May 2002.

Model Standard Urban Storm Water Mitigation Plan (SUSMP) for San Diego County, Port of San Diego, and Cities in San Diego County, February 14, 2002.

Model Water Quality Management Plan (WQMP) for County of Orange, Orange County Flood Control District, and the Incorporated Cities of Orange County, Draft February 2003.

Ventura Countywide Technical Guidance Manual for Storm Water Quality Control Measures, July 2002.

Outdoor Material Storage SD-34

Design Objectives	
	Maximize Infiltration
	Provide On-site Retention
	Slow Runoff
	Minimize Impervious Land Coverage
	Implement LID
	Prohibit Dumping of Improper Materials
✓	Contain Pollutants
✓	Collect and Convey

Description

Proper design of outdoor storage areas for materials reduces opportunity for toxic compounds, oil and grease, heavy metals, nutrients, suspended solids, and other pollutants to enter the storm water conveyance system. Materials may be in the form of raw products, by-products, finished products, and waste products. The type of pollutants associated with the materials will vary depending on the type of commercial or industrial activity.

Approach

Outdoor storage areas require a drainage approach different from the typical infiltration/detention strategy. In outdoor storage areas, infiltration is discouraged. Containment is encouraged. Preventative measures include enclosures, secondary containment structures and impervious surfaces.

Suitable Applications

Appropriate applications include residential, commercial and industrial areas planned for development or redevelopment.

Design Considerations

Some materials are more of a concern than others. Toxic and hazardous materials must be prevented from coming in contact with storm water. Non-toxic or non-hazardous materials do not have to be prevented from storm water contact. However, these materials may have toxic effects on receiving waters if allowed to be discharged with storm water in significant quantities. Accumulated material on an impervious surface could result in significant impact on the rivers or streams that receive the runoff.

Material may be stored in a variety of ways, including bulk piles, containers, shelving, stacking, and tanks. Storm water contamination may be prevented by eliminating the possibility of storm water contact with the material storage areas either through diversion, cover, or capture of the storm water. Control measures may also include minimizing the storage area. Design requirements for material storage areas are governed by Building and Fire Codes, and by current City ordinances and zoning requirements. Control measures are site specific, and must meet local agency requirements.

Designing New Installations

Where proposed project plans include outdoor areas for storage of materials that may contribute pollutants to the storm water conveyance system, the following structural or treatment BMPs should be considered:

- Materials with the potential to contaminate storm water should be:
  - Placed in an enclosure such as, but not limited to, a cabinet, shed, or similar structure that prevents contact with runoff or spillage to the storm water conveyance system, or
  - Protected by secondary containment structures such as berms, dikes, or curbs.
- The storage area should be paved and sufficiently impervious to contain leaks and spills.
- The storage area should slope towards a dead-end sump to contain spills and direct runoff from downspouts/roofs should be directed away from storage areas.
- The storage area should have a roof or awning that extends beyond the storage area to minimize collection of storm water within the secondary containment area. A manufactured storage shed may be used for small containers.

Note that the location(s) of installations of where these preventative measures will be employed must be included on the map or plans identifying BMPs.

Redeveloping Existing Installations

The City's SWMPP defines "redevelopment" as development that would create or add impervious surface area on an already developed site. The definition of "redevelopment" must be consulted to determine whether or not the requirements for new development apply to areas intended for redevelopment. If the definition applies, the steps outlined under "designing new installations" above should be followed.

Supplemental Information

Storm water and non-storm water will accumulate in containment areas and sumps with impervious surfaces. Contaminated accumulated water must be disposed of in accordance with applicable laws and cannot be discharged directly to the storm drain or sanitary sewer system without the appropriate permits.

References

California Stormwater Quality Association (CASQA) Best Management Practices Handbook New Development and Redevelopment, 2003.

A Manual for the Standard Urban Stormwater Mitigation Plan (SUSMP), Los Angeles County Department of Public Works, May 2002.

Model Standard Urban Storm Water Mitigation Plan (SUSMP) for San Diego County, Port of San Diego, and Cities in San Diego County, February 14, 2002.

Model Water Quality Management Plan (WQMP) for County of Orange, Orange County Flood Control District, and the Incorporated Cities of Orange County, Draft February 2003.

Ventura Countywide Technical Guidance Manual for Stormwater Quality Control Measures, July 2002.

Outdoor Work Areas SD-35

Design Objectives	
	Maximize Infiltration
	Provide On-site Retention
	Slow Runoff
	Minimize Impervious Land Coverage
	Implement LID
	Prohibit Dumping of Improper Materials
✓	Contain Pollutants
✓	Collect and Convey

Description

Proper design of outdoor work areas for materials reduces opportunity for toxic compounds, oil and grease, heavy metals, nutrients, suspended solids, and other pollutants to enter the storm water conveyance system.

Approach

Outdoor work areas require a drainage approach different from the typical infiltration/detention strategy. In outdoor work areas, infiltration is discouraged; collection and conveyance are encouraged. In outdoor work areas, infiltration is discouraged and runoff is often routed directly to the sanitary sewer, not the storm drain. Because this runoff is being added to the loads normally received by the wastewater treatment plants, City storm water programs and/or private developers must work with the local plant to develop solutions that minimize effects on the treatment facility. These concerns are best addressed in the planning and design stage of the outdoor work area.

Suitable Applications

Appropriate applications include residential, commercial, and industrial areas planned for development or redevelopment.

Design Considerations

Design requirements for outdoor work areas are governed by Building and Fire Codes, and by current City ordinances, and zoning requirements.

Designing New Installations

Outdoor work areas can be designed in particular ways to reduce impacts on both storm water quality and sewage treatment plants.

- Create an impermeable surface such as concrete or sealed asphalt, or a prefabricated metal drip pan, depending on the use.
- Cover the area with a roof. This prevents rain from falling on the work area and becoming polluted runoff.
- Berm or perform mounding around the perimeter of the area to prevent water from adjacent areas from flowing on to the surface of the work area.

- Directly connect runoff. Unlike other areas, runoff from work areas is directly connected to the sanitary sewer or other specialized containment system(s). This allows the more highly concentrated pollutants from these areas to receive special treatment that removes particular constituents. Approval for this connection must be obtained from the appropriate sanitary sewer agency.
- Locate the work area away from storm drains or catch basins.

Redeveloping Existing Installations

The City's SWMPP defines "redevelopment" as development that would create or add impervious surface area on an already developed site. The definition of "redevelopment" must be consulted to determine whether or not the requirements for new development apply to areas intended for redevelopment. If the definition applies, the steps outlined under "designing new installations" above should be followed.

References

California Stormwater Quality Association (CASQA) Best Management Practices Handbook New Development and Redevelopment, 2003.

A Manual for the Standard Urban Stormwater Mitigation Plan (SUSMP), Los Angeles County Department of Public Works, May 2002.

Model Standard Urban Storm Water Mitigation Plan (SUSMP) for San Diego County, Port of San Diego, and Cities in San Diego County, February 14, 2002.

Model Water Quality Management Plan (WQMP) for County of Orange, Orange County Flood Control District, and the Incorporated Cities of Orange County, Draft February 2003.

Ventura Countywide Technical Guidance Manual for Stormwater Quality Control Measures, July 2002.

Outdoor Process Equipment Operations SD-36

Design Objectives	
	Maximize Infiltration
	Provide On-site Retention
	Slow Runoff
	Minimize Impervious Land Coverage
	Implement LID
	Prohibit Dumping of Improper Materials
✓	Contain Pollutants
✓	Collect and Convey

Description

Outdoor process equipment operations such as rock grinding or crushing, painting or coating, grinding or sanding, degreasing or parts cleaning, landfills, waste piles, wastewater and solid waste treatment and disposal, and others operations may contribute a variety of toxic compounds, oil and grease, heavy metals, nutrients, suspended solids, and other pollutants to the storm conveyance system.

Approach

Outdoor processing areas require a drainage approach different from the typical infiltration/detention strategy. In outdoor process equipment areas, infiltration is discouraged. Containment is encouraged, accompanied by collection and conveyance. Preventative measures include enclosures, secondary containment structures, dead-end sumps, and conveyance to treatment facilities in accordance with conditions established by the applicable sewer agency.

Suitable Applications

Appropriate applications include commercial and industrial areas planned for development or redevelopment.

Design Considerations

Design requirements for outdoor processing areas are governed by Building and Fire codes, and by current local agency ordinances, and zoning requirements.

Designing New Installations

Operations determined to be a potential threat to water quality should consider to the following recommendations:

- Cover or enclose areas that would be the most significant source of pollutants; or slope the area toward a dead-end sump; or, discharge to the sanitary sewer system following appropriate treatment in accordance with conditions established by the applicable sewer agency.
- Grade or berm area to prevent run-on from surrounding areas.
- Do not install storm drains in areas of equipment repair.
- Consider other features that are comparable or equally effective.

- Provide secondary containment structures (not double wall containers) where wet material processing occurs (i.e., electroplating), to hold spills resulting from accidents, leaking tanks, or equipment, or any other unplanned releases. (Note: if these are plumbed to the sanitary sewer, they must be with the prior approval of the City or other applicable sanitary sewer agency.)

Redeveloping Existing Installations

The City's SWMPP defines "redevelopment" as development that would create or add impervious surface area on an already developed site. The definition of "redevelopment" must be consulted to determine whether or not the requirements for new development apply to areas intended for redevelopment. If the definition applies, the steps outlined under "designing new installations" above should be followed.

Supplemental Information

Storm water and non-storm water will accumulate in containment areas and sumps with impervious surfaces. Contaminated accumulated water must be disposed of in accordance with applicable laws and cannot be discharged directly to the storm drain or sanitary sewer system without the appropriate permit.

References

California Stormwater Quality Association (CASQA) Best Management Practices Handbook New Development and Redevelopment, 2003.

A Manual for the Standard Urban Storm Water Mitigation Plan (SUSMP), Los Angeles County Department of Public Works, May 2002.

Model Standard Urban Storm Water Mitigation Plan (SUSMP) for San Diego County, Port of San Diego, and Cities in San Diego County, February 14, 2002.

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5. TREATMENT CONTROL BMPS

5.1. Introduction

This section describes treatment control BMPs to be considered for incorporation into newly developed public and private infrastructure, as well as retrofit into existing facilities to meet storm water management objectives. BMP fact sheets are divided into two (2) groups: public domain BMPs and manufactured (proprietary) BMPs. In some cases, the same BMP may exist in each group, for example, media filtration. However, treatment BMPs are typically very different between the two (2) groups.

Descriptions of manufactured BMPs in this document should not be inferred as endorsement by the authors. Products mentioned and shown in this document are not approved products, as they do not necessarily meet city storm water quality TSS pollutant removal criteria.

5.2. Treatment Control BMPs

Public domain and manufactured BMP controls are listed in Table 5.1.

Table 5.1: Treatment Control BMPs

Public Domain	Manufactured (Proprietary)
Infiltration	**Infiltration**
TC-10 Infiltration Trench TC-11 Infiltration Basin TC-12 Retention/Irrigation TC-13 Permeable Pavement	---- ---- ---- ----
Detention and Settling	**Detention and Settling**
TC-20 Wet Ponds TC-21 Constructed Wetlands TC-22 Detention Basin	---- MP-20 Wetland ----
Biofiltration	**Biofiltration**
TC-30 Vegetated Swale TC-31 Vegetated Buffer Strip TC-32 Vegetated Biofilter TC-33 Green Roof	---- ---- ---- ----
Filtration	**Filtration**
TC-40 Media Filter	MP-40 Media Filter
Flow Through Separation	Flow Through Separation
---- TC-50 Water Quality Inlet ----	MP-50 Wet Vault MP-51 Vortex Separator MP-52 Drain Inlet Inserts
Other	**Other**
TC-60 Multiple Systems	----

5.3. Fact Sheet Format

A BMP fact sheet is a short document that gives all the information about a particular BMP. Typically, each public domain and manufactured BMP fact sheet contains the information outlined in Figure 5.1. The fact sheets also contain side bar presentations with information on BMP design considerations, targeted constituents, and removal effectiveness (if known).

Figure 5.1: Example Fact Sheet

TCxx/MPxx Example Fact Sheet

Description

Advantages

Limitations

Design and Sizing Guidelines

Performance

Siting Criteria

Design Guidelines

Maintenance

Cost

References and Sources of Additional Information

Treatment BMP performance and other selection factors are discussed in Section 5.4 to 5.6. BMP Fact sheets are included in Section 5.7.

5.4. Comparing Performance of Treatment Control BMPs

With a myriad of storm water treatment BMPs from which to choose, a question commonly asked is "which one is best." Particularly when considering a manufactured treatment system, the engineer wants to know if it provides performance that is reasonably comparable to the typical public-domain BMPs like wet ponds or grass swales. With so many BMPs, it is not likely that they perform equally for all pollutants.

Methodology for comparing BMP performance may need to be expanded to include more than removal effectiveness. Many studies have been conducted on the performance of storm water treatment BMPs. Several publications have provided summaries of performance (ASCE, 1998; ASCE, 2001; Brown and Schueler, 1997; Shoemaker et al., 2000; Winter, 2001). These summaries indicate a wide variation in the performance of each type of BMP, making effectiveness comparisons between BMPs problematic.

5.4.1. Variation in Performance

There are several reasons for the observed variation.

The Variability of Storm Water Quality

Storm water quality is highly variable during a storm, from storm to storm at a site, and between sites even of the same land use. For pollutants of interest, maximum observed concentrations commonly exceed the average concentration by a factor of 100. The average concentration of a storm, known as the event mean concentration (EMC) commonly varies at a site by a factor of 5. One (1) aspect of storm water quality that is highly variable is the particle size distribution (PSD) of the suspended sediments. This results in variation in the settle ability of these sediments and the pollutants that are attached.

Most Field Studies Monitor Too Few Storms

High variability of storm water quality requires that a large number of storms be sampled to discern if there is a significant difference in performance among BMPs. The smaller the actual difference in performance between BMPs, the greater the number of storms that must be sampled to statistically discern the difference between them. For example, a researcher attempting to determine a difference in performance between two (2) BMPs of 10% must monitor many more storms than if the interest is to define the difference within 50%. Given the expense and difficulty, few studies have monitored enough storms to determine the actual performance with a high level of precision.

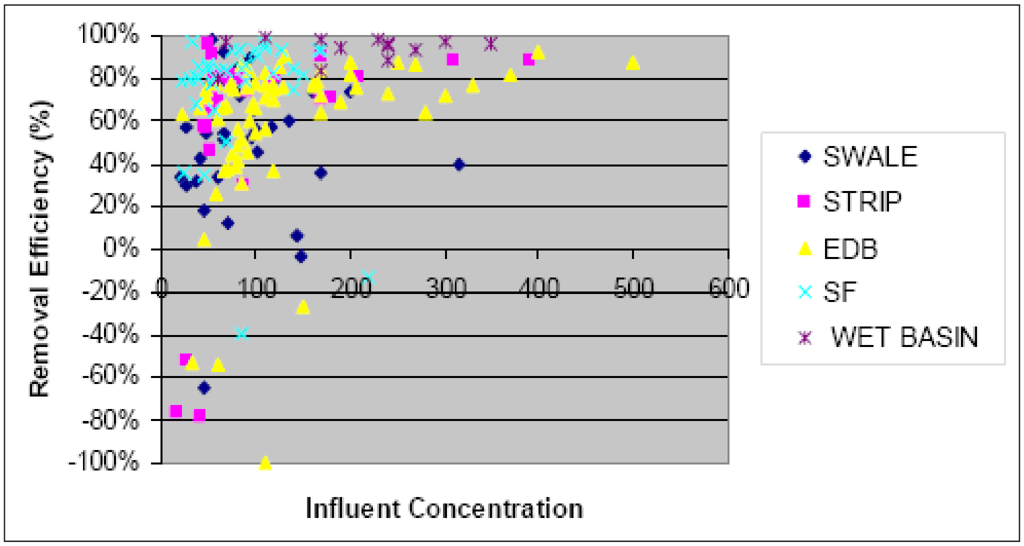
Different Design Criteria

Performance of different systems within the same group (i.e., wet ponds) differs significantly in part because of differing design criteria for each system. This in turn can make it problematic to compare different groups of treatment BMPs to each other (i.e., wet ponds to vortex separators).

Differing Influent Concentrations and Analytical Variability

With most treatment BMPs, efficiency decreases with decreasing influent concentration. This is illustrated in Figure 5.2. Thus, a low removal efficiency may be observed during a study not because the device is inherently a poorer performer, but possibly because the influent concentrations for the site were unusually low. In addition, as the concentration of a particular constituent such as TSS approaches its analytical detection limit, the effect of the variability of the laboratory technique becomes more significant. This factor also accounts for the wide variability of observations on the left of Figure 5.2.

Figure 5.2: Removal Efficiency versus Influent Concentration



The variability of the laboratory results as the TSS approaches its analytical detection limit may also account for negative efficiencies at very low influent concentrations (i.e., TSS less than 10 mg/L). However, some negative efficiencies observed at higher concentrations may not necessarily be an artifact of laboratory analysis. The cause varies to some extent with the type of treatment BMP. Negative efficiencies may be due to the re-suspension of previously deposited pollutants, a change in pH that dissolves precipitated or sorbed pollutants, discharge of algae in the case of BMPs with open wet pools, erosion of unprotected basin side or bottom, and the degradation of leaves that entered the system the previous fall.

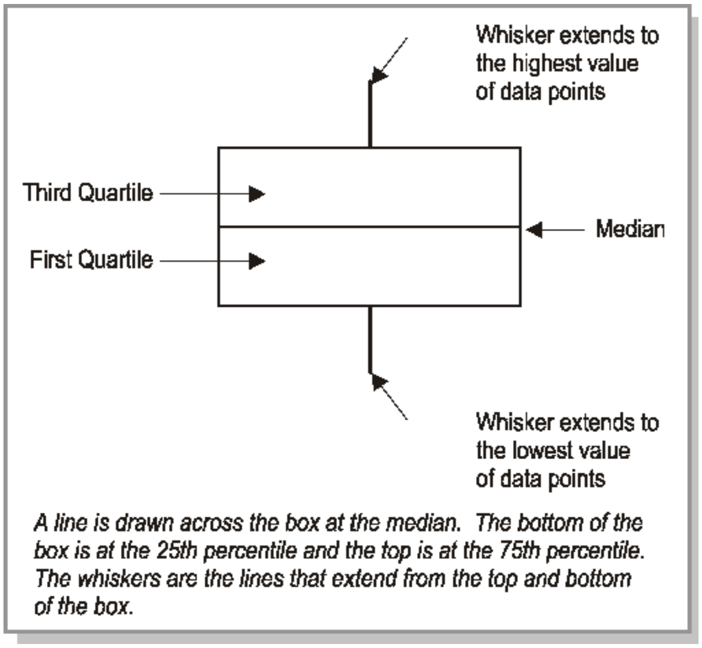
Different Methods of Calculating Efficiency

Researchers (1) have used different methods to calculate efficiency, (2) do not always indicate which method they have used, and (3) often do not provide sufficient information in their report to allow others to recalculate the efficiency using a common method.

One approach to quantifying BMP efficiency is to determine first if the BMP is providing treatment (that the influent and effluent mean event mean concentrations are statistically different from one another) and then examine either a cumulative distribution function of influent and effluent quality or a standard parallel probability plot. This approach is called the Effluent Probability Method. While this approach has been used in the past by USEPA and ASCE, some researchers have experienced problems with the general applicability of this method.

A second approach to comparing performance among BMPs is to compare effluent concentrations, using a box-whisker plot, the basic form of which is illustrated in Figure 5.3. The plot represents all of the data points, of one study, several studies, or of individual storms. The plots provide insight into the variability of performance within each BMP type, and possible differences in performance among the types. To explain the plot: 50% of the data points as well as the median value of all the data points is represented by the box. That is, the median falls within the 75th and 25th percentile of data (top and bottom of the box). The whisker extends to the highest point within a range of 1.5 times the difference between the first and third quartiles. Individual points beyond this range are shown as asterisks.

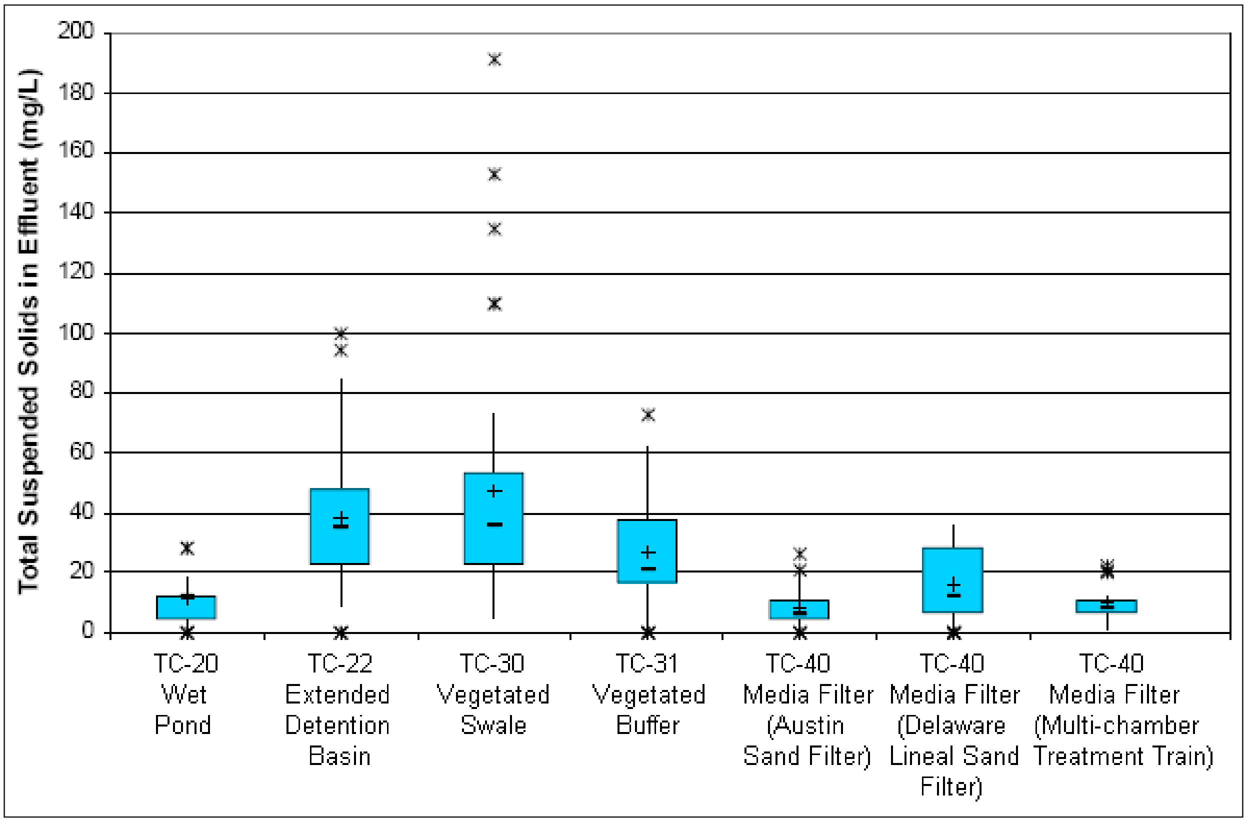
Figure 5.3: Box Whisker Plot



Recognizing the possible effect of influent concentration on efficiency, an alternative is to compare effluent concentrations. The reasoning is that regardless of the influent concentration, a particular BMP will generate a narrower range of effluent concentrations. Figure 5.4 shows observed effluent concentrations for several different types of BMPs. This data was generated in an extensive field program conducted by the California Department of Transportation (Caltrans). As this program is the most extensive effort to date in the entire United States, the observations about performance in this manual rely heavily on these data. The Caltrans study is unique in that many of the BMPs were tested under reasonably similar conditions (climate, storms, freeway storm water quality), with each type of BMP sized with the same design criteria.

An additional factor to consider when comparing BMPs is the effect of infiltration. BMPs with concrete or metal structures will have no infiltration, whereas the infiltration in earthen BMPs will vary from none to substantial. For example, in the Caltrans study, infiltration in vegetated swales averaged nearly 50%. This point is illustrated with Figure 5.4 where effluent quality of several BMPs is compared. As seen in Figure 5.4, effluent concentration for grass swales is higher than either filters or wet basins (30 versus 10 to 15 mg/L), suggesting that swales in comparison are not particularly effective. However, surface water entering swales may infiltrate into the ground, resulting in a loading reduction (flow times concentration) that is similar to those BMPs with minimal or no infiltration.

Figure 5.4: Observed Effluent Concentrations for Several Different Public Domain BMPs



With equation shown below, it is possible using the data from Figure 5.4 to estimate different levels of loading reduction as a function of the fraction of storm water that is infiltrated.

EEC = (1-I)(EC) + (I)(GC)

Where:

EEC = the effective effluent concentration
I = fraction of storm water discharged by infiltration
EC = the median concentration observed in the effluent
GC = expected concentration of storm water when it reaches the groundwater

To illustrate the use of the equation above, the effect of infiltration is considered on the effective effluent concentration of TSS from swales. From Figure 5.4, the median effluent concentration for swales is about 30 mg/L. Infiltration of 50% is assumed with an expected concentration of 5 mg/L when the storm water reaches the groundwater. This gives:

EEC = (1-0.5)(30) + (0.5)(5) = 17.5 mg/L

The above value can be compared to other BMPs that may directly produce a lower effluent concentration, but do not exhibit infiltration, such as concrete wet vaults.

5.4.2. Other Issues Related to Performance Comparisons

A further consideration related to performance comparisons is whether or not the treatment BMP removes dissolved pollutants. Receiving water standards for most metals are based on the dissolved fraction; the form of nitrogen or phosphorus of most concern as a nutrient is the dissolved fraction.

The common practice of comparing the performance of BMPs using TSS may not be considered sufficient by local governments and regulatory agencies, as there is not always a strong, consistent relationship between TSS and the pollutants of interest, particularly those identified in the 303d list for specific water bodies in Hawaii. These pollutants frequently include metals, nitrogen, nutrients (but often nutrients without specifying nitrogen or phosphorus), indicator bacteria (i.e., fecal coliform), pesticides, and trash. Less commonly cited pollutants include sediment, PAHs, PCBs, and dioxin. With respect to metals, typically, only the general term is used. In some cases, a specific metal is identified. The most commonly listed metals are mercury, copper, lead, selenium, zinc, and nickel. Less frequently listed metals are cadmium, arsenic, silver, chromium, molybdenum, and thallium. Commonly, only the general term “metals” is indicated for a water body without reference to a particular metal.

It is desirable to know how each of the treatment BMPs performs with respect to the removal of the above pollutants. Unfortunately, the performance data are non-existent or very limited for many of the cited pollutants, particularly trash, PAHs, PCBs, dioxin, mercury, selenium, and pesticides. Furthermore, the concentrations of these constituents are very low, often below the detection limit. This prevents the determination of which BMPs are most effective. However, with the exception of trash and possibly dioxin, these pollutants readily sorb to sediments in storm water, and therefore absent data at this time can be considered to be removed in proportion to the removal of TSS (i.e., sediment.) Therefore, in general, those treatment systems that are most effective at removing TSS will be most effective at removing pollutants noted above.

While there is little data on the removal of trash, those treatment BMPs that include a basin such as a wet pond or vault, or extended detention basin should be similarly effective at removing trash as long as the design incorporates a means of retaining the floating trash in the BMP. Whether or not manufactured products that are configured as a basin (i.e., round vaults or vortex separators) are as effective as public domain BMPs is unknown. However, their ability to retain floating debris may be limited by the fact that many of these products are relatively small and therefore may have limited storage capacity. Only one (1) manufactured BMP is specifically designed to remove floating debris.

There are considerable amounts of performance data for zinc, copper, and lead, with a less substantial database for nickel, cadmium, and chromium. An exception is high-use freeways where metals in general are at higher concentrations than residential and commercial properties. Lead sorbs easily to the sediments in storm water, with typically only 10% in the dissolved phase. Hence, its removal is generally in direct proportion to the removal of TSS. In contrast, zinc, copper, and cadmium are highly soluble with 50% or more in the dissolved phase. Hence, two treatment BMPs may remove TSS at the same level, but if one is capable of removing dissolved metals, it provides better treatment overall for the more soluble metals.

5.4.3. Comparisons of Treatment BMPs for TSS

Presented in Figure 5.4 are observed effluent concentrations for several different public domain BMPs. This data is from the Caltrans study previously cited. (Note that while box-whisker plots are used here to compare BMPs, other methodologies, such as effluent cumulative probability distribution plots, are used by others.)

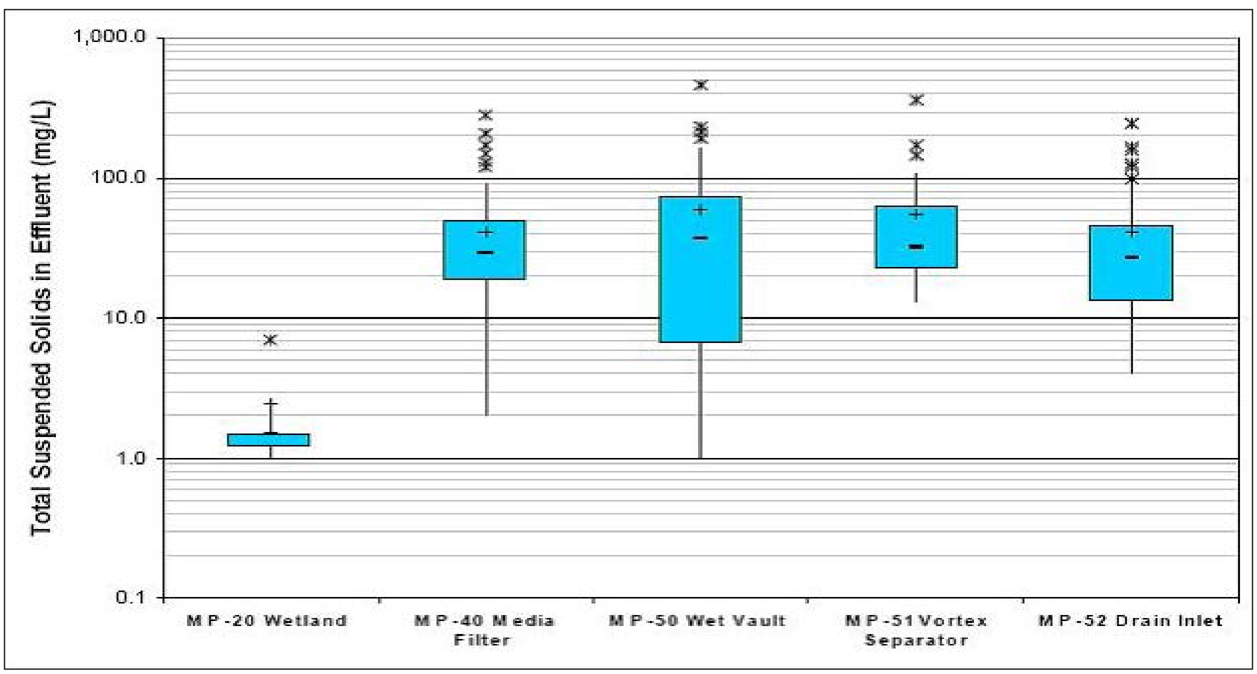
5.4.4. General Performance of Manufactured BMPs

An important question is how the performance of manufactured treatment BMPs compares to those in the public domain. Figure 5.5 presents box-whisker plots of the removal of TSS for the manufactured systems. Data are presented for five (5) general types of manufactured BMPs: wet vaults, drain inserts, constructed wetlands, media filters, and vortex separators. The figure indicate wide ranges in effluent concentrations, reflecting in part the different products and design criteria within each type. Manufactured products may perform as well as the less effective public domain BMPs such as swales and extended detention basins (excluding the additional benefits of infiltration with the latter). Manufactured wetlands may perform as well as the most effective public domain BMPs.

Product performance within each grouping of manufactured BMPs varies as follows:

- Filters – TSS effluent concentrations range from 2 to 280 mg/L, with a median value of 29 mg/L.
- Inserts – TSS effluent concentrations range from 4 to 248 mg/L with a median value of 27 mg/L.
- Wetlands – TSS effluent concentrations vary little, and have a median value of 1.2 mg/L.
- Vaults – TSS effluent concentrations range from 1 to 467 mg/L, with a median value of 36 mg/L.
- Vortex – TSS effluent concentrations range from 13 to 359 mg/L, with a median value of 32 mg/L.

Figure 5.5: Total Suspended Solids in Effluent (Log Format)



As noted earlier, performance of particular products in a grouping may be due to different design criteria within the group. For example, wet vault products differ with respect to the volume of the permanent wet pool to the design event volume; filter products differ with respect to the type of media.

5.4.5. Technology Certification

This manual does not endorse proprietary products, although many are described. It is left to each developer to determine which proprietary products may be used, and under what circumstances. When considering a proprietary product, it is strongly advised that the developer consider performance data, but only performance data that have been collected following a widely accepted protocol. Protocols have been developed by the Technology Acceptance and Reciprocity Partnership (TARP), American Society of Civil Engineering (ASCE BMP Data Base Program), and by the USEPA (Environmental Technology Certification Program). To obtain specific criteria contact the manufacturer of the product to submit a report that describes the product and protocol that was followed to produce the performance data.

It can be expected that subsequent to the publishing of this manual, new public-domain technologies will be proposed (or design criteria for existing technologies will be altered) by development engineers. As with proprietary products, it is advised that new public-domain technologies be considered only if performance data are available and have been collected following a widely accepted protocol.

5.5. BMP Design Criteria for Flow and Volume

The City's storm water discharge permit contains provisions that require many new development and redevelopment projects to capture and then infiltrate or treat runoff from the project site prior to being discharged to storm drains. These provisions include minimum standards for sizing these treatment control BMPs. Sizing standards are prescribed for both volume-based and flow-based BMPs. Refer to the City Drainage Rules.

A key point to consider when developing, reviewing, or complying with requirements for the sizing of treatment control BMPs for storm water quality enhancement is that BMPs are most efficient and economical when they target small, frequent storm events that over time produce more total runoff than the larger, infrequent storms targeted for design of flood control facilities.

It is important to note that arbitrarily targeting large, infrequent storm events can actually reduce the pollutant removal capabilities of some BMPs. This occurs when outlet structures, detention times, and drain down times are designed to accommodate unusually large volumes and high flows. When BMPs are over-designed, the more frequent, small storms that produce the most annual runoff pass quickly through the over-sized BMPs and therefore receive inadequate treatment. For example, a detention basin might normally be designed to capture 0.5 inch of runoff and to release that runoff over 48 hours, providing a high level of sediment removal. If the basin were to be oversized to capture 1.0 inch of runoff and to release that runoff over 48 hours, a more common 0.5 inch runoff event entering basin would drain in approximately 24 hours, meaning the smaller, more frequent storm that is responsible for more total runoff would receive less treatment than if the basin were designed for the smaller event. Therefore, efficient and economical BMP sizing criteria are usually based on design criteria that correspond to the "knee of the curve" or point of diminishing returns.

5.5.1. Volume-Based BMP Design

Volume-based BMP design standards apply to BMPs whose primary mode of pollutant removal depends on the volumetric capacity of the BMP. Examples of BMPs in this category include detention basins, retention basins, and infiltration. Typically, a volume-based BMP design criteria calls for the capture and infiltration or treatment of a certain percentage of the runoff from the project site. The reader is referred to the City Drainage Rules.

5.5.2. Flow-Based BMP Design

Flow-based BMP design standards apply to BMPs whose primary mode of pollutant removal depends on the rate of flow of runoff through the BMP. Examples of BMPs in this category include swales, screening devices, and many proprietary products. Typically, a flow-based BMP design criteria calls for the capture and infiltration or treatment of the flow runoff produced by rain events of a specified magnitude. The reader is referred to the City Drainage Rules, for various levels of treatment.

5.5.3. Combined Volume-Based and Flow-Based BMP Design

Volume-based BMPs and flow-based BMPs do not necessarily treat precisely the same storm water runoff. For example, an on-line volume-based BMP such as a detention basin will treat the design runoff volume and is essentially unaffected by runoff entering the basin at an extremely high rate, say from a very short, but intense storm that produces the design volume of runoff. However, a flow-based BMP might be overwhelmed by the same short, but intense storm if the storm intensity results in runoff rates that exceed the flow-based BMP design flow rate. By contrast, a flow-based BMP such as a swale will treat the design flow rate of runoff and is essentially unaffected by the duration of the design flow, say from a long, low intensity storm. However, a volume-based detention basin subjected to this same rainfall and runoff event will begin to provide less treatment or will go into bypass or overflow mode after the design runoff volume is delivered.

Therefore, there may be some situations where designers need to consider both volume-based and flow-based BMP design criteria. An example of where both types of criteria might apply is an off-line detention basin. For an off-line detention basin, the capacity of the diversion structure could be designed to comply with the flow-based BMP design criteria while the detention basin itself could be designed to comply with the volume-based criteria.

When both volume-based and flow based criteria apply, the designer should determine which of the criteria apply to each element of the BMP system, and then size the elements accordingly.

5.6. Other BMP Selection Factors

Other factors that influence the selection of BMPs include cost, vector control issues, and endangered species issues. Each of these is discussed briefly as follows.

5.6.1. Costs

The relative costs for implementing various public domain and manufactured BMPs based on flow and volume parameters are shown in Tables 5.2 and 5.3.

Table 5.2: Economic Comparison Matrix- Flow

BMP	Cost/cfs.
Strip	$$
Swale	$$
Wet Vault	Not Available
Media Filter	$$$$
Vortex	Not Available
Drain Insert	Not Available

cfs: cubic feet per second

Table 5.2 and 5.3 Legend: Low: $, High: $$$$

Table 5.3: Economic Comparison Matrix- Volume

BMP	Cost/Acre-feet
Austin Sand Filter Basin	$$$$
Delaware Lineal Sand Filter	$$$$
Extended Detention Basin	$$
Multi Chamber Treatment Train (MCTT)	$$$$
Wet Basin	$$$$
Manufactured Wetland	Not Available
Infiltration Basin	$
Wet Pond and Constructed Wetland	$$$$

Note that Hawaii's unit prices are higher than California's unit prices.

5.6.2. Vector Breeding Considerations

The potential of a BMP to create vector breeding habitat and/or harborage should be considered when selecting BMPs. Mosquito and other vector production is a nuisance and public health threat. Mosquitoes can breed in standing water almost immediately following a BMP installation and may persist at unnaturally high levels and for longer seasonal periods in created habitats. BMP siting, design, construction, and maintenance must be considered in order to select a BMP that is least conducive to providing habitat for vectors. Tips for minimizing vector-breeding problems in the design and maintenance of BMPs are presented in the BMP fact sheets. Certain BMPs, including ponds and wetlands and those designed with permanent water sumps, vaults, and/or catch basins (including below ground installations), may require routine inspections and treatments.

5.6.3. Threatened and Endangered Species Considerations

The presence or potential presence of threatened and endangered species should also be considered when selecting BMPs. Although preservation of threatened endangered species is crucial, treatment BMPs are not intended to supplement or replace species habitat except under special circumstances. The presence of threatened or endangered species can hinder timely and routine maintenance, which in turn can result in reduced BMP performance and an increase in vector production. In extreme cases, rights to the treatment BMP and surrounding land may be lost if threatened or endangered species utilize or become established in the BMP.

When considering BMPs where there is a presence or potential presence of threatened or endangered species, early coordination with DLNR and USFWS is essential. During this coordination, the purpose and the long-term operation and maintenance requirements of the BMPs need to be clearly established through written agreements or memorandums of understanding. Absent firm agreements or understandings, proceeding with BMPs under these circumstances is not recommended.

5.7. Treatment Control Public Domain and Manufactured Proprietary Fact Sheets

The Treatment Control Public Domain and Manufactured Proprietary fact sheets are presented in the following pages. Each fact sheet is individually page numbered and suitable for photocopying.

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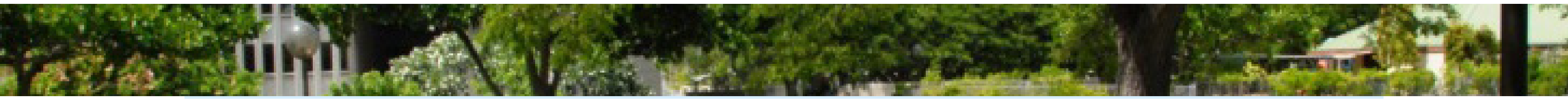
Treatment Control Public Domain (TC) Fact Sheets

- TC-10 Infiltration Trench
- TC-11 Infiltration Basin
- TC-12 Retention/Irrigation
- TC-13 Permeable Pavement
- TC-20 Wet Ponds
- TC-21 Constructed Wetlands
- TC-22 Detention Basin
- TC-30 Vegetated Swales
- TC-31 Vegetated Buffer Strip
- TC-32 Vegetated Biofilter
- TC-33 Green Roof
- TC-40 Media Filter
- TC-50 Water Quality Inlet
- TC-60 Multiple Systems



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Design Considerations		
•	Accumulation of Metal	
•	Clogged Soil Outlet	
•	Vegetation/ Landscape Maintenance	
Target Constituents		
✓	Sediments	H
✓	Nutrients	H
✓	Trash	H
✓	Metals	H
✓	Bacteria	H
✓	Oil and Grease	H
✓	Organics	H
Legend (Removal Effectiveness)		
L	Low	
M	Medium	
H	High	

Description

An infiltration trench (a.k.a. infiltration galley) is a long, narrow, rock-filled trench with no outlet that receives storm water runoff. Runoff is stored in the void space between the stones and infiltrates through the bottom and into the soil matrix. Infiltration trenches perform well for removal of fine sediment and associated pollutants. Pretreatment using buffer strips, swales, or detention basins is important for limiting amounts of coarse sediment entering the trench which can clog and render the trench ineffective.

Advantages

- Provides 100% reduction in the load discharged to surface waters.
- An important benefit of infiltration trenches is the approximation of pre-development hydrology during which a significant portion of the average annual rainfall runoff is infiltrated rather than flushed directly to streams.
- If the water quality volume (WQV) is adequately sized, infiltration trenches can be useful for providing control of channel forming (erosion) and high frequency (generally less than the 2-year) flood events.
- As an underground BMP, trenches are unobtrusive and have little impact of site aesthetics.
- Infiltration trenches typically consume about 2 to 20% of the site draining to them, depending on the soil's infiltration rate. In addition, infiltration trenches can fit into thin, linear areas. Thus, they can generally fit into relatively unusable portions of a site.

Limitations

- The soil should have ≤ 30% clay or ≤ 40% clay and silt combined.
- Have a high failure rate if soil and subsurface conditions are not suitable.
- May not be appropriate for industrial sites or locations where spills may occur.
- The maximum contributing area to an individual infiltration practice should generally be less than five (5) acres.
- Infiltration trenches require a minimum soil infiltration of 0.5 inch/hour. Not appropriate at sites with Natural Resource Conservation Service (NRCS) hydrologic Soil Groups C and D.

- If infiltration rates exceed 3.0 inches/hour, then the runoff shall be pre-treated prior to infiltration to protect groundwater quality.
- Not suitable on fill sites or steep slopes.
- Risk of groundwater contamination in very coarse soils.
- Upstream drainage area must be completely stabilized before construction.
- Difficult to restore functioning of infiltration trenches once clogged.

Design and Sizing Guidelines

- The infiltration trench is sized to capture the water quality volume based on a one (1) inch rain storm as specified in the City Drainage Rules.
- Provide pretreatment for infiltration trenches in order to reduce the sediment load. Pretreatment refers to design features that provide settling of large particles before runoff reaches a management practice, easing the long-term maintenance burden. Pretreatment is important for all structural storm water management practices, but it is particularly important for infiltration practices. To ensure that pretreatment mechanisms are effective, designers should incorporate practices such as grassed swales, vegetated filter strips, detention, or a plunge pool in series.
- Specify locally available trench rock that is 1.5 to 3.0 inches in diameter.
- Determine the trench volume by assuming the WQV will fill the void space based on the computed porosity of the rock matrix (normally about 35%).
- Determine the bottom surface area needed to drain the trench within 48 hours by dividing the WQV by the infiltration rate.
- Calculate maximum allowable trench depth using the following equation.

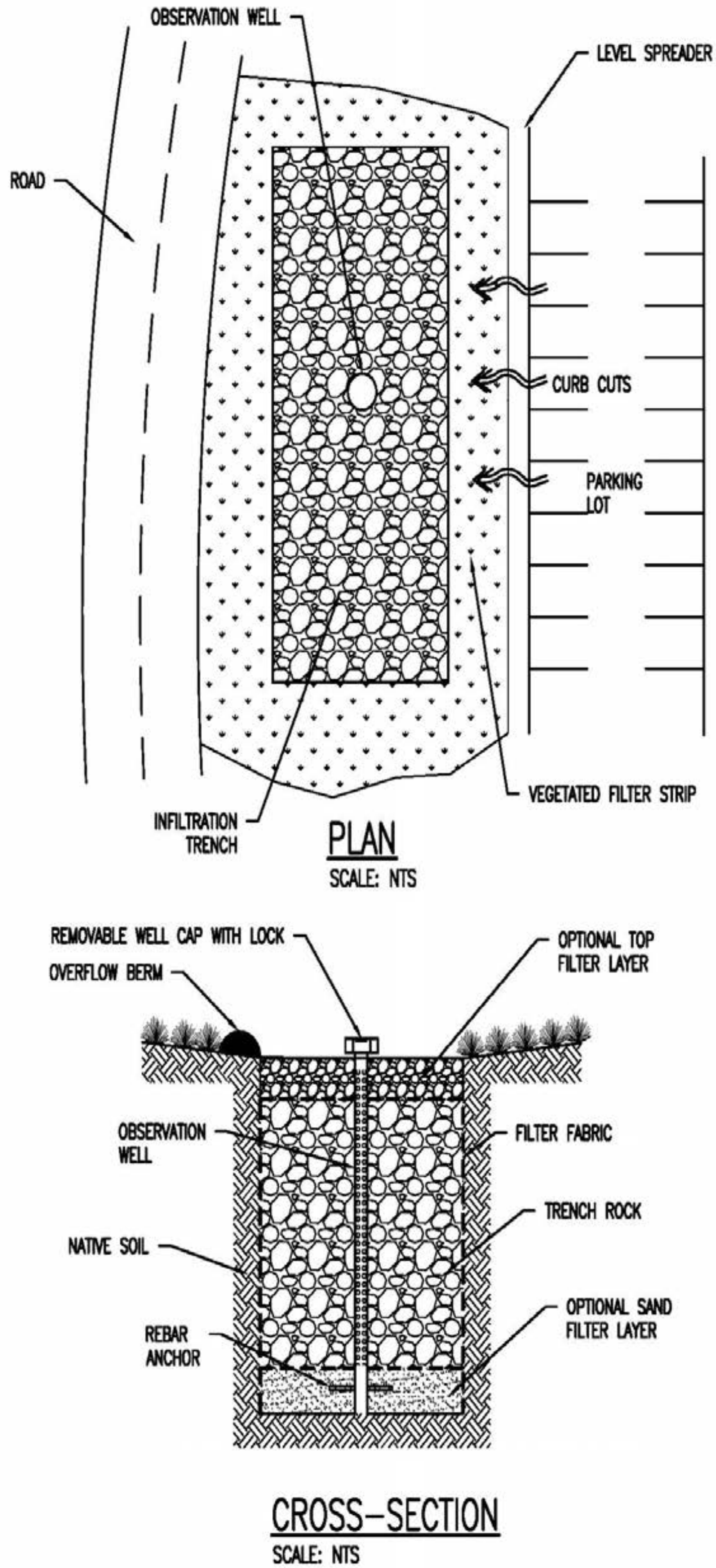
$$\mathbf{d_{max} = kt/(F_s \times 12)}$$

Where:

d_{max} = maximum storage (depth (feet)
k = soil infiltration rate (inch/hour)
t = drawdown (drain) time (hours)
F_s = infiltration rate Factor of Safety (see Storm Water BMP Guide)

- When using vertical piping, either for distribution or infiltration enhancement, only Class V wells are permissible, without exception, per 40 CFR 146.5(e)(4) and State of Hawaii Administrative Rules (HAR) Chapter 23 Underground Injection Control §11-23-06(B).
- Provide observation well to allow observation of drain time.
- May include a horizontal layer of filter fabric just below the surface of the trench to retain sediment and reduce the potential for clogging.
- The following figure illustrates a conceptual layout of an infiltration trench.

Infiltration Trench



Construction/Inspection Considerations

Stabilize the entire area draining to the facility before construction begins. If impossible, place a diversion berm around the perimeter of the infiltration site to prevent sediment entrance during construction. Stabilize the entire contributing drainage area before allowing any runoff to enter once construction is complete.

Performance

Infiltration trenches eliminate the discharge of the water quality volume to surface receiving waters and consequently can be considered to have 100% removal of all pollutants within this volume. Transport of some of these constituents to groundwater is likely, although the attenuation in the soil and subsurface layers will be substantial for many constituents.

Infiltration trenches can be expected to remove up to 90% of sediments, metals, coliform bacteria and organic matter, and up to 60% of phosphorus and nitrogen in the infiltrated runoff (Schueler, 1992). Biochemical oxygen demand (BOD) removal is estimated to be between 70 to 80%. Lower removal rates for nitrate, chlorides and soluble metals should be expected, especially in sandy soils (Schueler, 1992). Pollutant removal efficiencies may be improved by using washed aggregate and adding organic matter and loam to the subsoil. The stone aggregate should be washed to remove dirt and fines before placement in the trench. The addition of organic material and loam to the trench subsoil may enhance metals removal through adsorption.

Siting Criteria

The use of infiltration trenches may be limited by a number of factors, including type of native soils, climate, and location of groundwater table. Site characteristics, such as excessive slope of the drainage area, fine-grained soil types, and proximate location of the water table and bedrock, may preclude the use of infiltration trenches. Generally, infiltration trenches are not suitable for areas with relatively impermeable soils containing clay and silt or in areas with fill.

As with any infiltration BMP, the potential for groundwater contamination must be carefully considered, especially if the groundwater is used for human consumption or agricultural purposes. The infiltration trench is not suitable for sites that use or store chemicals or hazardous materials unless hazardous and toxic materials are prevented from entering the trench. In these areas, other BMPs that do not allow interaction with the groundwater should be considered.

The potential for spills can be minimized by aggressive pollution prevention measures. Many municipalities and industries have developed comprehensive spill prevention control and countermeasure (SPCC) plans. These plans should be modified to include the infiltration trench and the contributing drainage area. For example, diversion structures can be used to prevent spills from entering the infiltration trench. Because of the potential to contaminate groundwater, extensive site investigation must be undertaken early in the site planning process to establish site suitability for the installation of an infiltration trench.

Longevity can be increased by careful geotechnical evaluation prior to construction and by designing and implementing an inspection and maintenance plan. Soil infiltration rates and the water table depth should be evaluated to ensure that conditions are satisfactory for proper operation of an infiltration trench. Pretreatment structures, such as a vegetated buffer strip or water quality inlet, can increase longevity by removing sediments, hydrocarbons, and other materials that may clog the trench. Regular maintenance, including the replacement of clogged aggregate, will also increase the effectiveness and life of the trench.

Evaluation of the viability of a particular site is the same as for infiltration basins and includes:

- Determine soil type from mapping and consult United States Department of Agriculture (USDA) NRCS soil survey tables to review other parameters such as the amount of silt and clay, presence of a restrictive layer or seasonal high water table, and estimated permeability.
- Groundwater separation should be at least 3 ft from the trench invert to the measured ground water elevation. There is concern of the impact on groundwater quality from infiltrated runoff, especially when the separation between groundwater and the surface is small.
- Location away from buildings, slopes and highway pavement (greater than 6 meters), and wells and bridge structures (greater than 30 meters). Sites constructed of fill, having a base flow or with a slope greater than 15% should not be considered.
- Ensure that adequate head is available to operate flow splitter structures (to allow the basin to be offline) without ponding in the splitter structure or creating backwater upstream of the splitter.
- Base flow should not be present in the tributary watershed.

Secondary Screening Based on Site Geotechnical Investigation

- For the purposes of determining a field infiltration rate, a saturated hydraulic conductivity test should be performed at the bottom of the proposed infiltration facility. The measured infiltration rate of the underlying soil shall be determined using either the Falling Head Percolation Test or the Double-Ring Infiltrometer Test. One (1) test per 100 feet shall be performed if manmade soils are not present, and one test per 50 feet shall be performed if manmade soils are present.
- The minimum acceptable hydraulic conductivity as measured in any of the required test holes is 0.5 inch/hour. If any test hole shows less than the minimum value, the site should be disqualified from further consideration.
- Exclude from consideration sites constructed in fill or partially in fill unless no silts or clays are present in the soil boring. Fill tends to be compacted, with clays in a dispersed rather than flocculated state, greatly reducing permeability.
- The geotechnical investigation should be such that a good understanding is gained as to how the storm water runoff will move in the soil (horizontally or vertically) and if there are any geological conditions that could inhibit the movement of water.

Maintenance

Infiltration trenches required the least maintenance of any of the BMPs that were evaluated in the Caltrans study, with approximately 17 field hours spent on the operation and maintenance of each site. Inspection of the infiltration trench was the largest field activity, requiring approximately 8 hours/year.

In addition to reduced water quality performance, clogged infiltration trenches with surface standing water can become a nuisance due to mosquito breeding. If the trench takes more than 72 hours to drain, then the rock fill should be removed and all dimensions of the trench should be increased by two (2) inches to provide a fresh surface for infiltration.

Cost

Construction Cost

Infiltration trenches are somewhat expensive, when compared to other storm water practices, in terms of cost per area treated. Typical construction costs, including contingency and design costs, are about \$5/$feet^3$ of storm water treated (SWRPC, 1991; Brown and Schueler, 1997). Note that Hawaii's unit prices are higher than California's unit prices.

Maintenance Cost

One cost concern associated with infiltration practices is the maintenance burden and longevity. If improperly sited or maintained, infiltration trenches have a high failure rate. In general, maintenance costs for infiltration trenches are estimated at between 5% and 20% of the construction cost. More realistic values are probably closer to the 20% range, to ensure long-term functionality of the practice.

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Infiltration Basin TC-11

Design Considerations		
•	Soil Infiltration	
•	Slope	
•	Aesthetics	
Target Constituents		
✓	Sediments	H
✓	Nutrients	H
✓	Trash	H
✓	Metals	H
✓	Bacteria	H
✓	Oil and Grease	H
✓	Organics	H
Legend (Removal Effectiveness)		
L	Low	
M	Medium	
H	High	

Description

An infiltration basin is a shallow impoundment that is designed to infiltrate storm water. Infiltration basins use the natural filtering ability of the soil to remove pollutants in storm water runoff. Infiltration facilities store runoff until it gradually exfiltrates through the soil and eventually into the water table. This practice has high pollutant removal efficiency and can also help recharge groundwater, thus helping to maintain low flows in stream systems. Infiltration basins can be challenging to apply on many sites, due to variability of soil characteristics such as permeability, relative groundwater depth, and site characteristics such as hydrology, land use, slopes and site development restrictions. In addition, some studies have shown relatively high failure rates compared with other management practices.

Advantages

- Provides 100% reduction in the load discharged to surface waters.
- The principal benefit of infiltration basins is the approximation of pre-development hydrology during which a significant portion of the average annual rainfall runoff is infiltrated and evaporated rather than flushed directly to creeks.
- If the water quality volume is adequately sized, infiltration basins can be useful for providing control of channel forming (erosion) and high frequency (generally less than the 2-year) flood events.

Limitations

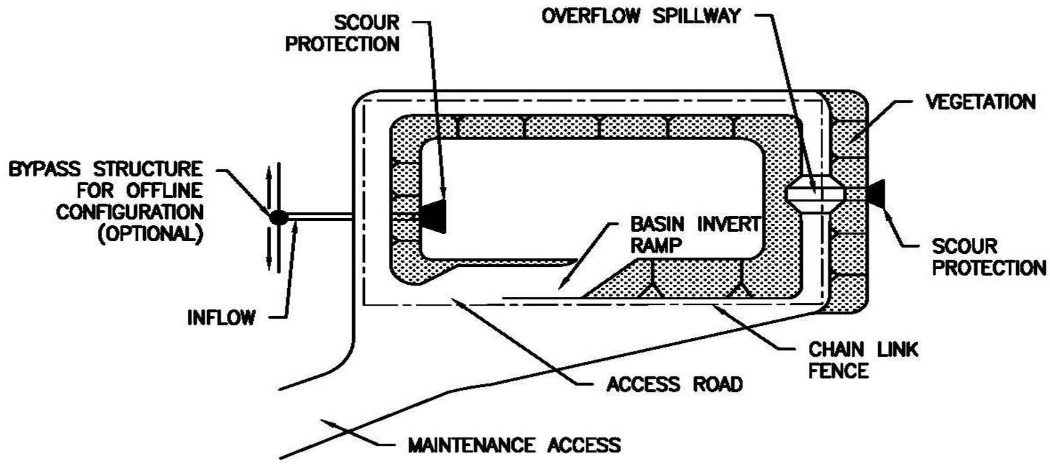
- May not be appropriate for industrial sites or locations where spills may occur.
- Infiltration basins require a minimum soil infiltration rate of 0.5 inches/hour, not appropriate at sites with hydrologic NRCS soil groups C (sandy clay loam) and D (clay loam, silty clay loam, sandy clay, silty clay or clay).
- If infiltration rates exceed 3.0 inches/hour, then the runoff shall be pre-treated prior to infiltration to protect groundwater quality.
- Not suitable on fill sites or steep slopes.
- Risk of groundwater contamination in very coarse soils.

- Upstream drainage area must be completely stabilized before construction.
- Difficult to restore functioning of infiltration basins once clogged.

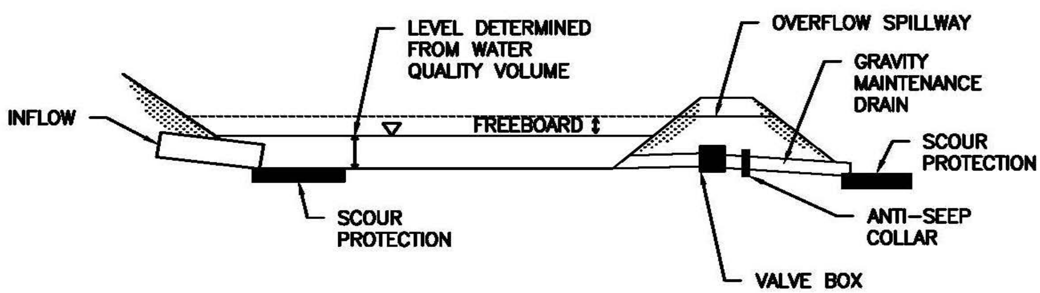
Design and Sizing Guidelines

- Assuming infiltration basin design is volume based, water quality volume determined by City Drainage Rules. Design volume is based on a 1 inch rain storm.
- Size basin such that the volume is infiltrated within a minimum of 48 hours.
- Vegetation establishment on the basin floor may help reduce the clogging rate.
- A conceptual layout of an infiltration basin is illustrated in the figure that follows.

Infiltration Basin



PLAN
SCALE: NTS



CROSS-SECTION
SCALE: NTS

Construction/Inspection Considerations

- Before construction begins, stabilize the entire area draining to the facility. If impossible, place a diversion berm around the perimeter of the infiltration site to prevent sediment entrance during construction or remove the top two (2) inches of soil after the site is stabilized. Stabilize the entire contributing drainage area, including the side slopes, before allowing any runoff to enter once construction is complete.
- Place excavated material such that it cannot be washed back into the basin if a storm occurs during construction of the facility.
- Build the basin without driving heavy equipment over the infiltration surface. Any equipment driven on the surface should have extra-wide ("low pressure") tires. Prior to any construction, rope off the infiltration area to stop entrance by unwanted equipment.
- After final grading, till the infiltration surface deeply.
- Use appropriate erosion control seed mix for the specific project and location.

Performance

As water migrates through porous soil and rock, pollutant attenuation mechanisms include precipitation, sorption, physical filtration, and bacterial degradation. If functioning properly, this approach is presumed to have high removal efficiencies for particulate pollutants and moderate removal of soluble pollutants. Actual pollutant removal in the subsurface would be expected to vary depending upon site-specific soil types. This technology eliminates discharge to surface waters except for the very largest storms; consequently, complete removal of all storm water constituents can be assumed.

There remain some concerns about the potential for groundwater contamination despite the findings of the NURP and Nightingale (1975; 1987a, b, c; 1989). For instance, a report by Pitt et al. (1994) highlighted the potential for groundwater contamination from intentional and unintentional storm water infiltration. That report recommends that infiltration facilities not be sited in areas where high concentrations are present or where there is a potential for spills of toxic material.

Siting Criteria

The key element in siting infiltration basins is identifying sites with appropriate soil and hydro- geologic properties, which is critical for long term performance. In one study conducted in Prince George's County, Maryland (Galli, 1992), all of the infiltration basins investigated clogged within two years. It is believed that these failures were for the most part due to allowing infiltration at sites with rates of less than 0.5 inch/hour, basing siting on soil type rather than field infiltration tests, and poor construction practices that resulted in soil compaction of the basin invert.

A study of 23 infiltration basins in the Pacific Northwest showed better long-term performance in an area with highly permeable soils (Hilding, 1996). In this study, few of the infiltration basins had failed after 10 years. Consequently, the following guidelines for identifying appropriate soil and subsurface conditions should be rigorously adhered to.

- Determine soil type (consider NRCS soil group 'A, B or C' only) from mapping and consult USDA soil survey tables to review other parameters such as the amount of silt and clay, presence of a restrictive layer or seasonal high water table, and estimated permeability. The soil should not have more than 30% clay or more than 40% of clay and silt combined. Eliminate sites that are clearly unsuitable for infiltration.

- Groundwater separation should be at least 3 feet from the basin invert to the seasonally high ground water elevation. There is concern of the impact on groundwater quality from infiltrated runoff, especially when the separation between groundwater and the surface is small.
- Locate away from buildings, slopes and highway pavement (greater than 6 meters) and wells and bridge structures (greater than 30 meters). Sites constructed of fill, having a base flow or with a slope greater than 15% should not be considered.
- Ensure that adequate head is available to operate flow splitter structures (to allow the basin to be offline) without ponding in the splitter structure or creating backwater upstream of the splitter.
- Base flow should not be present in the tributary watershed.

Secondary Screening Based on Site Geotechnical Investigation

- For the purposes of determining a field infiltration rate, a saturated hydraulic conductivity test should be performed at the bottom of the proposed infiltration facility. The measured infiltration rate of the underlying soil shall be determined using either the Falling Head Percolation Test or the Double-Ring Infiltrometer Test. One (1) test per 2,500 square-feet shall be performed if man-made soils are not present, and one test per 1,000 feet shall be performed if man-made soils are present.
- The minimum acceptable hydraulic conductivity as measured in any of the three required test holes is 0.5 inch/hour. If any test hole shows less than the minimum value, the site should be disqualified from further consideration.
- Exclude from consideration sites constructed in fill or partially in fill unless no silts or clays are present in the soil boring. Fill tends to be compacted, with clays in a dispersed rather than flocculated state, greatly reducing permeability.
- The geotechnical investigation should be such that a good understanding is gained as to how the storm water runoff will move in the soil (horizontally or vertically) and if there are any geological conditions that could inhibit the movement of water.

Additional Design Guidelines

- Basin Sizing - The required water quality volume is determined by City Drainage Rules.
- Provide pretreatment if sediment loading is a maintenance concern for the basin.
- Include energy dissipation in the inlet design for the basins. Avoid designs that include a permanent pool to reduce opportunity for standing water and associated vector problems.
- Basin invert area should be determined by the equation:

$$\mathbf{A_b = WQV / (d_p + kT / 12F_s)}$$

Where:

A_b = bottom surface area (square feet)
WQV = water quality volume (cubic feet)
d_p = designing ponding depth (feet)
k = soil infiltration rate (inch/hour)
T = fill time (time for the BMP to fill with water, hours)
F_s = infiltration rate Factor of Safety (see Storm Water BMP Guide)

- When using vertical piping, either for distribution or infiltration enhancement, only Class V wells are permissible, without exception, per 40 CFR 146.5(e)(4) and State of Hawaii Administrative Rules (HAR) Chapter 23 Underground Injection Control §11-23-06(B).

Maintenance

Regular maintenance is critical to the successful operation of infiltration basins. Recommended operation and maintenance guidelines include:

- Inspections and maintenance to ensure that water infiltrates into the subsurface completely (recommended infiltration rate of 72 hours or less) and that vegetation is carefully managed to prevent creating mosquito and other vector habitats.
- Observe drain time for the design storm after completion or modification of the facility to confirm that the desired drain time has been obtained.
- Schedule semiannual inspections for beginning and end of the wet season to identify potential problems such as erosion of the basin side slopes and invert, standing water, trash and debris, and sediment accumulation.
- Remove accumulated trash and debris in the basin at the start and end of the wet season.
- Inspect for standing water at the end of the wet season.
- Trim vegetation at the beginning and end of the wet season to prevent establishment of woody vegetation and for aesthetic and vector reasons.
- Remove accumulated sediment and regrade when the accumulated sediment volume exceeds 10% of the basin.
- If erosion is occurring within the basin, revegetate immediately and stabilize with an erosion control mulch or mat until vegetation cover is established.
- To avoid reversing soil development, scarification or other disturbance should only be performed when there are actual signs of clogging, rather than on a routine basis. Always remove deposited sediments before scarification, and use a hand-guided rotary tiller, if possible, or a disc harrow pulled by a very light tractor.

Cost

Infiltration basins are relatively cost-effective practices because little infrastructure is needed when constructing them. One study estimated the total construction cost at about $2 per feet (adjusted for inflation) of storage for a 0.25-acre basin (SWRPC, 1991). As with other BMPs, these published cost estimates may deviate greatly from what might be incurred at a specific site.

Infiltration basins typically consume about 7 to 20% of the site draining to them, depending on the soil's infiltration rate. Additional space may be required for buffer, landscaping, access road, and fencing. Maintenance costs are estimated at 5 to 10% of construction costs.

One cost concern associated with infiltration practices is the maintenance burden and longevity. If improperly maintained, infiltration basins have a high failure rate. Thus, it may be necessary to replace the basin with a different technology after a relatively short period of time.

In general, Hawaii's unit prices are higher than California's unit prices.

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Design Considerations		
•	Soil for Infiltration	
•	Area Required	
•	Slope	
•	Environmental Side Effects	
Target Constituents		
✓	Sediments	H
✓	Nutrients	H
✓	Trash	H
✓	Metals	H
✓	Bacteria	H
✓	Oil and Grease	H
✓	Organics	H
Legend (Removal Effectiveness)		
L	Low	
M	Medium	
H	High	

Description

Retention/irrigation refers to the capture of storm water runoff in holding pond and subsequent use of the captured volume for irrigation of landscape of natural pervious areas. This technology is very effective as a storm water quality practice; it provides virtually no discharge to receiving waters and high storm water constituent removal efficiencies. This technology mimics natural undeveloped watershed conditions wherein the vast majority of the rainfall volume during smaller rainfall events is infiltrated through the soil profile. Their main advantage over other infiltration technologies is the use of an irrigation system to spread the runoff over a larger area for infiltration. This allows them to be used in areas with low permeability soils.

Capture of storm water can be accomplished in almost any kind of runoff storage facility, ranging from dry, concrete-lined ponds to those with vegetated basins and permanent pools. The pump and wet well should be automated with a rainfall sensor to provide irrigation only during periods when required infiltration rates can be realized. Generally, a spray irrigation system is required to provide an adequate flow rate for distributing the water quality volume (LCRA, 1998).

This technology is still in its infancy and there are no published reports on its effectiveness, cost, or operational requirements. The guidelines presented below should be considered tentative until additional data are available.

Advantages

- Pollutant removal effectiveness is high, accomplished primarily by:
  - Sedimentation in the primary storage facility.
  - Physical filtration of particulates through the soil profile.
  - Dissolved constituents uptake in the vegetative root zone by the soil-resident microbial community.
- The hydrologic characteristics of this technique are effective for simulating pre-developed watershed conditions through:
  - Containment of higher frequency flood volumes.
  - Reduction of flow rates and velocities for erosive flow events.

- Pollutant removal rates are estimated to be nearly 100% for all pollutants in the captured and irrigated storm water volume. However, relatively frequent inspection and maintenance is necessary to assure proper operation of these facilities.
- This technology is particularly appropriate for areas with infrequent rainfall because the system is not required to operate often and the ability to provide storm water for irrigation can reduce demand on surface and groundwater supplies.

Limitations

- Retention/irrigation is a relatively expensive technology due primarily to mechanical systems, power requirements, and high maintenance needs.
- Due to the relative complexity of irrigation systems, they must be inspected and maintained at regular intervals to ensure reliable system function.
- Retention/irrigation systems use pumps requiring electrical energy inputs (which cost money, create pollution, and can be interrupted). Mechanical systems are also more complex, requiring skilled maintenance, and they are more vulnerable to vandalism than simpler, passive systems.
- Retention/irrigation systems require open space for irrigation and thus may be difficult to retrofit in urban areas.
- Effective use of retention/irrigation requires some form of pre-treatment of runoff flows (i.e., sediment forebay or vegetated filter) to remove coarse sediment and to protect the long-term operating capacity of the irrigation equipment.
- Retention/irrigation BMPs capture and store water that, depending on design may be accessible to mosquitoes and other vectors for breeding.

Design and Sizing Guidelines

- Runoff Storage Facility Configuration and Sizing - Design of the runoff storage facility is flexible as long as the water quality volume and an appropriate pump and wet well system can be accommodated.
- Pump and Wet Well System - A reliable pump, wet well, and rainfall or soil moisture sensor system should be used to distribute the water quality volume. These systems should be similar to those used for wastewater effluent irrigation, which are commonly used in areas where “no discharge” wastewater treatment plant permits are issued.
- Detention Time - The irrigation schedule should allow for complete drawdown of the water quality volume within a minimum of 36 to 48 hours, as required by the City Drainage Rules. Irrigation should not begin within 12 hours of the end of rainfall so that direct storm runoff has ceased and soils are not saturated. Consequently, the length of the active irrigation period is 60 hours. The irrigation should include a cycling factor of ½, so that each portion of the area will be irrigated for only 30 hours during the total of 60 hours allowed for disposal of the water quality volume. Irrigation also should not occur during subsequent rainfall events.
- Irrigation System - Generally a spray irrigation system is required to provide an adequate flow rate for timely distribution of the water quality volume.
- Designs that utilize covered water storage should be accessible to vector control personnel via access doors to facilitate vector surveillance and control if needed.

- Irrigation Site Criteria – The area selected for irrigation must be pervious, on slopes of less than 10%. A geological assessment is required for proposed irrigation areas to assure that there is a minimum of 12 inches of soil cover. Rocky soils are acceptable for irrigation; however, the coarse material (diameter greater than 0.5 inches) should not account for more than 30% of the soil volume. Optimum sites for irrigation include recreational and greenbelt areas as well as landscaping in commercial developments. The storm water irrigation area should be distinct and different from any areas used for wastewater effluent irrigation. Finally, the area designated for irrigation should have at least a 100-foot buffer from wells, septic systems, and natural wetlands.
- Irrigation Area – The irrigation rate must be low enough so that the irrigation does not produce any surface runoff; consequently, the irrigation rate may not exceed the permeability of the soil. The minimum required irrigation area should be calculated using the following formula:

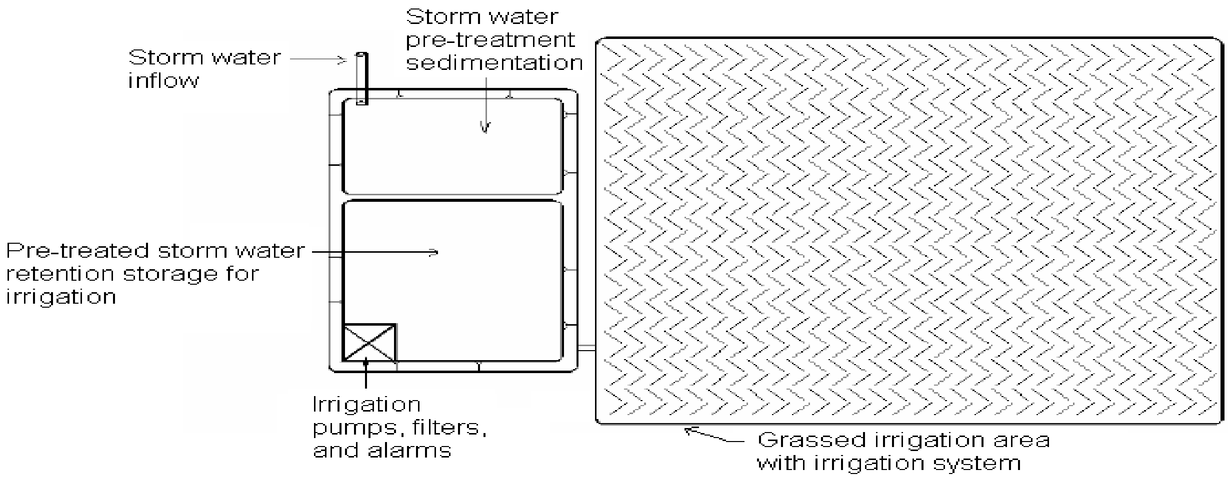
$$A = \frac{12V}{(T)(r)}$$

Where:

A = area required for irrigation ($feet^2$)
V = water quality volume ($feet^3$)
T = period of active irrigation (30 hours)
r = permeability (inch/hour)

- The permeability of the soils in the area proposed for irrigation should be determined using a double ring infiltrometer (ASTM D 3385-94) or from county soil surveys prepared by the Natural Resource Conservation Service. If a range of permeability is reported, the average value should be used in the calculation. If no permeability data is available, a value of 0.1 inches/hour should be assumed.
- It should be noted that the minimum area requires intermittent irrigation over a period of 60 hours at low rates to use the entire water quality volume. This intensive irrigation may be harmful to vegetation that is not adapted to long periods of wet conditions. In practice, a much larger irrigation area will provide better use of the retained water and promote a healthy landscape.
- A conceptual layout of a retention/irrigation basin is illustrated in the figure that follows.

Retention/Irrigation Basin



Performance

This technology is still in its infancy and there are no published reports on its effectiveness, cost, or operational requirements.

Siting Criteria

Capture of storm water can be accomplished in almost any kind of runoff storage facility, ranging from dry, concrete-lined ponds to those with vegetated basins and permanent pools. Siting is contingent upon the type of facility used.

Additional Design Guidelines

Minimum Design Criteria for the Irrigation System

- Irrigation Timing: The detention basin must be emptied within 48 to 86 hours after a rain event ends (City Drainage Rules). Irrigation must be initiated no sooner than 12 hours after the rain event ceases. The irrigation controller must be set to provide alternating, equivalent irrigation and rest periods until the basin is emptied. The time of irrigation on any area must not exceed the rest time. Continuous application on any area must not exceed 2 hours. Division of the irrigation area into two or more sections such that irrigation occurs alternately in each section is an acceptable way to meet the requirement for a rest period.
- Irrigation Rate: The rate at which the soil can accept the irrigated storm water must be derived from the permeability listed in the US Department of Agriculture National Resources Conservation Service Soil Survey for the county, location, and soil type verified to be present at the irrigation site. If a range is given, the minimum permeability rate is to be used, not to be less than .03 inches/hour.
- Irrigation Area: Calculations must be provided which demonstrate that adequate irrigation area will be provided based on the application rate, soil permeability, water quality volume, and the actual irrigation time. For publicly maintained facilities the irrigation area and system must be included within the water quality easement.
- Irrigation Area Slope: Irrigation must not occur on land with slopes greater than 10%.

- Piping and Valves.
  - All irrigation system distribution and lateral piping (i.e., from the pumps to the spray heads) must be Schedule 80 PVC. All pipes and electrical bundles passing beneath driveways or paved areas must be sleeved with PVC Class 200 pipe with solvent welded joints. Sleeve diameter must equal twice that of the pipe or electrical bundle.
  - Valves: All valves must be designed specifically for sediment bearing water, and be of appropriate design for the intended purpose. All remote control, gate, and quick coupling valves must be located in ten-inch or larger plastic valve boxes. All pipes and valves must be marked to indicate that they contain non-potable water. All piping must be buried to protect it from weather and vandalism. The depth and method of burial must be adequate to protect the pipe from vehicular traffic such as maintenance equipment. Velocities in all pipelines should be sufficient to prevent settling of solids. The irrigation design and layout must be integrated with the tree protection plan and presented as part of the Site Plan or Subdivision Construction Plan.
  - Systems must include a plug valve to allow flushing at the end of every line.
- Sprinklers: All sprinkler heads must have full or partial circle rotor pop-up heads and must be capable of delivering the required rate of irrigation over the designated area in a uniform manner. Irrigation must not occur beyond the limits of the designated irrigation area. Partial circle sprinkler heads must be used as necessary to prevent irrigation beyond the designated limits. Sprinkler heads must be capable of passing solids that may pass through the intake. Sprinkler heads must be flush mounted and encased within a 2 feet by 2 feet concrete housing capable of protecting the head from mowing and service equipment.
- Vegetation: The irrigation area must have native vegetation or be restored or re-established with native vegetation. These areas must not receive any fertilizers, pesticides, or herbicides. For publicly maintained systems, fencing or signs must be installed to limit unauthorized use of the irrigation area. If signs are installed they must include the phrase “Storm Water Irrigation Area – No Trespassing.”
- Soil: A minimum of 12 inches of soil, with the identified permeability rates, must be present in the irrigation area. Soil enhancement is allowed to achieve this requirement. A soils report must be provided and must include at a minimum a soils map verifying soil types in the irrigation area, permeability rates, soil depths, percent of coarse fragments gravel size (2.0-mm diameter) and larger, found on the soil surface and in the subsurface soils, depth of roots, locations of borings or trenches, photographs of exposed soils, location and type of soil enhancement performed, soils testing results, etc. A site visit may be conducted by the City to confirm soil conditions, including when representative trenches have been opened or borings are being conducted.
- Geological Features: The irrigation area must not contain any Critical Environmental Feature Buffer Zones.
- Irrigation Area Buffer: A buffer area of non-irrigated vegetation must be provided downstream of the irrigation area to treat any runoff that may occur from the irrigation area during heavy rainfall or from excessive irrigation. This area must be a minimum of 50 feet in length (in the direction of flow) and be adjacent to all downstream edges of the irrigation area. As an option, a diversion system (i.e., a swale or berm) may be provided to route any runoff to the retention basin. This diversion system must be designed to carry the runoff from the 2-year storm. Alternatively, the irrigation area may be located upstream from the development such that any runoff will be routed to the retention pond.

Maintenance

Relatively frequent inspection and maintenance is necessary to verify proper operation of these facilities. Some maintenance concerns are specific to the type or irrigation system practice used.

BMPs that store water can become a nuisance due to mosquito and other vector breeding. Preventing mosquito access to standing water sources in BMPs (particularly below-ground) is the best prevention plan, but can prove challenging due to multiple entrances and the need to maintain the hydraulic integrity of the system. Reliance on electrical pumps is prone to failure and in some designs (i.e., sumps, vaults) may not provide complete dewatering, both which increase the chances of water standing for over 72 hours and becoming a breeding place for vectors. BMPs that hold water for over 72 hours and/or rely on electrical or mechanical devices to dewater may require routine inspections and treatments by local mosquito and vector control agencies to suppress mosquito production. Open storage designs such as ponds and basins (see appropriate fact sheets) will require routine preventative maintenance plans and may also require routine inspections and treatments by local mosquito and vector control agencies.

Cost

This technology is still in its infancy and there are no published reports on its effectiveness, cost, or operational requirements. However, O&M costs for retention-irrigation systems are high compared to virtually all other storm water quality control practices because of the need for: (1) frequent inspections; (2) the reliance on mechanical equipment; and (3) power costs.

In general, Hawaii's unit prices are higher than California's unit prices.

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Photo Source: Retention Pond Services, Inc. http://www.retentionponds.com.

Design Considerations		
•	Area Required	
•	Slope	
•	Adjacent Runoff	
•	Traffic Loads	
•	Maintenance	
Target Constituents		
✓	Sediments	H
✓	Nutrients	H
✓	Trash	L
✓	Metals	H
✓	Bacteria	H
✓	Oil and Grease	H
✓	Organics	H
Legend (Removal Effectiveness)		
L	Low	
M	Medium	
H	High	

Description

Pervious, or porous pavement, is a permeable pavement surface, often built with an underlying stone reservoir that temporarily stores surface runoff before it infiltrates into the subsoil. Pervious paving is used for light vehicle loading in parking areas, replacing traditional pavement, and allowing parking lot storm water to infiltrate directly and receive water quality treatment. From the surface, porous asphalt and pervious concrete appear to be the same as traditional pavement. However, instead of having fine material as in traditional pavement, porous pavement contains air voids that encourage infiltration.

Porous asphalt pavement consists of an open-graded coarse aggregate, bonded together by asphalt cement, with sufficient interconnected voids to make it highly permeable to water, creating a system of a durable, load-bearing surface with an underlying layered structure that temporarily stores water before infiltration or drainage to a controlled outlet. Pervious concrete typically consists of specially formulated mixtures of Portland cement, uniform, open-graded coarse aggregate, and water. Pervious concrete has enough void space to allow rapid percolation of liquids through the pavement. Grass or permeable pavers consist of interlocking concrete blocks or synthetic fibrous grids having voids filled with grass, sand, or gravel, permitting water to infiltrate across the entire surface of the material (see TC-10). While porous pavement can be a highly effective treatment practice, maintenance and proper installation are necessary to ensure its long-term effectiveness.

Attenuation of flow is provided by the storage within the underlying structure or sub base, together with appropriate flow controls. An underlying geotextile may permit groundwater recharge, thus contributing to the restoration of the natural water cycle. Alternatively, where infiltration is inappropriate (i.e., if the groundwater vulnerability is high, or the soil type is unsuitable), the surface can be constructed above an impermeable membrane. The system offers a valuable solution for drainage of spatially constrained urban areas.

Significant attenuation and improvement in water quality can be achieved by permeable pavements, whichever method is used. The surface and subsurface infrastructure can remove both the soluble and fine particulate pollutants that occur within urban runoff. Roof water can be piped into the storage area directly, adding areas from which the flow can be attenuated. Also, within lined systems, there is the opportunity for stored runoff to be piped out for reuse.

Advantages

Advantages of pervious pavements are that they reduce runoff volume while providing treatment, and are unobtrusive resulting in a high level of acceptability.

Like all BMPs, porous pavement should be combined with other practices to capitalize on each technology's benefits and to allow protection in case of BMP failure. However, construction using pervious materials may not require as much treatment as other BMP approaches. For instance, a small facility using porous pavement may only need several bioretention basins or a grass swale, rather than a full dry detention basin. This combined approach might prove less land intensive and more cost effective. It may increase the amount of open space for public or tenant use. It may also lead to an increase in environmental benefits.

Limitations

The use of permeable pavement may be restricted in cold regions, arid regions or regions with high wind erosion. There are some specific disadvantages associated with permeable pavement, which are as follows:

- Permeable pavement can become clogged if improperly installed or maintained. However, this is countered by the ease with which small areas of paving can be cleaned or replaced when blocked or damaged.
- When using un-lined, infiltration systems, there is some risk of contaminating groundwater, depending on soil conditions and aquifer susceptibility. However, this risk is likely to be small because the areas drained tend to have inherently low pollutant loadings.
- The use of permeable pavement is restricted to gentle slopes. The bottom of the stone reservoir should be flat, such that runoff can infiltrate through the entire surface.
- Porous block paving has a higher risk of abrasion and damage than solid blocks.

Design and Sizing Guidelines

If the grades, sub-soils, drainage characteristics, and groundwater conditions are suitable, permeable paving may be substituted for conventional pavement on parking areas, cul-de-sacs and other areas with light traffic. Storm water retrofits may also be considered. A storm water retrofit is a storm water management practice (usually structural) installed post-development to improve water quality, protect downstream channels, reduce flooding, or to meet other specific objectives. The best retrofit application for porous pavement is parking lot replacement on individual sites. If many impervious lots are replaced with porous pavement, the overall storm water peak flows can be reduced.

Slopes should be flat or very gentle. Ideally, the pervious surface should be horizontal in order to intercept local rainfall at source. On sloping sites, pervious surfaces may be terraced to accommodate differences in levels.

Soils need to have a permeability of at least 0.5 inches per hour. Soil permeability requirements should be determined by a licensed engineer.

Scottish experience has shown that permeable paving systems can be installed in a wide range of ground conditions, and the flow attenuation performance is excellent even when the systems are lined. The suitability of a pervious system at a particular pavement site will, however, depend on the loading criteria required of the pavement. If porous pavement is used near an industrial site or similar area, the pavement should be sited at least 2 to 5 feet above the seasonally high ground water table and at least 100 feet away from drinking water wells. Porous pavement should be sited on low to medium traffic areas, such as residential roads and parking lots.

Where the system is to be used for infiltrating drainage waters into the ground, the vulnerability of local groundwater sources to pollution from the site should be low, and the seasonal high water table should be at least 3 feet below the invert of the reservoir layer.

Performance

Porous pavement can be used to provide ground water recharge and to reduce pollutants in storm water runoff. Some data suggest that as much as 70 to 80% of annual rainfall will go toward ground water recharge (Gburek and Urban, 1980). These data will vary depending on design characteristics and underlying soils. Two studies have been conducted on the long-term pollutant removal of porous pavement, both in the Washington, DC area. They suggest high pollutant removal, although it is difficult to extrapolate these results to all applications of the practice. The results of the studies are presented in the table that follows.

Effectiveness of Porous Pavement Pollutant Removal

Study	Pollutant Removal (%)				
	TSS	TP	TN	COD	Metals
Prince William, VA	82	65	80	-	-
Rockville, MD	95	65	85	82	98.99

A third study by Brattebo and Booth (2003) indicates that many trademarked permeable paver systems effectively reduced concentrations of motor oil, copper, and zinc. Furthermore, the study found that almost all precipitation that fell on the permeable pavers infiltrated even after six (6) years of daily use as a parking area.

Siting Criteria

Their application should be limited to highways with low traffic volumes, axle loads and speeds (less than 30 miles per hour limit), car parking areas and other lightly trafficked or non-trafficked areas. Permeable surfaces are currently not considered suitable for adoptable roads due to the risks associated with failure on high speed roads, the safety implications of ponding, and disruption arising from reconstruction.

Since porous pavement is an infiltration practice, it should not be applied at storm water hotspots because of the potential for groundwater contamination. Storm water hot spots are areas where land use/activities generate highly contaminated runoff. Hot spot runoff frequently contains pollutant concentrations exceeding those typically found in storm water. Hot spots include, (but are not limited to) commercial nurseries, auto recycle facilities, fueling stations, storage areas, industrial rooftops, marinas, outdoor liquid storage containers, outdoor loading and unloading facilities, public works storage areas, hazardous materials generators, (if containers are exposed to rainfall), vehicle service and maintenance areas, and vehicle and equipment washing and steam cleaning facilities.

Design Guidelines

The design of each layer of the pavement must be determined by the likely traffic loadings and their required operational life. To provide satisfactory performance, the following criteria should be considered:

- The subgrade should be able to sustain traffic loading without excessive deformation.
- The granular capping and sub-base layers should give sufficient load-bearing to provide an adequate construction platform and base for the overlying pavement layers.
- The pavement materials should not crack or suffer excessive rutting under the influence of traffic. This is controlled by the horizontal tensile stress at the base of these layers.

There is no current structural design method specifically for pervious pavements. Allowances should be considered the following factors in the design and specification of materials:

- Pervious pavements use materials with high permeability and void space. All the current UK pavement design methods are based on the use of conventional materials that are dense and relatively impermeable. The stiffness of the materials must therefore be assessed.
- Water is present within the construction and can soften and weaken materials, and this must be allowed for.
- Existing design methods assume full friction between layers. Any geotextiles or geomembranes must be carefully specified to minimize loss of friction between layers.
- Porous asphalt loses adhesion and becomes brittle as air passes through the voids. Its durability is therefore lower than conventional materials.

The single sized grading of materials used means that care should be taken to ensure that loss of finer particles between unbound layers does not occur.

Positioning a geotextile near the surface of the pervious construction should enable pollutants to be trapped and retained close to the surface of the construction. This has both advantages and disadvantages. The main disadvantage is that the filtering of sediments and their associated pollutants at this level may hamper percolation of waters and can eventually lead to surface ponding. One (1) advantage is that even if eventual maintenance is required to reinstate infiltration, only a limited amount of the construction needs to be disturbed, since the sub-base below the geotextile is protected. In addition, the pollutant concentration at a high level in the structure allows for its release over time. It is slowly transported in the storm water to lower levels where chemical and biological processes may be operating to retain or degrade pollutants.

The design should ensure that sufficient void space exists for the storage of sediments to limit the period between remedial works. The following should be taken into account:

- Pervious pavements require a single size grading to give open voids. The choice of materials is therefore a compromise between stiffness, permeability and storage capacity.
- Because the sub-base and capping will be in contact with water for a large part of the time, the strength and durability of the aggregate particles when saturated and subjected to wetting and drying should be assessed.
- A uniformly graded single size material cannot be compacted and is liable to move when construction traffic passes over it. This effect can be reduced by the use of angular crushed rock material with a high surface friction.

In pollution control terms, these layers represent the site of long term chemical and biological pollutant retention and degradation processes. The construction materials should be selected, in addition to their structural strength properties, for their ability to sustain such processes. In general, this means that materials should create neutral or slightly alkaline conditions and they should provide favorable sites for colonization by microbial populations.

Some basic features should be incorporated into all porous pavement practices. These design features can be divided into five basic categories: pretreatment, treatment, conveyance, maintenance reduction, and landscaping.

- Pretreatment: In porous pavement designs, the pavement itself acts as pretreatment to the stone reservoir below. Because of this, frequent maintenance of the surface, such as sweeping, is critical to prevent clogging. A layer of fine gravel can be laid atop the coarse gravel treatment reservoir as an additional pretreatment item. Both of these pretreatment measures are marginal
- Treatment: If used, the stone reservoir below the pavement surface should be composed of layers of small stone laid directly below the pavement surface. The stone bed below the permeable surface should be sized to attenuate storm flows for the storm event to be treated. Typically, porous pavement is sized to treat a small event, such as a water quality storm (i.e., the storm that will be treated for pollutant removal), which can range from 0.5 to 1.5 inches. As in infiltration trenches, water can be stored in the voids of the stone reservoir. With certain designs in warm weather climates, the pavement can also store storm water if it is properly maintained.
- Conveyance: Water conveyed to the stone reservoir though the pavement surface infiltrates into the ground below. A geosynthetic liner and a sand layer may be placed below the stone reservoir to prevent preferential flow paths and to maintain a flat bottom. Designs also need a means to convey larger amounts of storm water to the storm drain system. Storm drain inlets set slightly above the pavement surface is one option. This allows for some ponding above the surface, but bypasses flows too large to be treated by the system or when the surface clogs.
- Maintenance Reduction: One nonstructural component that can help ensure proper maintenance of porous pavement is a carefully worded maintenance agreement providing specific guidance, including how to conduct routine maintenance and how the surface should be repaved. Ideally, signs should be posted on the site identifying porous pavement areas. One design option incorporates an "overflow edge," which is a trench surrounding the edge of the pavement. The trench connects to the stone reservoir below the pavement surface. Although this feature does not in itself reduce maintenance requirements, it acts as a backup in case the surface clogs. If the surface clogs, storm water will flow over the surface and into the trench where some infiltration and treatment will occur.
- Landscaping: For porous pavement, the most important landscaping feature is a fully stabilized upland drainage. Reducing sediment loads entering the pavement can help to prevent clogging.

Construction/Inspection Considerations

- Permeable surfaces can be laid without cross-falls or longitudinal gradients.
- The blocks should be lain level.
- They should not be used for storage of site materials, unless the surface is well protected from deposition of silt and other spillages.

- The pavement should be constructed in a single operation, as one of the last items to be built, on a development site. Landscape development should be completed before pavement construction to avoid contamination by silt or soil from this source.
- Surfaces draining to the pavement should be stabilized before construction of the pavement.
- Inappropriate construction equipment should be kept away from the pavement to prevent damage to the surface, sub-base or sub-grade.

Maintenance

The maintenance requirements of a pervious surface should be reviewed at the time of design and should be clearly specified. Maintenance is required to prevent clogging of the pervious surface. The factors to be considered when defining maintenance requirements must include:

- Type of use.
- Level of trafficking.
- The local environment and any contributing catchments.
- Ownership: Owners should be aware of a site's porous pavement because failure to perform maintenance is a primary reason for failure of this practice. Furthermore, using knowledgeable contractors skilled in techniques required for installation of pervious concrete, permeable pavers, or porous asphalt will increase performance and longevity of the system. Typical requirements are shown in the table below.

Typical Maintenance Activities for Porous Pavements

Activity	Schedule
Do not seal or repave on non-porous materials.	N/A
Ensure that paving area is clean of debris. Ensure that paving dewaters between storms. Ensure that the area is clean of sediments.	Monthly
Mow upland and adjacent areas and seed bare areas. Vacuum sweep frequently to keep the surface free of sediment.	As needed (typically 3-4 times per year)
Inspect the surface for deterioration.	Annually

Studies in the UK have shown satisfactory operation of porous pavement systems without maintenance for over 10 years and recent work by Imbe et al. at 9th ICUD, Portland, 2002 describes systems operating for over 20 years without maintenance. However, performance under such regimes could not be guaranteed, the following table shows typical recommended maintenance regimes.

Typical Recommended Maintenance Regimes

Activity	Schedule
• Minimize use of salt or grit for de-icing. • Keep landscaped areas well maintained. • Prevent soil being washed onto pavement.	Ongoing
• Vacuum clean surface using commercially available sweeping machines at the following times: ▪ End of winter (April) ▪ Mid-summer (July/August) ▪ After Autumn leaf-fall (November)	2/3 times per year
• Inspect outlets.	Annual
• If routine cleaning does not restore infiltration rates, then reconstruction of part of the whole of a pervious surface may be required. • The surface area affected by hydraulic failure should be lifted for inspection of the internal materials to identify the location and extent of the blockage. • Surface materials should be lifted and replaced after brush cleaning. Geotextiles may need complete replacement. • Sub-surface layers may need cleaning and replacing. • Removed silts may need to be disposed of as controlled waste.	As needed (infrequent) Maximum 15-20 years

Cost

While porous pavement itself is more expensive than traditional asphalt (depending on design, traditional asphalt and concrete can cost between \$0.50 to \$3.00 per feet^2 while porous pavement can range from \$2 to \$8 per feet^2), when used in combination with other techniques, it may eliminate or reduce the need for land intensive BMPs, and generate savings associated with decreased land consumption and underground pipework. Because of this, permeable pavements are up to 25% cheaper (or at least no more expensive than the traditional forms of pavement construction), when all construction and drainage costs are taken into account. (Accepting that the porous asphalt itself is a more expensive surfacing, the extra cost of which is offset by the savings in underground pipework etc) (Niemczynowicz, et al., 1987)

The next table gives US cost estimates for capital and maintenance costs of porous pavements (Landphair et al., 2000).

Engineer's Estimate for Porous Pavement

Item	Units	Price	Cycles/ Years	Quantity 1 acre WS	Total	Quantity 2 Acres WS	Total	Quantity 3 Acres WS	Total	Quantity 4 Acres WS	Total	Quantity 5 Acres WS	Total
Porous Pavement													
Grading	SY	$2	-	604	$1,208	1209	$2,418	1812	$3,624	2419	$4,838	3020	$6,040
Paving	SY	$19	-	212	$4,028	424	$8,056	636	$12,084	848	$16.112	1060	$20,140
Excavation	CY	$4	-	201	$724	403	$1,451	604	$2,174	806	$2,902	1008	$3,629
Filter Fabric	SY	$1	-	700	$805	1400	$1,610	2000	$2,300	2800	$3,220	3600	$4,140
Stone Fill	CY	$16	-	201	$3,216	403	$6,448	604	$9,664	806	$12,896	1008	$16,128
Sand	CY	$7	-	100	$700	200	$1,400	300	$2,100	400	$2,800	500	$3,500
Sight Wall	EA	$300	-	2	$600	3	$900	4	$1,200	7	$2,100	7	$2,100
Seeding	LF	$0	-	64	$32	1288	$64	1932	$97	2576	$129	3220	$161
Check Dam	CY	$35	-	0	$0	0	$0	0	$0	0	$0	0	$0
Total Construction Costs					$11,313		$22,347		$33,243		$44,996		$55,838
Construction Cost Amortized for 20 Years					$505		$996		$1,481		$2,008		$2,490
Annual Maintenance Expense													
Item	**Units**	**Price**	**Cycles/ Years**	**Quantity 1 acre WS**	**Total**	**Quantity 2 Acres WS**	**Total**	**Quantity 3 Acres WS**	**Total**	**Quantity 4 Acres WS**	**Total**	**Quantity 5 Acres WS**	**Total**
Sweeping	AC	$250	6	1	$1,500	2	$3,000	3	$4,500	4	$6,000	5	$7,500
Washing	AC	$250	6	1	$1,500	2	$3,000	3	$4,500	4	$6,000	5	$7,500
Inspection	MH	$20	5	5	$500	5	$500	5	$500	5	$500	5	$500
Deep Clean	AC	$450	0.5	1	$225	2	$225	3	$675	3.9	$878	5	$1,125
Total Annual Maintenance Expense					$3,725		$6,950		$10,175		$13,378		$16,625

Source: Texas Transportaion Institute 2000

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Design Considerations
• Area Required
• Slope
• Water Availability
• Aesthetics
• Environmental Side Effects

Target Constituents		
✓	Sediments	H
✓	Nutrients	M
✓	Trash	H
✓	Metals	H
✓	Bacteria	H
✓	Oil and Grease	H
✓	Organics	H

Legend (Removal Effectiveness)	
L	Low
M	Medium
H	High

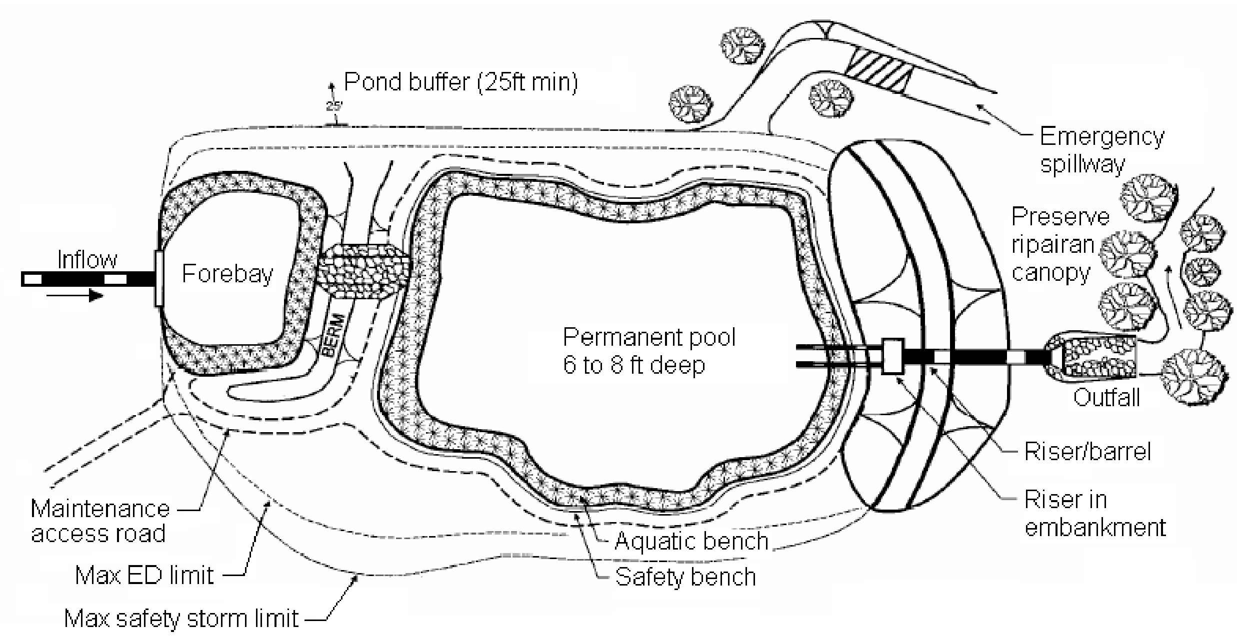
Description

Wet ponds (a.k.a. small storm water ponds, retention ponds, wet extended detention ponds) are constructed basins that have a permanent pool of water throughout the year (or at least throughout the wet season) and differ from constructed wetlands primarily in having a greater average depth. Ponds treat incoming storm water runoff by settling and biological uptake. The primary removal mechanism is settling as storm water runoff resides in this pool, but pollutant uptake, particularly of nutrients, also occurs to some degree through biological activity in the pond. Wet ponds are among the most widely used storm water practices. While there are several different versions of the wet pond design, the most common modification is the extended detention wet pond, where storage is provided above the permanent pool in order to detain storm water runoff and promote settling. The schematic diagram is of an on-line pond that includes detention for larger events, but this is not required in all areas of the state.

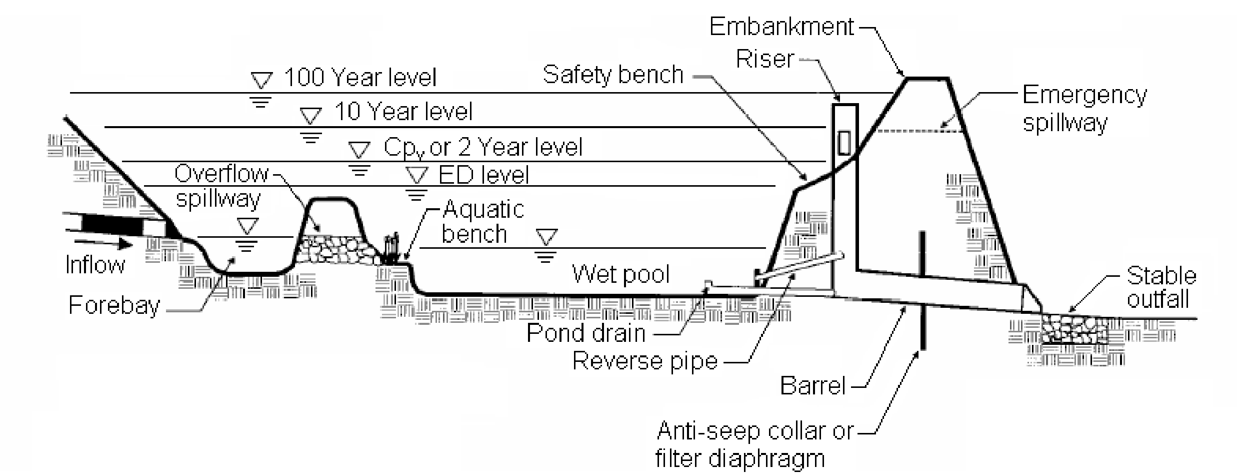
The design, construction and maintenance of wet detention ponds shall comply with all federal, state, and City and County of Honolulu, rules or regulations. The owner/operator is responsible for securing required permits. This standard does not contain the text of any federal, state or city governing wet detention ponds. The volume of the wet ponds are based on a 1-year storm, versus the 2-year 1-inch runoff design volume for city detention pond design criteria under the City Drainage Rules. The drainage area should be less than five (5) acres. The next figure illustrates a conceptual wet pond layout.

The location and use of wet detention ponds may be limited by regulations relating to storm water management, navigable waters (Hawaii Administrative Rules Chapter 11-54 Water Quality), floodplains, wetlands, buildings, wells and other structures, or by land uses such as waste disposal sites and airports. The pond embankment may be regulated as a dam under HRS 179.D (HAR Chapter 13-190D Dams and Reservoirs).

Conceptual Wet Pond Layout



PLAN VIEW



PROFILE

Note: If maximum storage capacity is > 15 acres/ft, Hawaii Dam Safety Rules Apply.
If dam height is > 6 feet then the Hawaii Dam Safety Rules Apply.

Advantages

- If properly designed, constructed and maintained, wet basins can provide substantial aesthetic/ recreational value and wildlife and wetlands habitat.
- Ponds are often viewed as a public amenity when integrated into a park setting.
- Due to the presence of the permanent wet pool, properly designed and maintained wet basins can provide significant water quality improvement across a relatively broad spectrum of constituents including dissolved nutrients.
- Widespread application with sufficient capture volume can provide significant control of channel erosion and enlargement caused by changes to flow frequency relationships resulting from the increase of impervious cover in a watershed.

Limitations

- Some concern about safety when constructed where there is public access.
- Mosquito and midge breeding is likely to occur in ponds.
- Cannot be placed on steep unstable slopes.
- Need for base flow or supplemental water if water level is to be maintained.
- Require a relatively large footprint.
- Depending on volume and depth, pond designs may require approval from the State Department of Land and Natural Resources Engineering Division, Hawaii Dam Safety Program. (HAR Chapter 13-190 Dams and Reservoirs).

Design and Sizing Guidelines

- Capture volume determined by City requirements.
- Use a draw down time of 48 hours in most areas. Draw down times in excess of 48 hours may result in vector breeding, and should be used only after coordination with local vector control authorities. Draw down times of less than 48 hours should be limited to BMP drainage areas with coarse soils that readily settle and to watersheds where warming may be detrimental to downstream marine environment.
- Permanent pool volume equal to twice the water quality volume.
- Water depth not to exceed about 8 feet.
- Wetland vegetation occupying no more than 25% of surface area.
- Include energy dissipation in the inlet design and a sediment forebay to reduce re-suspension of accumulated sediment and facilitate maintenance.
- A maintenance ramp should be included in the design to facilitate access to the forebay for maintenance activities and for vector surveillance and control.
- To facilitate vector surveillance and control activities, road access should be provided along at least one side of BMPs that are 20 feet or less in width. Those BMPs that have shoreline-to-shoreline distances in excess of 20 feet should have perimeter road access on both sides or be designed such that no parcel of water is greater than 20 feet from the road.

Construction/Inspection Considerations

- In areas with porous soils an impermeable liner may be required to maintain an adequate permanent pool level.
- Outlet structures and piping should be installed with collars to prevent water from seeping through the fill and causing structural failure.
- Inspect facility after first large storm to determine whether the desired residence time has been achieved.

Performance

The observed pollutant removal of a wet pond is highly dependent on two factors: the volume of the permanent pool relative to the amount of runoff from the typical event in the area and the quality of the base flow that sustains the permanent pool. A recent study (Caltrans, 2002) has documented that if the permanent pool is much larger than the volume of runoff from an average event, then displacement of the permanent pool by the wet weather flow is the primary process. A statistical comparison of the wet pond discharge quality during dry and wet weather shows that they are not significantly different. Consequently, there is a relatively constant discharge quality during storms that is the same as the concentrations observed in the pond during ambient (dry weather) conditions. Consequently, for most constituents the performance of the pond is better characterized by the average effluent concentration, rather than the “percent reduction,” which has been the conventional measure of performance. Since the effluent quality is essentially constant, the percent reduction observed is mainly a function of the influent concentrations observed at a particular site.

The dry and wet weather discharge quality is, therefore, related to the quality of the base flow that sustains the permanent pool and of the transformations that occur to those constituents during their residence in the basin. One could potentially expect a wide range of effluent concentrations at different locations even if the wet ponds were designed according to the same guidelines, if the quality of the base flow differed significantly. This may explain the wide range of concentration reductions reported in various studies.

Concentrations of nutrients in base flow may be substantially higher than in urban storm water runoff. Even though these concentrations may be substantially reduced during the residence time of the base flow in the pond, when this water is displaced by wet weather flows, concentrations may still be quite elevated compared to the levels that promote eutrophication in surface water systems. Consequently comparing influent and effluent nutrient concentrations during wet weather can make the performance seem highly variable.

Relatively small perennial flows may often substantially exceed the wet weather flow treated. Consequently, one should also consider the load reduction observed under ambient conditions when assessing the potential benefit to the receiving water.

Water Quality

(Reference: US EPA 840-B-92-002 Guidance Specifying Management Measures for sources on Nonpoint Pollution in Coastal Waters)– Pollutant reduction (Total Suspended Solids (TSS) and Phosphorus) is a function of the permanent pool area and depth, the outlet structure and the active storage volume. The following criteria apply:

- Permanent Pool – The elevation below which runoff volume is not discharged and particles are stored.

- Design ponds to include a permanent pool of water. The surface area of the permanent pool is measured at the invert of the lowest outlet. The minimum surface area of the permanent pool must address the total drainage area to the pond.
- The permanent pool surface area is sized based on the particle size and the peak outflow during the 1-yr., 24-hour design storm using the equation that follows:

$$S_a = 1.2 \frac{q_0}{v_s} \qquad \textit{[Equation 1(a)]}$$

Or

$$q_0 = \frac{(v_s)(S_a)}{1.2} \qquad \textit{[Equation 1(b)]}$$

Where:

S_a = permanent pool surface area measured at the invert of the lowest outlet of the wet detention pond ($feet^2$)

q_o = post-construction peak overflow ($feet^3$/second)

v_s = particle settling velocity (feet/second)

1.2 = USEPA recommended safety factor

- Particle settling velocities (v_s) shall be based on representative particle sizes for the desired percent TSS reduction.
  - 80% (3 micron): vs = 1.91 x 10-5 feet/second
  - 60% (6 micron): vs = 7.37 x 10-5 feet/second
  - 40% (12 micron): vs = 2.95 x 10-4 feet/second
- Note: Particle settling velocities were calculated assuming a specific gravity of 2.5, a water temperature of 50° Fahrenheit (10°Celsius), and a kinematic viscosity of 0.01308 $centimeter^2$/second (0.0020 $inch^2$/second). (Pitt, 2002). The calculations also assume discrete and quiescent settling conditions per Stoke's Law.

Siting Criteria

Wet ponds are a widely applicable storm water management practice and can be used over a broad range of storm frequencies and sizes, drainage areas and land use types. Although they have limited applicability in highly urbanized settings and in arid climates, they have few other restrictions. Wet basins may be constructed on- or off-line and can be sited at feasible locations along established drainage ways with consistent base flow. An off-line design is preferred. Wet basins are often utilized in smaller sub-watersheds and are particularly appropriate in areas with residential land uses or other areas where high nutrient loads are considered to be potential problems (i.e., golf courses).

Ponds do not consume a large area (typically 2 to 3% of the contributing drainage area); however, these facilities are generally large. Other practices, such as filters or swales, may be "squeezed" into relatively unusable land, but ponds need a relatively large continuous area. Wet basins are typically used in drainage basins of more than ten acres and less than one square mile (Schueler et al., 1992). Emphasis can be placed in siting wet basins in areas where the pond can also function as an aesthetic amenity or in conjunction with other storm water management functions.

Wet basin application is appropriate in the following settings: (1) where there is a need to achieve a reasonably high level of dissolved contaminant removal and/or sediment capture; (2) in small to medium-sized regional tributary areas with available open space and drainage areas greater than about 10 hectares (25 acres.); (3) where base flow rates or other channel flow sources are relatively consistent year-round; (4) in residential settings where aesthetic and wildlife habitat benefits can be appreciated and maintenance activities are likely to be consistently undertaken.

Traditional wet extended detention ponds can be applied in most regions of the United States, with the exception of arid climates. In arid regions, it is difficult to justify the supplemental water needed to maintain a permanent pool because of the scarcity of water. Even in semi-arid Austin, Texas, one study found that 2.6 acre-feet per year of supplemental water was needed to maintain a permanent pool of only 0.29 acre-feet (Saunders and Gilroy, 1997). Seasonal wet ponds (i.e., ponds that maintain a permanent pool only during the wet season) may prove effective in areas with distinct wet and dry seasons; however, this configuration has not been extensively evaluated.

Additional Design Guidelines

Specific designs may vary considerably, depending on site constraints or preferences of the designer or community. There are several variations of the wet pond design, including constructed wetlands, and wet extended detention ponds. Some of these design alternatives are intended to make the practice adaptable to various sites and to account for regional constraints and opportunities. In conventional wet ponds, the open water area comprises 50% or more of the total surface area of the pond. The permanent pool should be no deeper than 2.5 meters (8 feet) and should average 1.2 – 2 meters (4 to 6 feet) deep. The greater depth of this configuration helps limit the extent of the vegetation to an aquatic bench around the perimeter of the pond with a nominal depth of about 1 foot and variable width. This shallow bench also protects the banks from erosion, enhances habitat and aesthetic values, and reduces the drowning hazard.

The wet extended detention pond combines the treatment concepts of the dry extended detention pond and the wet pond. In this design, the water quality volume is detained above the permanent pool and released over 24 hours. In addition to increasing the residence time, which improves pollutant removal, this design also attenuates peak runoff rates. Consequently, this design alternative is recommended.

Pretreatment incorporates design features that help to settle out coarse sediment particles. By removing these particles from runoff before they reach the large permanent pool, the maintenance burden of the pond is reduced. In ponds, pretreatment is achieved with a sediment forebay. A sediment forebay is a small pool (typically about 10% of the volume of the permanent pool). Coarse particles remain trapped in the forebay, and maintenance is performed on this smaller pool, eliminating the need to dredge the entire pond.

There are a variety of sizing criteria for determining the volume of the permanent pool, mostly related to the water quality volume (i.e., the volume of water treated for pollutant removal) or the average storm size in a particular area. In addition, several theoretical approaches to determination of permanent pool volume have been developed. However, there is little empirical evidence to support these designs. Consequently, a simplified method (i.e., permanent pool volume equal to twice the water quality volume) is recommended.

Other design features do not increase the volume of a pond, but can increase the amount of time storm water remains in the device and eliminate short-circuiting. Ponds should always be designed with a length-to-width ratio of at least 1.5:1, where feasible. In addition, the design should incorporate features to lengthen the flow path through the pond, such as underwater berms designed to create a longer route through the pond. Combining these two measures helps ensure that the entire pond volume is used to treat storm water. Wet ponds with greater amounts of vegetation often have channels through the vegetated areas and contain dead areas where storm water is restricted from mixing with the entire permanent pool, which can lead to less pollutant removal. Consequently, a pond with open water comprising about 75% of the surface area is preferred.

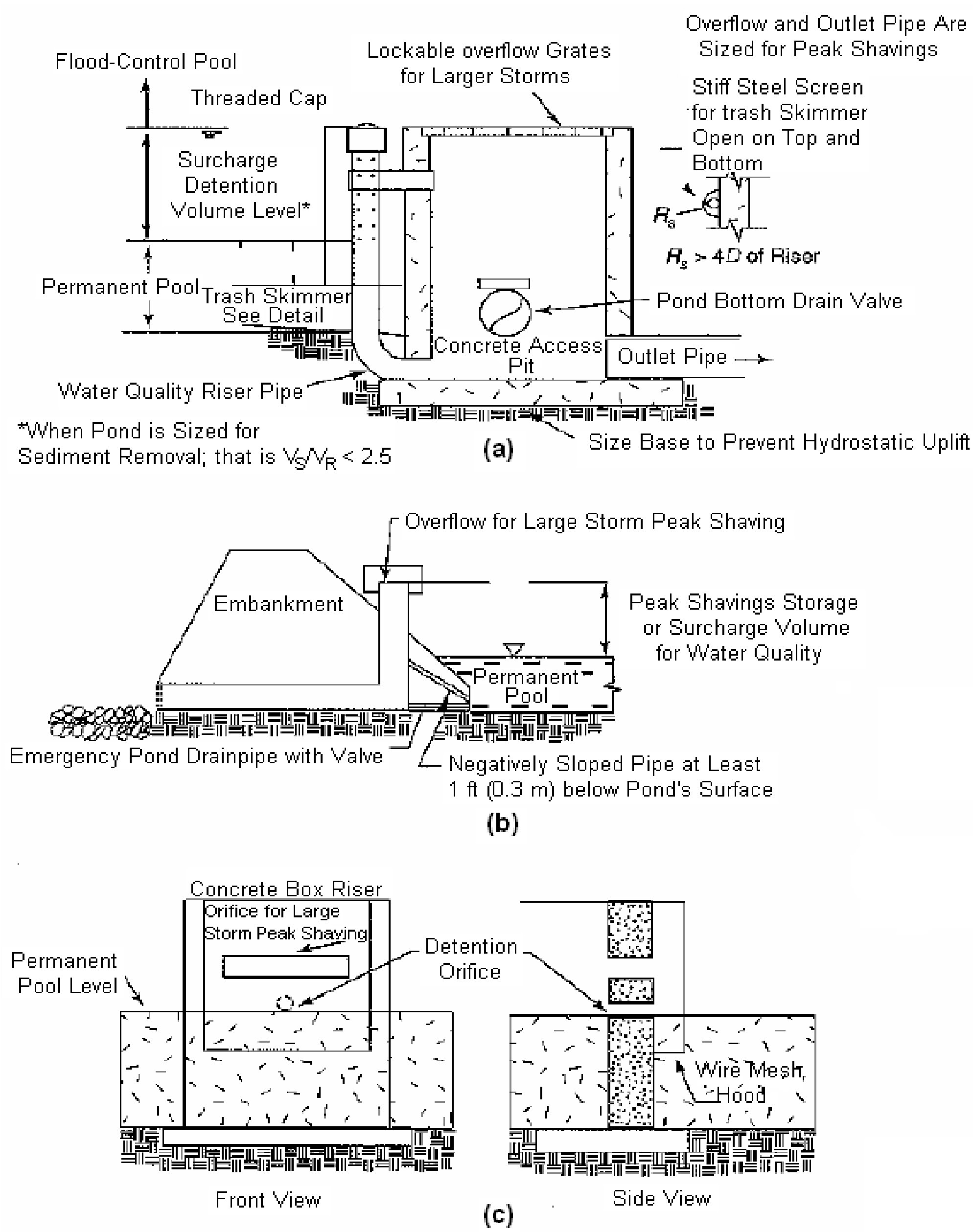
Design features are also incorporated to ease maintenance of both the forebay and the main pool of ponds. Ponds should be designed with a maintenance access to the forebay to ease this relatively routine (every 5 to 7 years) maintenance activity. In addition, ponds could be designed with a drain to draw down the pond for vegetation harvesting or less frequent dredging of the main cell of the pond.

Summary of Design Recommendations

- Facility Sizing: The basin should be sized to hold the permanent pool as well as the required water quality volume. The volume of the permanent pool should equal twice the water quality volume.
- Pond Configuration: The wet basin should be configured as a two stage facility with a sediment forebay and a main pool. The basins should be wedge-shaped, narrowest at the inlet and widest at the outlet. The minimum length to width ratio should be 1.5 where feasible. The perimeter of all permanent pool areas with depths of 4.0 feet or greater should be surrounded by an aquatic bench. This bench should extend inward 5 to 10 feet from the perimeter of the permanent pool and should be no more than 18 inches below normal depth. The area of the bench should not exceed about 25% of pond surface. The depth in the center of the basin should be 4 to 8 feet deep to prevent vegetation from encroaching on the pond open water surface.
- Pond Side Slopes: Side slopes of the basin should be 3:1 (H:V) or flatter for grass stabilized slopes. Slopes steeper than 3:1 should be stabilized with an appropriate slope stabilization practice.
- Sediment Forebay: A sediment forebay should be used to isolate gross sediments as they enter the facility and to simplify sediment removal. The sediment forebay should consist of a separate cell formed by an earthen berm, gabion, or loose riprap wall. The forebay should be sized to contain 15 to 25% of the permanent pool volume and should be at least 3 feet deep. Exit velocities from the forebay should not be erosive. Direct maintenance access should be provided to the forebay. The bottom of the forebay may be hardened (concrete) to make sediment removal easier. A fixed vertical sediment depth marker should be installed in the forebay to measure sediment accumulation.
- Outflow Structure: The figure that follows presents a schematic representation of suggested outflow structures. The outlet structure should be designed to drain the water quality volume over 24 hours with the orifice sized according to the equation presented in the Detention Basin fact sheet (TC-22). The facility should have a separate drain pipe with a manual valve that can completely or partially drain the pond for maintenance purposes. To allow for possible sediment accumulation, the submerged end of the pipe should be protected, and the drain pipe should be sized to drain the pond within 24 hours. The valve should be located at a point where it can be operated in a safe and convenient manner.

  For on-line facilities, the principal and emergency spillways must be sized to provide 1.0 foot of freeboard during the 25-year event and to safely pass the 100-year flood. The embankment should be designed in accordance with all relevant specifications for small dams.

Outflow Structure



- Splitter Box: When the pond is designed as an off-line facility, a splitter structure is used to isolate the water quality volume. The splitter box, or other flow diverting approach, should be designed to convey the 25-year event while providing at least 1.0 foot of freeboard along pond side slopes.
- Vegetation: A plan should be prepared that indicates how aquatic and terrestrial areas will be vegetative stabilized. Wetland vegetation elements should be placed along the aquatic bench or in the shallow portions of the permanent pool. The optimal elevation for planting of wetland vegetation is within 6 inches vertically of the normal pool elevation. A list of some wetland vegetation native to Hawaii is presented in the following table.

Native Hawaiian Wetland Plants

Species	Common Name	Hawaiian Name	Native Status
Bacopa monnieri (L.) Pennell	Water hyssop	Aeae	Indigenous
Carex alligara Boot	Hawaii sedge	N/A	Endemic
Cladium mariscus ssp. Jamaicense (Crantz) Kokenth	Sawgrass	Uki	Indigenous
Cyperus poystachyos Rottb.	Manyspike flatsedge	Kolohia	Indigenous
Cyperus laevigatus L.	Smooth flatsedge	Makaloa	Indigenous
Cyperus javanicus Houtt	Javanese flatsedge	Ahu awa	Indigenous
Eleocharis obtuse	Blunt spikerush	Pipi wai	Indigenous
Eragrostis grandis Hbd.	Lovegrass	Emoloa	Endemic
Fimbristylis dichotooma	Forked fimbry	N/A	Indigenous
Fimbristylis Cymosa	Tropical fimbry	Mauu akiaki	Indigenous
Machaerina angustriolla	Polynesian twigrush	Uki	Indigenous
Madchaerina mariscoldes	Tropical twigrush	Uki	Indigenous
Rhynchospora chinensis	Spiked beaksedge	Kuolohia	Indigenous
Schoenoplectus juncoldes	Rock bulrush	Kaluha	Indigenous
Schoenoplectus maritimus	Alkyl bulrush	Kaluha	Indigenous
Schoenoplectus tabernaemontani	Softstem (Great) bulrush	Aka akai	Indigenous
Sporbolus virginicus	Seashore dropseed	Aki aki	Indigenous

Maintenance

The amount of maintenance required for a wet pond is highly dependent on local regulations, particularly from the DOH Vector Control Branch which is concerned about the potential for mosquito breeding that may occur in the permanent pool. Even though mosquito fish (Gambusia affinis) were introduced into a wet pond constructed by Caltrans in the San Diego area, mosquito breeding was routinely observed during inspections. In addition, the vegetation at this site became sufficiently dense on the bench around the edge of the pool that mosquito fish were unable to enter this area to feed upon the mosquito larvae. The vegetation at this site was particularly vigorous because of the high nutrient concentrations in the perennial base flow (15.5 mg/L NO3-N) and the mild climate, which permitted growth year round. Consequently, the vector control agency required an annual harvest of vegetation to address this situation. This harvest can be very expensive.

On the other hand, routine harvesting may increase nutrient removal and prevent the export of these constituents from dead and dying plants falling in the water. A previous study (Faulkner and Richardson, 1991) documented dramatic reductions in nutrient removal after the first several years of operation and related it to the vegetation achieving a maximum density. That content then decreases through the growth season, as the total biomass increases. In effect, the total amount of nutrients/meters^2 of wetland remains essentially the same from June through September, when the plants start to put the P back into the rhizomes. Therefore harvesting should occur between June and September. Research also suggests that harvesting only the foliage is less effective, since a very small percentage of the removed nutrients are taken out with harvesting.

Since wet ponds are often selected for their aesthetic considerations as well as pollutant removal, they are often sited in areas of high visibility. Consequently, floating litter and debris are removed more frequently than would be required simply to support proper functioning of the pond and outlet. This is one of the primary maintenance activities performed at the Central Market Pond located in Austin, Texas. In this type of setting, vegetation management in the area surrounding the pond can also contribute substantially to the overall maintenance requirements.

One normally thinks of sediment removal as one of the typical activities performed at storm water BMPs. This activity does not normally constitute one of the major activities on an annual basis. At the concentrations of TSS observed in urban runoff from stable watersheds, sediment removal may only be required every 20 years or so. Because this activity is performed so infrequently, accurate costs for this activity are lacking.

In addition to regular maintenance activities needed to maintain the function of wet ponds, some design features can be incorporated to ease the maintenance burden. In wet ponds, maintenance reduction features include techniques to reduce the amount of maintenance needed, as well as techniques to make regular maintenance activities easier.

One potential maintenance concern in wet ponds is clogging of the outlet. Ponds should be designed with a non-clogging outlet such as a reverse-slope pipe, or a weir outlet with a trash rack. A reverse slope pipe draws from below the permanent pool extending in a reverse angle up to the riser and establishes the water elevation of the permanent pool. Because these outlets draw water from below the level of the permanent pool, they are less likely to be clogged by floating debris.

Typical maintenance activities and frequencies include:

- Schedule semiannual inspections for burrows, sediment accumulation, structural integrity of the outlet, and litter accumulation.
- Remove accumulated trash and debris in the basin at the middle and end of the wet season. The frequency of this activity may be altered to meet specific site conditions and aesthetic considerations.
- Where permitted by the Department of Land and Natural Resource (DLNR), stock wet ponds/ constructed wetlands regularly with mosquito eating fish (i.e., Gambusia spp.) to enhance natural mosquito and midge control.
- Introduce mosquito fish and maintain vegetation to assist their movements to control mosquitoes, as well as to provide access for vector inspectors. An annual vegetation harvest in summer appears to be optimum, in that it is after the bird breeding season, mosquito fish can provide the needed control until vegetation reaches late summer density, and there is time for re-growth for runoff treatment purposes before the wet season. In certain cases, more frequent plant harvesting may be required by local vector control agencies.
- Maintain emergent and perimeter shoreline vegetation as well as site and road access to facilitate vector surveillance and control activities.
- Remove accumulated sediment in the forebay and regrade about every 5 to 7 years or when the accumulated sediment volume exceeds 10% of the basin volume. Sediment removal may not be required in the main pool area for as long as 20 years.

Cost

In general, Hawaii's unit prices are higher than California's unit prices.

Construction Cost

Wet ponds can be relatively inexpensive storm water practices; however, the construction costs associated with these facilities vary considerably. Much of this variability can be attributed to the degree to which the existing topography will support a wet pond, the complexity and amount of concrete required for the outlet structure, and whether it is installed as part of new construction or implemented as a retrofit of existing storm drain system.

Maintenance Cost

For ponds, the annual cost of routine maintenance has typically been estimated at about 3 to 5% of the construction cost; however, the published literature is almost totally devoid of actual maintenance costs. Since ponds are long-lived facilities (typically longer than 20 years), major maintenance activities are unlikely to occur during a relatively short study.

Caltrans (2002) estimated annual maintenance costs of $17,000 based on three (3) years of monitoring of a pond treating runoff from 4.2 acres (1.7 hectares). Almost all the activities are associated with the annual vegetation harvest for vector control. Total cost at this site falls within the 3 to 5% range reported above; however, the construction costs were much higher than those estimated by Brown and Schueler (1997). The City of Austin has been reimbursing a developer about $25,000/year for wet pond maintenance at a site located at a very visible location. Maintenance costs are mainly the result of vegetation management and litter removal. On the other hand, King County estimates annual maintenance costs at about $3,000 per pond; however, this cost likely does not include annual extensive vegetation removal. Consequently, maintenance costs may vary considerably depending on the aggressiveness of the vegetation management in that area and the frequency of litter removal.

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Design Considerations		
•	Area Required	
•	Slope	
•	Water Availability	
•	Aesthetics	
•	Environmental Side Effects	
Target Constituents		
✓	Sediments	H
✓	Nutrients	M
✓	Trash	H
✓	Metals	H
✓	Bacteria	H
✓	Oil and Grease	H
✓	Organics	H
Legend (Removal Effectiveness)		
L	Low	
M	Medium	
H	High	

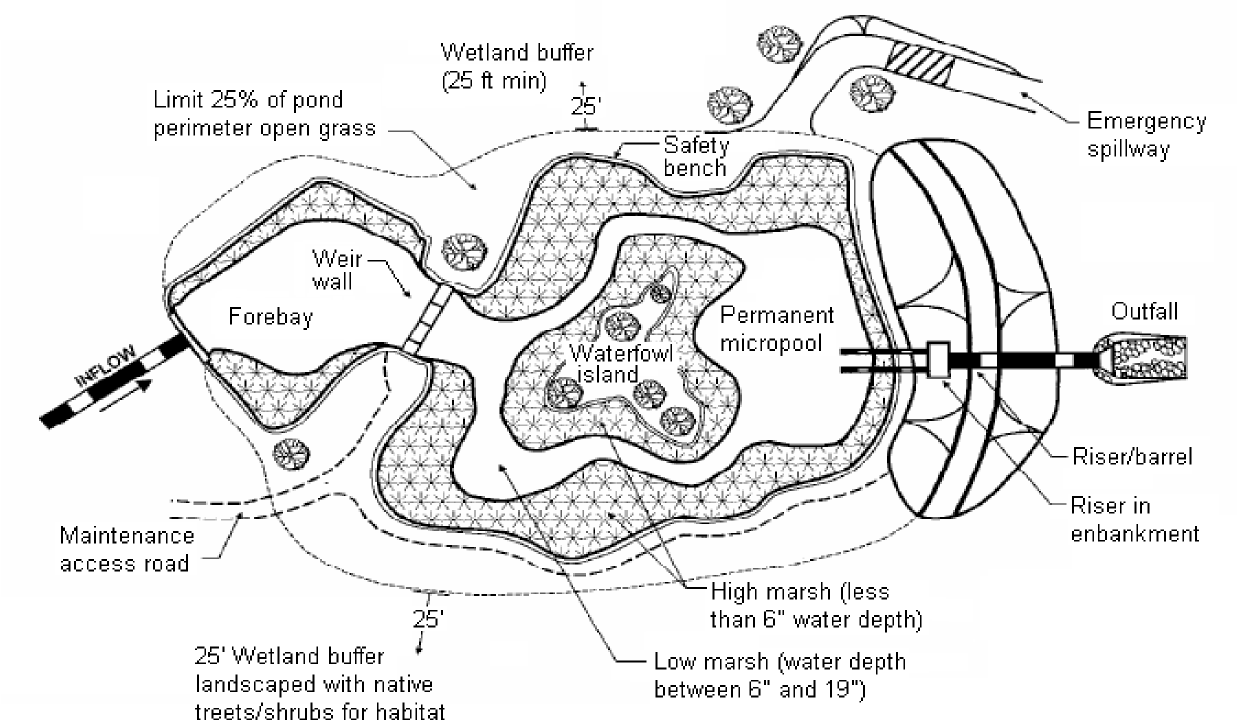
Description

Constructed wetlands are constructed basins that have a permanent pool of water throughout the year (or at least throughout the wet season) and differ from wet ponds primarily in being shallower and having greater vegetation coverage. The schematic diagram is of an on-line pond that includes detention for larger events, but this is not required in all areas of the state.

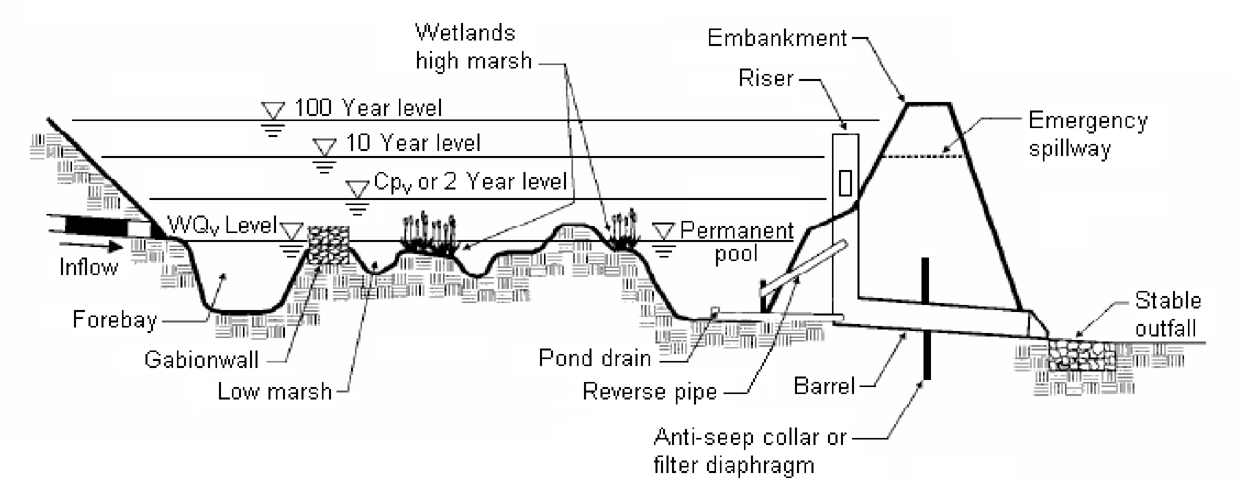
A distinction should be made between using a constructed wetland for storm water management and diverting storm water into a natural wetland. The latter practice is not recommended and in all circumstances, natural wetlands should be protected from the adverse effects of development, including impacts from increased storm water runoff. This is especially important because natural wetlands provide storm water and flood control benefits on a regional scale.

Wetlands are among the most effective storm water practices in terms of pollutant removal and they also offer aesthetic value. As storm water runoff flows through the wetland, pollutant removal is achieved through settling and biological uptake within the wetland. Flow through the root systems forces the vegetation to remove nutrients and dissolved pollutants from the storm water. The figure that follows illustrates a conceptual layout.

Conceptual Wet Pond Layout



PLAN VIEW



PROFILE

Note: If maximum storage capacity is > 15 acres/feet, Hawaii Dam Safety Rules Apply.
If dam height is > 6 feet than the Hawaii Dam Safety Rules Apply.

Advantages

- If properly designed, constructed and maintained, wet basins can provide substantial wildlife and wetlands habitat.
- Due to the presence of the permanent wet pool, properly designed and maintained wet basins can provide significant water quality improvement across a relatively broad spectrum of constituents including dissolved nutrients.
- Widespread application with sufficient capture volume can provide significant control of channel erosion and enlargement caused by changes to flow frequency relationships resulting from the increase of impervious cover in a watershed.

Limitations

- There may be some aesthetic concerns about a facility that looks swampy.
- Some concern about safety when constructed where there is public access.
- Mosquito and midge breeding is likely to occur in wetlands.
- Cannot be placed on steep unstable slopes.
- Need for base flow or supplemental water if water level is to be maintained.
- Require a relatively large footprint.
- Depending on volume and depth, pond designs may require approval from the City.

Design and Sizing Guidelines

- Capture volume determined by City Drainage Rules.
- Outlet designed to discharge the capture volume over a period of 24 hours.
- Permanent pool volume equal to twice the water quality volume.
- Water depth not to exceed about four (4) feet.
- Wetland vegetation occupying no more than 50% of surface area.
- Include energy dissipation in the inlet design and a sediment forebay to reduce re-suspension of accumulated sediment and facilitate maintenance.
- A maintenance ramp should be included in the design to facilitate access to the forebay for maintenance activities and for vector surveillance and control.
- To facilitate vector surveillance and control activities, road access should be provided along at least one side of BMPs that are 20 feet or less in width. Those BMPs that have shoreline-to-shoreline distances in excess of 20 feet should have perimeter road access on both sides or be designed such that no parcel of water is greater than 20 feet from the road.

Construction/Inspection Considerations

- In areas with porous soils an impermeable liner may be required to maintain an adequate permanent pool level.
- Outlet structures and piping should be installed with collars to prevent water from seeping through the fill and causing structural failure.
- Inspect facility after first large storm to determine whether the desired residence time has been achieved.

Performance

The processes that impact the performance of constructed wetlands are essentially the same as those operating in wet ponds and similar pollutant reduction would be expected. One concern about the long-term performance of wetlands is associated with the vegetation density. If vegetation covers the majority of the facility, open water is confined to a few well defined channels. This can limit mixing of the storm water runoff with the permanent pool and reduce the effectiveness as compared to a wet pond where a majority of the area is open water.

Siting Criteria

Wet ponds are a widely applicable storm water management practice and can be used over a broad range of storm frequencies and sizes, drainage areas and land use types. Although they have limited applicability in highly urbanized settings and in arid climates, they have few other restrictions. Constructed wetlands may be constructed on- or off-line and can be sited at feasible locations along established drainage ways with consistent base flow. An off-line design is preferred. Constructed wetlands are often utilized in smaller sub-watersheds and are particularly appropriate in areas with residential land uses or other areas where high nutrient loads are considered to be potential problems (i.e., golf courses).

Wetlands generally consume a fairly large area (typically 4 to 6% of the contributing drainage area), and these facilities are generally larger than wet ponds because the average depth is less.

Wet basin application is appropriate in the following settings:

- Where there is a need to achieve a reasonably high level of dissolved contaminant removal and/or sediment capture.
- In small to medium-sized regional tributary areas with available open space and drainage areas greater than about 25 acres (10 hectares).
- Where base flow rates or other channel flow sources are relatively consistent year-round.
- In settings where wildlife habitat benefits can be appreciated.

Additional Design Guidelines

Constructed wetlands generally feature relatively uniformly vegetated areas with depths of one foot or less and open water areas (25 to 50% of the total area) no more than about 4 feet (1.2 meters) deep, although design configuration options are relatively flexible. Wetland vegetation is comprised generally of a diverse, local aquatic plant species. Constructed wetlands can be designed on-line or off-line and generally serve relatively smaller drainage areas than wet ponds, although because of the shallow depths, the footprint of the facility will be larger than a wet pond serving the same tributary area.

The extended detention shallow wetland combines the treatment concepts of the dry extended detention pond and the constructed wetland. In this design, the water quality volume is detained above the permanent pool and released over 24 hours. In addition to increasing the residence time, which improves pollutant removal, this design also attenuates peak runoff rates. Consequently, this design alternative is recommended.

Pretreatment incorporates design features that help to settle out coarse sediment particles. By removing these particles from runoff before they reach the large permanent pool, the maintenance burden of the pond is reduced. In ponds, pretreatment is achieved with a sediment forebay. A sediment forebay is a small pool (typically about 10% of the volume of the permanent pool). Coarse particles remain trapped in the forebay, and maintenance is performed on this smaller pool, eliminating the need to dredge the entire pond.

Effective wetland design displays “complex micro topography.” In other words, wetlands should have zones of both very shallow (<6 inches) and moderately shallow (<18 inches) wetlands incorporated, using underwater earth berms to create the zones. This design will provide a longer flow path through the wetland to encourage settling, and it provides two depth zones to encourage plant diversity.

There are a variety of sizing criteria for determining the volume of the permanent pool, mostly related to the water quality volume (i.e., the volume of water treated for pollutant removal) or the average storm size in a particular area. In addition, several theoretical approaches to determination of permanent pool volume have been developed. However, there is little empirical evidence to support these designs. Consequently, a simplified method (i.e., permanent pool volume equal to twice the water quality volume) is recommended.

Design features are also incorporated to ease maintenance of both the forebay and the main pool of ponds. Ponds should be designed with a maintenance access to the forebay to ease this relatively routine (every 5 to 7 year) maintenance activity. In addition, ponds should generally have a drain to draw down the pond for vegetation harvesting or the more infrequent dredging of the main cell of the pond.

Summary of Design Recommendations

- Facility Sizing: The basin should be sized to hold the permanent pool as well as the required water quality volume. The volume of the permanent pool should equal twice the water quality volume.
- Pond Configuration: The wet basin should be configured as a two (2) stage facility with a sediment forebay and a main pool. The basins should be wedge-shaped, narrowest at the inlet and widest at the outlet. The minimum length to width ratio should be 1.5 where feasible. The depth in the center of the basin should be about 4 feet deep to prevent vegetation from encroaching on the pond open water surface.
- Pond Side Slopes: Side slopes of the basin should be 3:1 (H:V) or flatter for grass stabilized slopes. Slopes steeper than 3:1 should be stabilized with an appropriate slope stabilization practice.
- Sediment Forebay: A sediment forebay should be used to isolate gross sediments as they enter the facility and to simplify sediment removal. The sediment forebay should consist of a separate cell formed by an earthen berm, gabion, or loose riprap wall. The forebay should be sized to contain 15 to 25% of the permanent pool volume and should be at least 3 feet deep. Exit velocities from the forebay should not be erosive. Direct maintenance access should be provided to the forebay. The bottom of the forebay may be hardened (concrete) to make sediment removal easier. A fixed vertical sediment depth marker should be installed in the forebay to measure sediment accumulation.
- Splitter Box: When the pond is designed as an off-line facility, a splitter structure is used to isolate the water quality volume. The splitter box, or other flow diverting approach, should be designed to convey the necessary recurrence interval event while providing at least 1.0 foot of freeboard along pond side slopes.
    - For drainage areas of 100 acres or less, the recurrence interval shall be 10 years.
    - For drainage areas greater than 100 acres, the recurrence interval shall be 100 years.

- Vegetation: A plan should be prepared that indicates how aquatic and terrestrial areas will be vegetative stabilized. Wetland vegetation elements should be placed along the aquatic bench or in the shallow portions of the permanent pool. The optimal elevation for planting of wetland vegetation is within 6 inches vertically of the normal pool elevation. A list of some wetland vegetation native to Hawaii is presented in the wet pond fact sheet (TC-20).

Maintenance

The amount of maintenance required for a constructed wetland is highly dependent on State and City approval, particular health and vector control agencies. These agencies are often extremely concerned about the potential for mosquito breeding that may occur in the permanent pool.

Routine harvesting of vegetation may increase nutrient removal and prevent the export of these constituents from dead and dying plants falling in the water. A previous study (Faulkner and Richardson, 1991) documented dramatic reductions in nutrient removal after the first several years of operation and related it to the vegetation achieving a maximum density. Vegetation harvesting in the summer is recommended.

Typical maintenance activities and frequencies include:

- Schedule semiannual inspections for burrows, sediment accumulation, structural integrity of the outlet, and litter accumulation.
- Remove accumulated trash and debris in the basin at the middle and end of the wet season. The frequency of this activity may be altered to meet specific site conditions and aesthetic considerations.
- Where permitted by stock wet ponds/constructed wetlands regularly with mosquito eating fish (i.e., Gambusia spp.) to enhance natural mosquito and midge control.
- Introduce mosquito fish and maintain vegetation to assist their movements to control mosquitoes, as well as to provide access for vector inspectors. An annual vegetation harvest in summer appears to be optimum, in that it is after the bird breeding season, mosquito fish can provide the needed control until vegetation reaches late summer density, and there is time for re-growth for runoff treatment purposes before the wet season. In certain cases, more frequent plant harvesting may be required by local vector control agencies.
- Maintain emergent and perimeter shoreline vegetation as well as site and road access to facilitate vector surveillance and control activities.
- Remove accumulated sediment in the forebay and regrade about every 5 to 7 years or when the accumulated sediment volume exceeds 10% of the basin volume. Sediment removal may not be required in the main pool area for as long as 20 years.

Cost

Construction Cost

Wetlands are relatively inexpensive storm water practices. Construction cost data for wetlands are rare, but one simplifying assumption is that they are typically about 25% more expensive than storm water ponds of an equivalent volume. Using this assumption, an equation developed by Brown and Schueler (1997) to estimate the cost of wet ponds can be modified to estimate the cost of storm water wetlands in California using the following equation.

$$C = 30.6^{0.705V}$$

Where:

C = construction, design, and permitting cost
V = wetland volume needed to control the 10-year storm (feet^3)

Using this equation, typical construction costs are the following:

- $57,100 for a 1 acre-foot facility.
- $289,000 for a 10 acre-foot facility.
- $1,470,000 for a 100 acre-foot facility.

Wetlands consume about 3 to 5% of the land that drains to them, which is relatively high compared with other storm water management practices. In areas where land value is high, this may make wetlands an infeasible option.

In general, Hawaii's unit prices are higher than California's unit prices.

Maintenance Cost

For ponds, the annual cost of routine maintenance has typically been estimated at about 3 to 5% of the construction cost; however, the published literature is almost totally devoid of actual maintenance costs. Since ponds are long-lived facilities (typically longer than 20 years), major maintenance activities are unlikely to occur during a relatively short study.

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Design Considerations		
•	Tributary Area	
•	Area Required	
•	Hydraulic Head	
Target Constituents		
✓	Sediments	M
✓	Nutrients	L
✓	Trash	H
✓	Metals	L/M
✓	Bacteria	L
✓	Oil and Grease	M
✓	Organics	U
Legend (Removal Effectiveness)		
L	Low	
M	Medium	
H	High	
U	Unknown	

Description

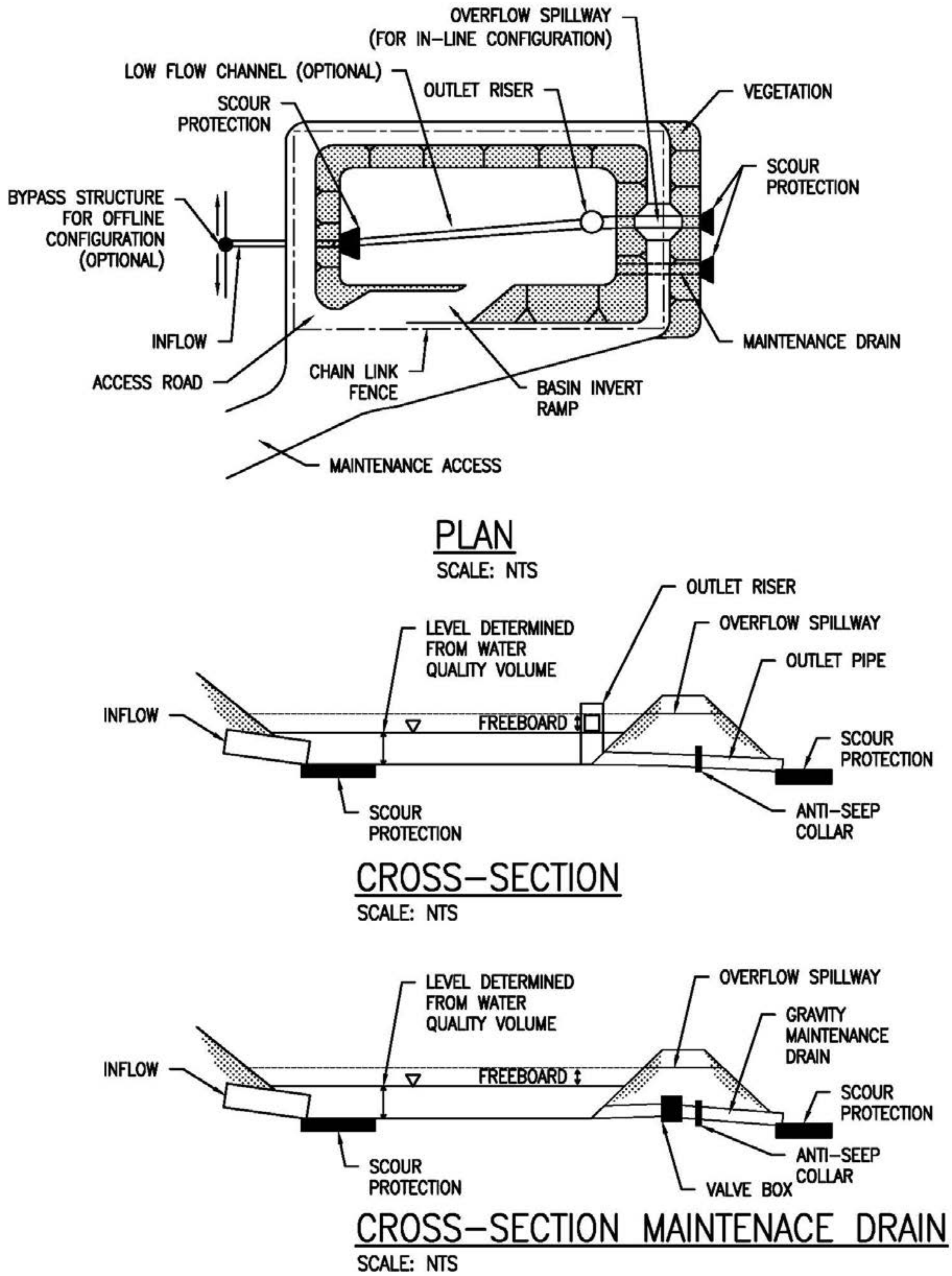
Detention basins (a.k.a. dry ponds, detention ponds, extended detention ponds) are basins whose outlets have been designed to detain the storm water runoff from a water quality design storm for some minimum time (i.e., 36 to 48 hours) to allow particles and associated pollutants to settle. Unlike wet ponds, these facilities do not have a large permanent pool. They can also be used to provide flood control by including additional flood detention storage.

The criteria presented for detention basins is not intended for dams and reservoirs defined by the State of Hawaii Department of Land and Natural Resources, Dam Safety Requirements, Hawaii Administrative Rules (HAR) Chapter 13-190 Dams and Reservoirs. A dam has a maximum storage capacity of 50-acre-feet and height greater than 6 feet, or a storage capacity of 15 acre-feet and dam height greater than 25 feet.

Field Experience

Caltrans constructed and monitored five (5) extended detention basins in southern California with design drain times of 72 hours (longer than drain time required by City Drainage Rules). Four (4) of the basins were earthen, less costly and had substantially better load reduction because of infiltration that occurred, than the concrete basin. The Caltrans study reaffirmed the flexibility and performance of this conventional technology. The small headloss and few siting constraints suggest that these devices are one of the most applicable technologies for storm water treatment. The figure that follows illustrates a conceptual detention basin layout.

Schematic of a Detention Basin



Advantages

- Due to the simplicity of design, detention basins are relatively easy and inexpensive to construct and operate.
- Detention basins can provide substantial capture of sediment and the toxic fraction associated with particulates
- Widespread application with sufficient capture volume can provide significant control of channel erosion and enlargement caused by changes to flow frequency relationships resulting from the increase of impervious cover in a watershed.

Limitations

- Limitation of the diameter of the orifice may not allow use of extended detention in watersheds of less than five (5) acres (would require an orifice with a diameter of less than 4 inches that would be prone to clogging).
- Detention basins have only moderate pollutant removal when compared to some other structural storm water practices, and they are relatively ineffective at removing soluble pollutants.
- Although wet basins can increase property values, dry basins can actually detract from the value of a home due to the adverse aesthetics of dry, bare areas and inlet and outlet structures.

Design and Sizing Guidelines

- Capture volume determined by City Drainage Rules for a minimum detention volume for a 1-inch storm over a 24 hour duration
- Outlet designed to discharge the capture volume over a period of 48 hours and half the capture volume over 24 to 36 hours.
- Length to width ratio of at least 2:1 where feasible.
- Basin depths optimally range from 2 to 5 feet.
- Include energy dissipation in the inlet design to reduce re-suspension of accumulated sediment.
- Consider public safety as it relates to children.
- A maintenance ramp and perimeter access should be included in the design to facilitate access to the basin for maintenance activities and for vector surveillance and control.
- Use a draw down time of 36 to 48 hours in most areas; See City Drainage Rules. Draw down times in excess of 48 hours may result in vector breeding, and should be used only after coordination with local vector control authorities.

Construction/Inspection Considerations

- Inspect facility after first large storm to determine whether the desired residence time has been achieved.
- When constructed with small tributary area, orifice sizing is critical and inspection should verify that flow through additional openings such as bolt holes does not occur.

Performance

One (1) objective of storm water management practices can be to reduce the flood hazard associated with large storm events by reducing the peak flow associated with these storms. Detention basins can easily be designed for flood control, and this is actually the primary purpose of most detention basins.

Detention basins provide moderate pollutant removal, provided that the recommended design features are incorporated. Although they can be effective at removing some pollutants through settling, they are less effective at removing soluble pollutants because of the absence of a permanent pool. Several studies are available on the effectiveness of detention basins.

The load reduction is greater than the concentration reduction because of the substantial infiltration that occurs. Although the infiltration of storm water is clearly beneficial to surface receiving waters, there is the potential for groundwater contamination. Previous research on the effects of incidental infiltration on groundwater quality indicated that the risk of contamination is minimal.

There were substantial differences in the amount of infiltration that were observed in the earthen basins during the Caltrans study. On average, approximately 40% of the runoff entering the unlined basins infiltrated and was not discharged. The percentage ranged from a high of about 60% to a low of only about 8% for the different facilities. Climatic conditions and local water table elevation are likely the principal causes of this difference. The least infiltration occurred at a site located on the coast where humidity is higher and the basin invert is within a few meters of sea level.

Vegetated detention basins appear to have a greater pollutant removal than concrete basins. In a Caltrans study, the concrete basin exported sediment and associated pollutants during a number of storms. Export was not as common in the earthen basins, where the vegetation appeared to help stabilize the retained sediment.

Siting Criteria

Detention basins are among the most widely applicable storm water management practices and are especially useful in retrofit situations where their low hydraulic head requirements allow them to be sited within the constraints of the existing storm drain system. In addition, many communities have detention basins designed for flood control. It is possible to modify these facilities to incorporate features that provide water quality treatment and/or channel protection. Although detention basins can be applied rather broadly, designers need to ensure that they are feasible at the site in question. This section provides basic guidelines for siting detention basins.

In general, detention basins should be used on sites with a minimum area of five (5) acres. With this size catchment area, the orifice size can be on the order of 0.5 inches. On smaller sites, it can be challenging to provide channel or water quality control because the orifice diameter at the outlet needed to control relatively small storms becomes very small and thus prone to clogging. In addition, it is generally more cost-effective to control larger drainage areas due to the economies of scale.

Detention basins can be used with almost all soils and geology, with minor design adjustments for regions of rapidly percolating soils such as sand. In these areas, detention basins may need an impermeable liner to prevent ground water contamination.

The base of the detention facility should not intersect the water table. A permanently wet bottom may become a mosquito breeding ground. Research in Southwest Florida (Santana et al., 1994) demonstrated that intermittently flooded systems, such as detention basins, produce more mosquitoes than other basin systems, particularly when the facilities remained wet for more than three (3) days following heavy rainfall.

Additional Design Guidelines

In order to enhance the effectiveness of detention basins, the dimensions of the basin must be sized appropriately. Merely providing the required storage volume will not ensure maximum constituent removal. By effectively configuring the basin, the designer will create a long flow path, promote the establishment of low velocities, and avoid having stagnant areas of the basin. To promote settling and to attain an appealing environment, the design of the basin should consider the length to width ratio, cross-sectional areas, basin slopes and basin configuration, and aesthetics (Young et al., 1996).

Energy dissipation structures should be included for the basin inlet to prevent re-suspension of accumulated sediment. The use of stilling basins for this purpose should be avoided because the standing water provides a breeding area for mosquitoes.

Detention facilities should be sized to completely capture the water quality volume. An optional micropool is often included in the design and one is shown in the schematic diagram. These small permanent pools greatly increase the potential for mosquito breeding and complicate maintenance activities; consequently, they are not recommended.

A large aspect ratio may improve the performance of detention basins; consequently, the outlets should be placed to maximize the flowpath through the facility. The ratio of flowpath length to width from the inlet to the outlet should be at least 2:1 (L:W) where feasible. Basin depths optimally range from 2 to 5 feet.

The facility's drawdown time should be regulated by an orifice or weir. In general, the outflow structure should have a trash rack or other acceptable means of preventing clogging at the entrance to the outflow pipes. One effective method is outlet design implemented by Caltrans in the facilities constructed in San Diego County used an outlet riser with orifices sized to discharge the water quality volume; the riser overflow height was set to the design storm elevation. A stainless steel screen was placed around the outlet riser to ensure that the orifices would not become clogged with debris. Sites either used a separate riser or broad crested weir for overflow of runoff for the 25 and greater year storms. A picture of a typical outlet is presented in the figure below.

Generally the outflow structure should be sized to allow for complete drawdown of the water quality volume in 36 to 48 hours. No more than 50% of the water quality volume should drain from the facility within the first 24 hours. The outflow structure can be fitted with a valve so that discharge from the basin can be halted in case of an accidental spill in the watershed.

Example of Detention Outlet Structure

Summary of Design Recommendations

- Facility Sizing: The required water quality volume is determined by City Rules Relating to Storm Drainage:
  - Basin Configuration: A high aspect ratio may improve the performance of detention basins; consequently, the outlets should be placed to maximize the flowpath through the facility. The ratio of flowpath length to width from the inlet to the outlet should be at least 2:1 (L:W). The flowpath length is defined as the distance from the inlet to the outlet as measured at the surface. The width is defined as the mean width of the basin. Basin depths optimally range from 2 to 5 feet. The basin may include a sediment forebay to provide the opportunity for larger particles to settle out.
  - Basin Volume: Minimum detention for a 1-inch storm, 24 hour duration.
  - A micropool should not be incorporated in the design because of vector concerns. For online facilities, the principal and emergency spillways must be sized to provide 1.0 foot of freeboard during the necessary recurrence interval event and to safely pass the flow from a 100-year storm.
    - For drainage areas of 100 acres or less, the recurrence interval shall be 10 years.
    - For drainage areas greater than 100 acres, the recurrence interval shall be 100 years.
- Basin Side Slopes: Side slopes of the basin should be 3:1 (H:V) or flatter for grass stabilized slopes - Slopes steeper than 3:1 (H:V) must be approved by a licensed professional engineer with geotechnical expertise.
- Basin Lining: Basins must be constructed to prevent possible contamination of groundwater below the facility.
- Basin Inlet: Energy dissipation is required at the basin inlet to reduce re-suspension of accumulated sediment and to reduce the tendency for short-circuiting.
- Outflow Structure: The facility's drawdown time should be regulated by a gate valve or orifice plate. In general, the outflow structure should have a trash rack or other acceptable means of preventing clogging at the entrance to the outflow pipes.

  The discharge through a control orifice is calculated from:

  $$\mathbf{Q = CA(2gH\text{-}H_0)^{0.5}}$$

  Where:

  Q = discharge (feet^3/second)
  C = orifice coefficient
  A = area of orifice (feet^2)
  g = gravitational constant (32.2 feet/second^2)
  H = water surface elevation (feet)
  H_o = orifice elevation (feet)

Recommended values for C are 0.66 for thin materials and 0.80 when the material is thicker than the orifice diameter. This equation can be implemented in spreadsheet form with the basin stage/volume relationship to calculate drain time. To do this, use the initial height of the water above the orifice for the water quality volume. Calculate the discharge and assume that it remains constant for approximately

10 minutes. Based on that discharge, estimate the total discharge during that interval and the new elevation based on the stage volume relationship. Continue to iterate until H is approximately equal to H_0. When using multiple orifices the discharge from each is summed.

- Splitter Box: When the basin is designed as an offline facility, a splitter structure is used to isolate the water quality volume. The splitter box, or other flow diverting approach, should be designed to convey the necessary recurrence interval event while providing at least 1.0 foot of freeboard along basin side slopes.
  - For drainage areas of 100 acres or less, the recurrence interval shall be 10 years.
  - For drainage areas greater than 100 acres, the recurrence interval shall be 100 years.
- Erosion Protection at the Outfall: For online facilities, special consideration should be given to the facility's outfall location. Flared pipe end sections that discharge at or near the stream invert are preferred. The channel immediately below the basin outfall should be modified to conform to natural dimensions, and lined with large stone riprap placed over filter cloth. Energy dissipation may be required to reduce flow velocities from the primary spillway to non-erosive velocities.
- Safety Considerations: Safety is provided either by fencing of the facility or by managing the contours of the basin to eliminate dropoffs and other hazards. Earthen side slopes should not exceed 3:1 (H:V) and should terminate on a flat safety bench area. Landscaping can be used to impede access to the facility. The primary spillway opening must not permit access by small children. Outfall pipes above 48 inches in diameter should be fenced.

Maintenance

Routine maintenance activity is often thought to consist mostly of sediment and trash and debris removal; however, these activities often constitute only a small fraction of the maintenance hours.

The largest maintenance activity will most likely be vegetation management, including routine mowing. In most cases, basic housekeeping practices such as removal of debris accumulations and vegetation management to ensure that the basin dewaters completely in 36 to 48 hours is sufficient to prevent creating mosquito and other vector habitats.

Consequently, maintenance costs should be estimated based primarily on the mowing frequency and the time required. Mowing should be done at least annually to avoid establishment of woody vegetation, but may need to be performed much more frequently if aesthetics are an important consideration.

Typical activities and frequencies include:

- Schedule semiannual inspection for the beginning and end of the wet season for standing water, slope stability, sediment accumulation, trash and debris, and presence of burrows.
- Remove accumulated trash and debris in the basin and around the riser pipe during the semiannual inspections. The frequency of this activity may be altered to meet specific site conditions.
- Trim vegetation at the beginning and end of the wet season and inspect monthly to prevent establishment of woody vegetation and for aesthetic and vector reasons.
- Remove accumulated sediment and re-grade about every 10 years or when the accumulated sediment volume exceeds 10% of the basin volume. Inspect the basin each year for accumulated sediment volume.

Cost

In general, Hawaii's unit prices are higher than California's unit prices.

Construction Cost

The construction costs associated with detention basins vary considerably. One recent study evaluated the cost of all basin systems (Brown and Schueler, 1997). Adjusting for inflation, the cost of detention basins in California can be estimated with the equation:

$$C = 12.4V^{0.760}$$

Where:

C = construction, design, and permitting cost
V = volume ($feet^3$)

An economic concern associated with dry basins is that they might detract slightly from the value of adjacent properties. One study found that dry basins can actually detract from the perceived value of homes adjacent to a dry basin by between 3 and 10% (Emmerling-Dinovo, 1995).

Maintenance Cost

The annual cost of routine maintenance is typically estimated at about 3 to 5% of the construction cost (EPA website). Alternatively, a community can estimate the cost of the maintenance activities outlined in the maintenance section. The table below presents the maintenance costs estimated by Caltrans based on their experience with five basins located in southern California. Again, it should be emphasized that the vast majority of hours are related to vegetation management (mowing).

Estimated Average Annual Maintenance Effort

Activity	Labor Hours	Equipment & Materials	Costs
Inspections	4	7	$183
Maintenance	49	126	$2,282
Vector Control	0	0	$0
Administration	3	0	$132
Materials	-	535	535
Totals	**56**	**668**	**$3,132**

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Design Considerations		
•	Tributary Area	
•	Area Required	
•	Slope	
•	Water Availability	
•	LID/Green Design	
Target Constituents		
✓	Sediments	M
✓	Nutrients	L
✓	Trash	L
✓	Metals	M
✓	Bacteria	L
✓	Oil and Grease	M
✓	Organics	U
Legend (Removal Effectiveness)		
L	Low	
M	Medium	
H	High	
U	Unknown	

Description

Vegetated swales are open, shallow channels with vegetation covering the side slopes and bottom that collect and slowly convey runoff flow to downstream discharge points. They are designed to treat runoff through filtering by the vegetation in the channel, filtering through a subsoil matrix, and/or infiltration into the underlying soils. Swales can be natural or manmade. They trap particulate pollutants (suspended solids and trace metals), promote infiltration, and reduce the flow velocity of storm water runoff. Vegetated swales can serve as part of a storm water drainage system and can replace curbs, gutters and storm sewer systems.

Advantages

- Vegetated swales adhere to LID principles.
- If properly designed, vegetated, and operated, swales can serve as an aesthetic, potentially inexpensive urban development or roadway drainage conveyance measure with significant collateral water quality benefits.
- Because swales are linear practices, roadside ditches should be regarded as significant potential swale/buffer strip sites and should be utilized for this purpose whenever possible.
- Vegetated swales are appropriate for storm water retrofits. One retrofit opportunity using grassed swales modifies existing drainage ditches by incorporating features to enhance pollutant removal or infiltration such as check dams (i.e., small dams along the ditch that trap sediment, slow runoff, and reduce the effective longitudinal slope).
- Grassed channels and dry swales can provide some ground water recharge, depending on the underlying soil characteristics.

Limitations

- Can be difficult to avoid channelization.
- May not be appropriate for industrial sites or locations where spills may occur. With the exception of the enhanced swale design, hot spot runoff should not be directed toward vegetated channels. These practices either infiltrate storm water or intersect the ground water, making use of the practices for hot spot runoff a threat to ground water quality.

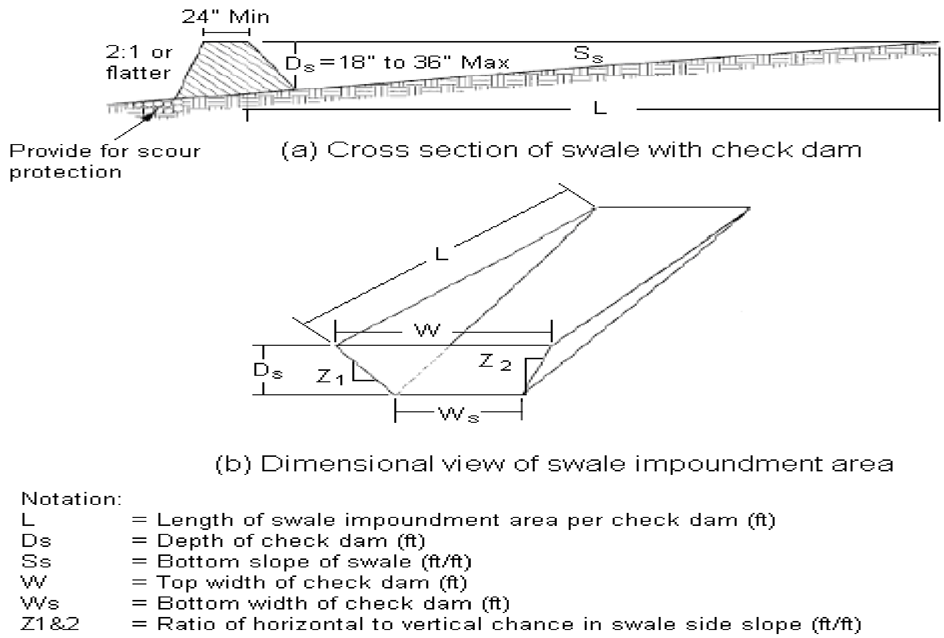
Note: Storm water hot spots are areas where land use or activities generate highly contaminated runoff, with concentrations of pollutants exceeding those typically found in storm water, i.e., gas stations.

- Grassed swales cannot treat a very large drainage area. Large areas may be divided and treated using multiple swales.
- A thick vegetative cover is needed for these practices to function properly.
- They are impractical in areas with steep topography. If the proper slope is not achieved, grassed channels will have very little pollutant removal.
- If flow velocities are high (velocities not to exceed one (1) feet per second), swales will not perform effectively and may erode if the grass cover is not properly maintained.
- Swales are more susceptible to failure when not properly maintained compared to other treatment BMPs.
- The value of vegetated practices for water quality needs to be balanced against the cost of water needed to maintain them in arid and semi-arid regions.
- Wet swales may become a nuisance, as they are susceptible to mosquito breeding.
- Vegetated swales may have restricted effectiveness on sites having highly impermeable soils.
- Wet swales generally make little, if any, contributions to ground water recharge.

Design and Sizing Guideline

- The vegetated swale should be sized for the water quality flow rate based on a peak rainfall intensity of 0.4 inches per hour as specified in the City Drainage Rules.
- Swales should also have the capacity to pass larger storms safely (typically a 10-year storm).
- Swale should be designed so that the water level does not exceed 2/3rds the height of the grass or 4 inches, whichever is less, at the design treatment rate. Grass design height of 6 inches is recommended.
- Generally a longitudinal 1% slope is minimum, but should not exceed 4% as it becomes more difficult to maintain a velocity below one (1) foot per second at steeper slopes. A slope of 1 to 2% is recommended.
- Consider the use of velocity reducing measures such as check dams. (See the figure that follows; Check Dam)

Check Dam



- Trapezoidal channels are normally recommended but other configurations, such as parabolic and triangular, can also provide substantial water quality improvement and may be easier to mow than designs with sharp breaks in slope. Either shape should have side slopes flatter than 3:1, which increases the wetted perimeter.
- Do not use side slopes constructed of fill, which are prone to structural damage by burrowing insects and animals.
- A diverse selection of low growing, plants that thrive under the specific site, climatic, and watering conditions should be specified. Vegetation whose growing season corresponds to the wet season is preferred. Drought tolerant vegetation should be considered especially for swales that are not part of a regularly irrigated landscaped area.
- The width of the swale should be determined using Manning’s Equation using a value of 0.20 for Manning’s n.
- The drainage area should be less than five (5) acres.
- Pretreatment may be provided in the form of a small forebay used at the front of the swale to trap incoming sediments. A pea gravel diaphragm, a small trench filled with river-run gravel, may be constructed along the length of the swale and used as pretreatment for runoff entering at the sides of the swale.
- Three variations of open channel vegetated swales include the grassed channel, the enhanced swale, and the wet swale.
  - Grassed Channel: Of the three (3) grassed swale designs, grassed channels are the most similar to a conventional drainage ditch, with the major differences being flatter side slopes, flatter longitudinal slopes, and a slower design velocity for water quality treatment of small storm events. Grassed channels are the least expensive but also provide the least reliable pollutant removal. An excellent application of a grassed channel is as pretreatment to other structural storm water practices. A major difference between the grassed channel and

many other structural practices is the method used to size the practice. Most storm water management water quality practices are sized by volume. This method sets the volume available in the practice equal to the water quality volume, or the volume of water to be treated in the practice. The grassed channel is a flow-rate-based design. Based on the peak flow from the water quality storm, the channel should be designed so that runoff takes, on average, seven (7) minutes to flow from the top to the bottom of the channel. A procedure for this design can be found in Design of Storm Water Filtering Systems (CWP, 1996).

- Enhanced Swales: Enhanced swales are similar in design to vegetated biofilters (see TC-32). Enhanced swales are a relatively new design, but studies of swales with a native soil similar to the man-made soil bed of dry swales suggest high pollutant removal.
- Wet Swales: Wet swales intersect the ground water and behave similarly to a linear wetland cell. This design variation incorporates a shallow permanent pool and wetland vegetation to provide storm water treatment. This design also has potentially high pollutant removal.

Construction/Inspection Considerations

- Include directions in the specifications for use of appropriate fertilizer and soil amendments based on soil properties determined through testing and compared to the needs of the vegetation requirements.
- Install swales at the time of the year when there is a reasonable chance of successful establishment without irrigation; however, it is recognized that rainfall in a given year may not be sufficient and temporary irrigation may be used.
- If sod tiles must be used, they should be placed so that there are no gaps between the tiles; stagger the ends of the tiles to prevent the formation of channels along the swale or strip.
- Use a roller on the sod to ensure that no air pockets form between the sod and the soil.
- Where seeds are used, erosion controls will be necessary to protect seeds for at least 75 days after the first rainfall of the season.

Performance

Generally, vegetated swales represent a practical and potentially effective technique for controlling urban runoff quality. While limited quantitative performance data exists for vegetated swales, it is known that check dams, slight slopes, permeable soils, dense grass cover, increased contact time, and small storm events all contribute to successful pollutant removal by the swale system. Factors decreasing the effectiveness of swales include compacted soils, short runoff contact time, large storm events, density of ground cover, short grass heights, steep slopes, and high runoff velocities and discharge rates.

Conventional vegetated swale designs have achieved mixed results in removing particulate pollutants. A study performed by the Nationwide Urban Runoff Program (NURP) monitored three grass swales in the Washington, D.C., area and found no significant improvement in urban runoff quality for the pollutants analyzed. However, the weak performance of these swales was attributed to the high flow velocities in the swales, soil compaction, steep slopes, and short grass height.

Another project in Durham, NC, monitored the performance of a carefully designed artificial swale that received runoff from a commercial parking lot. The project tracked 11 storms and concluded that particulate concentrations of heavy metals (Cu, Pb, Zn, and Cd) were reduced by approximately 50%. However, the swale proved largely ineffective for removing soluble nutrients.

The effectiveness of vegetated swales can be enhanced by adding check dams at approximately 50 foot (17 meters) increments along their length (see previous figure). These dams maximize the retention time within the swale, decrease flow velocities, and promote particulate settling. Finally, the incorporation of vegetated filter strips parallel to the top of the channel banks can help to treat sheet flows entering the swale.

Few studies are available regarding the effectiveness of grassed channels. Data from such studies suggest relatively high removal rates for some pollutants, negative removals for some bacteria, and fair performance for phosphorous. One study of available performance data estimates the removal rates for grassed channels as:

Grassed Swale Pollutant Removal Efficiency Data

Total Suspended Solids	*81%*
Total Phosphorus	*29%*
Nitrate Nitrgogen	*38%*
Metals	*14-55%*
Bacteria	*-50%*

Removal Efficiencies (% Removal)							
Study	**TSS**	**TP**	**TN**	**NO3**	**Metals**	**Bacteria**	**Type**
Caltrans 2002	77	8	67	66	83-90	-33	Dry swale
Goldberg 1993	67.8	4.5	-	-25	42-62	-100	Grassed channel
Seattle Metro and Washington Department of Ecology, 1992	60	45	-	-25	2-16	-25	Grassed channel
Seattle Metro and Washington Department of Ecology, 1992	83	29	-	-25	46-73	-25	Grassed channel
Wang et al., 1981	80	-	-	-	70-80	-	Dry swale
Dorman et al., 1989	98	18	-	45	37-81	-	Dry swale
Harper, 1988	87	83	84	80	88-90	-	Dry swale
Kercher et al., 1983	99	99	99	99	99	-	Dry swale
Harper, 1988	81	17	40	52	37-69	-	Wet swale
Koon , 1995	97	39	-	9	-35 to 6	-	Wet swale

Source: Schueler, 1997

While it is difficult to distinguish between different designs based on the small amount of available data, grassed channels generally have poorer removal rates than wet and dry swales, although some swales appear to export soluble phosphorus (Harper, 1988; Koon, 1995). It is not clear why swales export bacteria. One explanation is that bacteria thrive in the warm swale soils.

Siting Criteria

The suitability of a swale at a site will depend on land use, size of the area serviced, soil type, slope, imperviousness of the contributing watershed, and dimensions and slope of the swale system (Schueler et al., 1992). In general, swales can be used to serve areas of less than 10 acres, with slopes no greater than 5%. Use of natural topographic lows is encouraged and natural drainage courses should be regarded as significant local resources to be kept in use (Young et al., 1996).

Selection Criteria (NCTCOG, 1993)

- Comparable performance to wet basins.
- Limited to treating a few acres.
- Availability of water during dry periods to maintain vegetation.
- Sufficient available land area.

Research in the Austin area indicates that vegetated controls are effective at removing pollutants even when dormant. Therefore, irrigation is not required to maintain growth during dry periods, but may be necessary only to prevent the vegetation from dying.

The topography of the site should permit the design of a channel with appropriate slope and cross-sectional area. Site topography may also dictate a need for additional structural controls. Recommendations for longitudinal slopes range between 1 to 2.5%. Flatter slopes can be used, if sufficient to provide adequate conveyance. Steep slopes increase flow velocity, decrease detention time, and may require energy dissipating and grade check. Steep slopes also can be managed using a series of check dams to terrace the swale and reduce the slope to within acceptable limits. The use of check dams with swales also promotes infiltration.

Additional Design Guidelines

Most of the design guidelines adopted for swale design specify a minimum hydraulic residence time of nine (9) minutes. This criterion is based on the results of a single study conducted in Seattle, Washington (Seattle Metro and Washington Department of Ecology, 1992), and is not well supported. Analysis of the data collected in that study indicates that pollutant removal at a residence time of five (5) minutes was not significantly different, although there is more variability in that data. Therefore, additional research in the design criteria for swales is needed. Substantial pollutant removal has also been observed for vegetated controls designed solely for conveyance (Barrett et al, 1998); consequently, some flexibility in the design is warranted.

Many design guidelines recommend that grass be frequently mowed to maintain dense coverage near the ground surface. Recent research (Colwell et al., 2000) has shown mowing frequency or grass height has little or no effect on pollutant removal.

In arid or semi-arid climates, swales should be designed with drought-tolerant vegetation, i.e., buffalo grass.

Summary of Design Recommendations

- The swale should have a length that provides a minimum hydraulic residence time of at least seven (7) minutes. The maximum bottom width should not exceed 10 feet unless a dividing berm is provided. The depth of flow should not exceed 2/3 the height of the grass at the peak of the water quality design storm intensity.
- A design grass height of six (6) inches is recommended.
- The width of the swale should be determined using Manning's Equation, at the peak of the design storm, using a Manning's n of 0.20. The side slopes should be no steeper than 3:1 (H:V).
- Typical designs allow the runoff from the 2-year storm (i.e., the storm having the probability of occurring every 2 years), but flow rate based design should be determined by the hydrological methods by City Drainage Rules. Swales should also have the capacity to pass larger storms

safely (typically a 10-year storm). The swale can be sized as both a treatment facility for the design storm and as a conveyance system to pass the peak hydraulic flows of the 100-year storm if it is located "on-line."

- Roadside ditches should be regarded as significant potential swale/buffer strip sites and should be utilized for this purpose whenever possible. If flow is to be introduced through curb cuts, place pavement slightly above the elevation of the vegetated areas. Curb cuts should be at least 12 inches wide to prevent clogging.
- Swales must be vegetated in order to provide adequate treatment of runoff. It is important to maximize water contact with vegetation and the soil surface. For general purposes, select fine, close-growing, water-resistant grasses. If possible, divert runoff (other than necessary irrigation) during the period of vegetation establishment. Where runoff diversion is not possible, cover graded and seeded areas with suitable erosion control materials.

Maintenance

Maintenance of grassed swales mostly involves litter control, sediment and debris removal, and maintaining the grass or wetland plant cover. The useful life of a vegetated swale system is directly proportional to its maintenance frequency. If properly designed and regularly maintained, vegetated swales can last indefinitely. The maintenance objectives for vegetated swale systems include keeping up the hydraulic and removal efficiency of the channel and maintaining a dense, healthy grass cover.

Maintenance activities should include periodic mowing (with grass never cut shorter than the design flow depth), weed control, watering during drought conditions, reseeding of bare areas, and clearing of debris and blockages. Cuttings should be removed from the channel and disposed in a local composting facility. Accumulated sediment should also be removed manually to avoid concentrated flows in the swale. The application of fertilizers and pesticides should be minimal.

Another aspect of a good maintenance plan is repairing damaged areas within a channel. For example, if the channel develops ruts or holes, it should be repaired utilizing a suitable soil that is properly tamped and seeded. The grass cover should be thick; if it is not, reseed as necessary. Any standing water removed during the maintenance operation must be disposed to a sanitary sewer at an approved discharge location. Residuals (i.e., silt, grass cuttings) must be disposed in accordance with City and County of Honolulu requirements. Maintenance of grassed swales mostly involves maintenance of the grass or wetland plant cover. Typical maintenance activities are summarized below:

- Inspect swales at least twice annually for erosion, damage to vegetation, and sediment and debris accumulation, preferably at the end of the wet season. Additional inspection after periods of heavy runoff is desirable.
- Grass height and mowing frequency may not have a large impact on pollutant removal. Consequently, mowing may only be necessary once or twice a year for safety or aesthetics or to suppress weeds and woody vegetation.
- Trash tends to accumulate in swale areas, particularly along highways. The need for litter removal is determined through periodic inspection, but litter should always be removed prior to mowing.
- Sediment accumulating near culverts and in channels should be removed when it builds up to 75 mm (3 inches) at any spot, or covers vegetation.
- Regularly inspect swales for pools of standing water. Swales can become a nuisance due to mosquito breeding in standing water if obstructions develop (i.e., debris accumulation, invasive vegetation) and/or if proper drainage slopes are not implemented and maintained.

Cost

In general, Hawaii's unit prices are higher than California's unit prices.

Construction Cost

Little data is available to estimate the difference in cost between various swale designs. One study performed by the Southeastern Wisconsin Regional Planning Commission (SWRCP) estimated the construction cost of grassed channels at approximately \$0.25 per feet^2 (see the following table) (SWRPC, 1991). This price does not include design costs or contingencies. Brown and Schueler (1997) estimate these costs at approximately 32% of construction costs for most storm water management practices. For swales, however, these costs would probably be significantly higher since the construction costs are so low compared with other practices. A more realistic estimate would be a total cost of approximately \$0.50 per feet^2, which compares favorably with other storm water management practices.

Costs to construct swales should be taken in context. With most development designs, some conveyance structure must be constructed as part of the development. The construction of grass swales is less expensive than concrete ditches or sewers. Hence, the use of grass swales is often a less expensive alternative than traditional design approaches.

Swale Cost Estimate

Component	Unit	Extent	Unit Cost			Total Cost		
			Low	Moderate	High	Low	Moderate	High
Mobilization/ Demobilization-Light	Swale	1	\$107	\$274	\$441	\$107	\$274	\$441
Site Preparation								
Clearing[b]	Acre	0.5	\$2,200	\$3,800	\$5,400	\$1,100	\$1,900	\$2,700
Grubbing[c]	Acre	0.25	\$3,800	\$5,200	\$6,600	\$950	\$1,300	\$1,650
General Excavation[d]	Yard^3	372	\$2.10	\$3.70	\$5.30	\$781	\$1,376	\$1,972
Level and Till[e]	Yard^2	1,210	\$0.20	\$0.35	\$0.50	\$424	\$424	\$605
Sites Development								
Salvaged Topsoil								
Seed, and Mulch[f]	Yard^2	1,210	\$0.40	\$1.00	\$1.60	\$484	\$1,210	\$1,936
Sod[g]	Yard^2	1,210	\$1.20	\$2.40	\$3.60	\$1,452	\$2,904	\$4,356
Subtotal	--	--	--	--	--	\$5,116	\$9,388	\$13,660
Contingencies	Swale	1	25%	25%	25%	\$1,279	\$2,347	\$3,415
Total	--	--	--	--	--	\$6,395	\$11,735	\$17,075

Source: (SWRPC, 1991

Note: Mobilization/demobilization refers to the organization and planning involved in establishing a vegetative swale.
[a] Swale has a bottom width of 1.0 foot, a top width of 10 feet with 1:3 side slopes, and a 1,000-foot length
[b] Area cleared = (top width + 10 feet) x swale length
[c] Area grubbed = (top width x swale length)
[d] Volume excavated = (0.67 x top width x swale depth) x swale length (parabolic cross-section)
[e] Area tilled = (top width + $\frac{8(\text{swale depth } 2)}{3(\text{top width})}$ x swale length (parabolic cross-section))
[f] Area seeded = area cleared x 0.5
[g] Area sodded = area cleared x 0.5

Maintenance Cost

Caltrans (2002) estimated the expected annual maintenance cost for a swale with a tributary area of approximately 2 hectare at approximately $2,700. Since almost all maintenance consists of mowing, the cost is fundamentally a function of the mowing frequency. Unit costs developed by SEWRPC are shown in the next table. In many cases vegetated channels would be used to convey runoff and would require periodic mowing as well, so there may be little additional cost for the water quality component. Since essentially all the activities are related to vegetation management, no special training is required for maintenance personnel.

Estimated Maintenance Cost

Component	Unit Cost	Swale Size (Depth and Top width)		Comment
		1.5 feet Depth, 1 foot Bottom width, 10 feet Top Width	3 feet Depth, 3 feet Bottom width, 21 feet Top Width	
Lawn Mowing	$0.85/1,000 feet/mowing	$0.14/linear feet	$0.21/linear feet	Lawn maintenance area = (top width + 10 feet) x length. Mow 8 times per year
General Lawn Care	$9.00/1,000 feet/year	$0.18/linear feet	$0.28/linear feet	Law maintenance area = (top width + 10 feet) x length
Swale Debris and Litter Removal	$0.10/linear feet/year	$0.10/linear feet	$0.10/linear feet	--
Grass Reseeding with Mulch and Fertilizer	$0.30/yard	$0.01/linear feet	$0.01/linear feet	Area revegetated equals 1% of lawn maintenance area per year
Program Adminstration and Swale Inspection	$0.15/linear feet/year, plus $25/inspection--	$0.15/linear feet	$0.15/linear feet	Inspect 4 times per year
Total		$0.58/linear feet	$0.75/linear feet	--

Source: SEWRPC, 1991

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Vegetated Buffer Strip TC-31

Design Considerations		
•	Tributary Area	
•	Slope	
•	Water Availability	
•	Aesthetics	
•	LID/Green Design	
Target Constituents		
✓	Sediments	M
✓	Nutrients	L
✓	Trash	M
✓	Metals	M
✓	Bacteria	L
✓	Oil and Grease	M
✓	Organics	M
Legend (Removal Effectiveness)		
L	Low	
M	Medium	
H	High	

Description

Grassed buffer strips (vegetated filter strips, filter strips, and grassed filters) are vegetated surfaces that are designed to treat sheet flow from adjacent surfaces. Filter strips function by slowing runoff velocities and allowing sediment and other pollutants to settle and by providing some infiltration into underlying soils. Filter strips were originally used as an agricultural treatment practice and have more recently evolved into an urban practice. With proper design and maintenance, filter strips can provide relatively high pollutant removal. In addition, the public views them as landscaped amenities and not as storm water infrastructure. Consequently, there is little resistance to their use.

Advantages

- Vegetated buffer strips adhere to LID principles.
- Buffers require minimal maintenance activity (generally just erosion prevention and mowing).
- If properly designed, vegetated, and operated, buffer strips can provide reliable water quality benefits in conjunction with high aesthetic appeal.
- Flow characteristics and vegetation type and density can be closely controlled to maximize BMP effectiveness.
- Roadside shoulders act as effective buffer strips when slope and length meet criteria described as follows.

Limitations

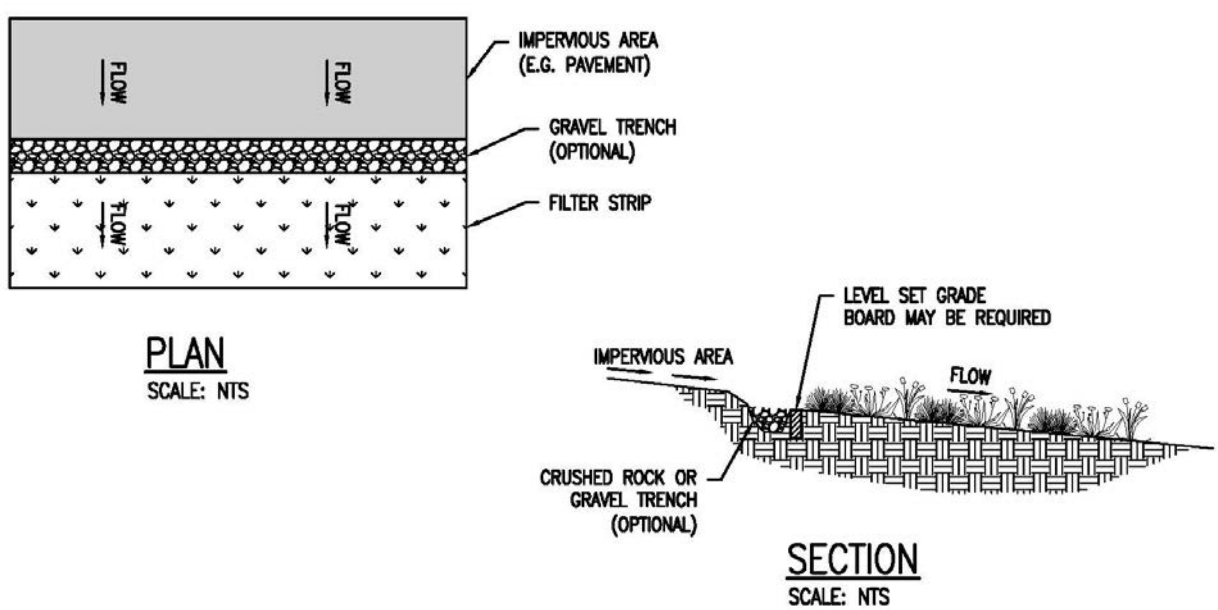
- May not be appropriate for industrial sites or locations where spills may occur.
- Buffer strips cannot treat a very large drainage area.
- A thick vegetative cover is needed for these practices to function properly. Vegetation shall be of a species not susceptible to rank growth.
- Buffer or vegetative filter length must be adequate and flow characteristics acceptable or water quality performance can be severely limited.

- Vegetative buffers may not provide treatment for dissolved constituents except to the extent that flows across the vegetated surface are infiltrated into the soil profile.
- This technology does not provide significant attenuation of the increased volume and flow rate of runoff during intense rain events.

Design and Sizing Guidelines

- Maximum length (in the direction of flow towards the buffer) of the tributary area should be 75 feet.
- Slopes should not exceed 15%.
- Minimum length (in direction of flow) is 15 feet.
- Either grass or a diverse selection of other low growing, drought tolerant, native vegetation should be specified. Vegetation whose growing season corresponds to the wet season is preferred.
- A conceptual layout of a vegetated buffer strip is illustrated in the figure below.
- Include directions in the specifications for use of appropriate fertilizer and soil amendments based on soil properties determined through testing and compared to the needs of the vegetation requirements.
- Install strips at the time of the year when there is a reasonable chance of successful establishment without irrigation; however, it is recognized that rainfall in a given year may not be sufficient and temporary irrigation may be required.
- If sod tiles must be used, they should be placed so that there are no gaps between the tiles; stagger the ends of the tiles to prevent the formation of channels along the strip.
- Use a roller on the sod to ensure that no air pockets form between the sod and the soil.
- Where seeds are used, erosion controls will be necessary to protect seeds for at least 75 days after the first rainfall of the season.

Vegetated Buffer Strip



Construction/Inspection Considerations

Performance

Structural storm water management practices can be used to achieve four broad resource protection goals. These include flood control, channel protection, ground water recharge, and pollutant removal. The first two goals, flood control and channel protection, require that a storm water practice be able to reduce the peak flows of relatively large storm events (at least 1- to 2-year storms for channel protection and at least 10- to 50-year storms for flood control). Filter strips do not have the capacity to detain these events, but can be designed with a bypass system that routes these flows around the practice entirely.

Filter strips can provide a small amount of ground water recharge as runoff flows over the vegetated surface and ponds at the toe of the slope. In addition, it is believed that filter strips can provide modest pollutant removal. Studies from agricultural settings suggest that a 15-foot-wide grass buffer can achieve a 50% removal rate of nitrogen, phosphorus, and sediment, and that a 100-foot buffer can reach closer to 70% removal of these constituents (Desbonette et al., 1994). It is unclear how these results can be translated to the urban environment, however. The characteristics of the incoming flows are radically different both in terms of pollutant concentration and the peak flows associated with similar storm events. To date, only one study (Yu et al., 1992) has investigated the effectiveness of a grassed filter strip to treat runoff from a large parking lot. The study found that the pollutant removal varied depending on the length of flow in the filter strip. The narrower (75-foot) filter strip had moderate removal for some pollutants and actually appeared to export lead, phosphorus, and nutrients. (See table below)

Pollutant Removal of an Urban Vegetated Filter Strip

	Pollutant Removal (%)	
	75-Feet Filter Strip	**150-Feet Filter Strip**
Total suspended solids	54	84
Nitrate+nitrite	-27	20
Total phosphorus	-25	40
Extractable lead	-16	50
Extracable zinc	-47	55

Filter strips also exhibit good removal of litter and other floatables because the water depth in these systems is well below the vegetation height and consequently these materials are not easily transported through them. Unfortunately little attenuation of peak runoff rates and volumes (particularly for larger events) is normally observed, depending on the soil properties. Therefore it may be prudent to follow the strips with another practice than can reduce flooding and channel erosion downstream.

Siting Criteria

The use of buffer strips is limited to gently sloping areas where the vegetative cover is robust and diffuse, and where shallow flow characteristics are possible. The practical water quality benefits can be effectively eliminated with the occurrence of significant erosion or when flow concentration occurs across the vegetated surface. Slopes should not exceed 15% or be less than 1%. The vegetative surface should extend across the full width of the area being drained. The upstream boundary of the filter should be located contiguous to the developed area. Use of an optional level spreading device (vegetated berm, sawtooth concrete border, rock trench, etc) to facilitate overland sheet flow is not normally recommended because of maintenance considerations and the potential for standing water.

Filter strips are applicable in most regions, but are restricted in some situations because they consume a large amount of space relative to other practices. Filter strips are best suited to treating runoff from roads and highways, roof downspouts, small parking lots, and pervious surfaces. They are also ideal components of the "outer zone" of a stream buffer or as pretreatment to a structural practice. In arid areas, however, the cost of irrigating the grass on the practice will most likely outweigh its water quality benefits, although aesthetic considerations may be sufficient to overcome this constraint. Filter strips are generally impractical in ultra-urban areas where little pervious surface exists.

Filter strips should be separated from the ground water by between 2 and 4 feet to prevent contamination and to ensure that the filter strip does not remain wet between storms.

Additional Design Guidelines

Filter strips appear to be a minimal design practice because they are basically no more than a grassed slope. Both the top and toe of the slope should be as flat as possible to encourage sheet flow and prevent erosion. The top of the strip should be installed 2 to 5 inches below the adjacent pavement, so that vegetation and sediment accumulation at the edge of the strip does not prevent runoff from entering the filter strips.

A major question that remains unresolved is how large the drainage area to a strip can be. Research has conclusively demonstrated that these are effective on roadside shoulders, where the contributing area is about twice the buffer area. They have also been installed on the perimeter of large parking lots where they performed fairly effectively; however much lower slopes may be needed to provide adequate water quality treatment.

The filter area should be densely vegetated with a mix of erosion-resistant plant species that effectively bind the soil. Native or adapted grasses, shrubs, and trees are preferred because they generally require less fertilizer and are more drought resistant than exotic plants. Runoff flow velocities should not exceed one (1) $foot^2$ across the vegetated surface.

For engineered vegetative strips, the facility surface should be graded flat prior to placement of vegetation. Initial establishment of vegetation requires attentive care including appropriate watering, fertilization, and prevention of excessive flow across the facility until vegetation completely covers the area and is well established. Use of a permanent irrigation system may help provide maximal water quality performance.

Maintenance

Filter strips require mainly vegetation management; therefore little special training is needed for maintenance crews. Typical maintenance activities and frequencies include:

- Inspect strips at least twice annually for erosion or damage to vegetation, ideally after periods of heavy runoff. The strip should be checked for debris and litter and areas of sediment accumulation.
- Recent research on biofiltration swales, but likely applicable to strips (Colwell et al., 2000), indicates that grass height and mowing frequency have little impact on pollutant removal; consequently, mowing may only be necessary once or twice a year for safety and aesthetics or to suppress weeds and woody vegetation.
- Trash tends to accumulate in strip areas, particularly along highways. The need for litter removal should be determined through periodic inspection but litter should always be removed prior to mowing.

- Regularly inspect vegetated buffer strips for pools of standing water. Vegetated buffer strips can become a nuisance due to mosquito breeding in level spreaders (unless designed to dewater completely in 48 to 72 hours), in pools of standing water if obstructions develop (i.e., debris accumulation, invasive vegetation), and/or if proper drainage slopes are not implemented and maintained.

Cost

In general, Hawaii's unit prices are higher than California's unit prices.

Cost Considerations

Little data is available on the actual construction costs of filter strips. One (1) rough estimate can be the cost of seed or sod, which is approximately 30¢ per feet^2 for seed or 70¢ per feet^2 for sod. This amounts to between $13,000 and $30,000 per acre of filter strip. This cost is relatively high compared with other treatment practices. However, the grassed area used as a filter strip may have been seeded or sodded even if it were not used for treatment. In these cases, the only additional cost is the design. Typical maintenance costs are about $350/acre/year (adapted from SWRPC, 1991). This cost is relatively inexpensive and, again, might overlap with regular landscape maintenance costs.

The true cost of filter strips is the land they consume. In some situations this land is available as wasted space beyond back yards or adjacent to roadsides, but this practice is cost-prohibitive when land prices are high and land could be used for other purposes.

Maintenance of vegetated buffer strips consists mainly of vegetation management (mowing, irrigation if needed, weeding) and litter removal. Consequently the costs are quite variable depending on the frequency of these activities and the local labor rate.

Maintenance Cost

Maintenance of vegetated buffer strips consists mainly of vegetation management (mowing, irrigation if needed, weeding) and litter removal. Consequently the costs are quite variable depending on the frequency of these activities and the local labor rate.

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Design Considerations		
•	LID/Green Design	
•	Soil for Infiltration	
•	Tributary Area	
•	Aesthetics	
•	Environmental Side Effects	
Target Constituents		
✓	Sediments	H
✓	Nutrients	M
✓	Trash	H
✓	Metals	H
✓	Bacteria	M
✓	Oil and Grease	H
✓	Organics	H
Legend (Removal Effectiveness)		
L	Low	
M	Medium	
H	High	

Description

Vegetated Biofilters, or bioretention areas or rain gardens, are landscaping features adapted to provide on-site treatment of storm water runoff. The vegetated biofilter functions as a soil and plant-based filtration device that removes pollutants through a variety of physical, biological, and chemical treatment processes similar to the mechanisms used in forested ecosystems. These facilities normally consist of a grass buffer strip, sand bed, ponding area, organic layer or mulch layer, planting soil, and plants. The runoff's velocity is reduced by passing over or through buffer strip and subsequently distributed evenly along a ponding area. The filtered runoff discharges through an underdrain system.

Other Jurisdictions

Vegetated Biofilters have been used as storm water BMPs since 1992. In addition to Prince George's County, MD and Alexandria, VA, vegetated biofilters have been used successfully at urban and suburban areas in Montgomery County, MD; Baltimore County, MD; Chesterfield County, VA; Prince William County, VA; Smith Mountain Lake State Park, VA; and Cary, NC.

Advantages

- Vegetated Biofilters adhere to LID principles.
- Vegetated Biofilters provide storm water treatment that enhances the quality of downstream water bodies by temporarily storing runoff in the BMP and releasing it over a period of four days to the receiving water (EPA, 1999).
- The vegetation provides shade and wind breaks, absorbs noise, and improves an area's landscape.
- Vegetated biofilters can be used to treat storm water hot spots as long as an impermeable liner is used at the bottom of the filter bed. Storm water hot spots are areas where land use or activities generate highly contaminated runoff, with concentrations of pollutants in excess of those typically found in storm water, i.e., gas stations.
- Vegetated biofilters are suited to be used in highly urbanized areas in which little pervious surfaces exist. They can be incorporated into existing parking lot islands or other landscaped areas.

- Vegetated biofilters may be applied on almost any soil type or topography because it utilizes a man-made soil bed and is returned to the storm water system.
- Vegetated biofilters implementing partial exfiltration may be used to promote ground water recharge. In the partial exfiltration system, the underdrain is only installed on a portion of the biofilter bed, allowing for some infiltration. (This system can only be applied where soil and other characteristics are appropriate for infiltration).
- Vegetated biofilters are appropriate for storm water retrofits.

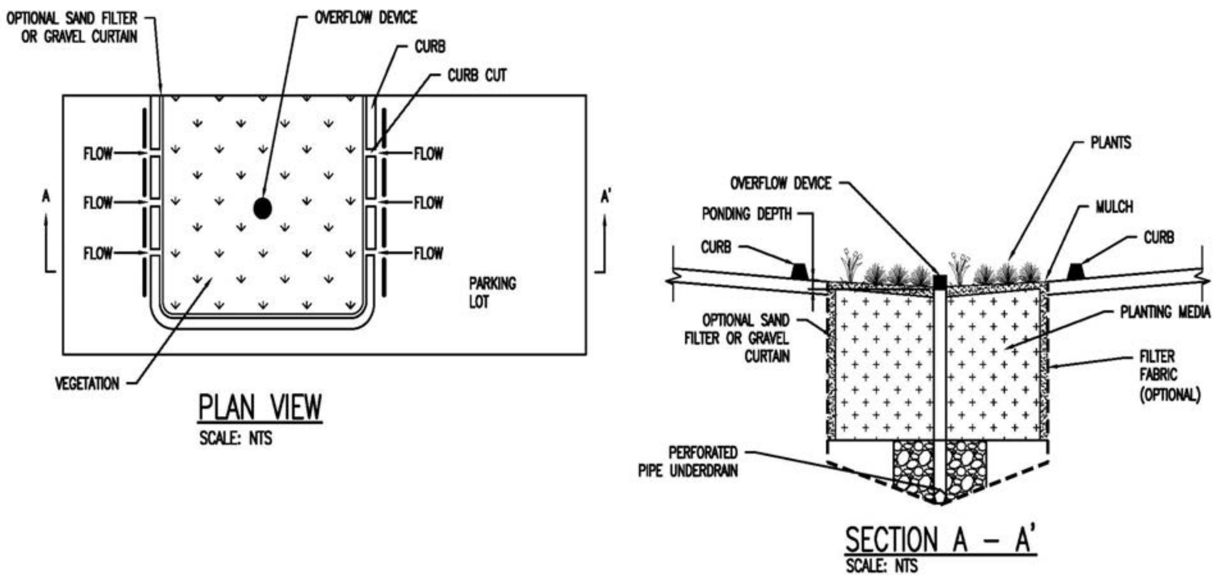
Limitations

- The vegetated biofilter BMP is not recommended for areas with slopes greater than 20% or where mature tree removal would be required since clogging may result, particularly if the BMP receives runoff with high sediment loads (EPA, 1999).
- Vegetated biofilters are not a suitable BMP at locations where the water table is within 6 feet of the ground surface and where the surrounding soil stratum is unstable.
- By design, vegetated biofilters have the potential to create very attractive habitats for mosquitoes and other vectors because of highly organic, often heavily vegetated areas mixed with shallow water.
- Vegetated biofilters do not provide substantial channel protection and are not able to infiltrate large volumes. They are typically designed to treat and infiltrate only the first inch of runoff and are bypassed by larger flows that can erode channels.
- Although a vegetated biofilter will only consume about 5% of the drainage area, it may reduce the number of parking spaces available if islands were not previously included in the layout design.
- The use of vegetated biofilters may not be feasible given an unstable surrounding soil stratum or soils with clay content greater than 25%.

Design and Sizing Guidelines

- The vegetated biofilter should be sized to capture the water quality volume based on a 1 inch rain storm as specified in the City Drainage Rules.
- In areas where the native soil permeability is less than 0.5 inch/hour an underdrain should be provided.
- Recommended minimum dimensions are 15 feet by 40 feet, although the preferred width is 25 feet. Excavated depth should be 4 feet.
- Area should drain completely within 48 hours.
- Approximately 1 tree or shrub per 50 feet^2 of vegetated biofilter should be included.
- Cover area with 2 to 4 inches of mulch.
- Vegetated biofilters are best applied to relatively shallow slopes (usually about 5%). Make sure, however, that there is sufficient slope to ensure water can connect with the storm drain system after infiltrating through biofilter area.
- The drainage area should be in the range of 0.25 to 1 acres (0.1 to 0.4 hectares).
- A conceptual layout of a vegetated biofilter is illustrated in the Example Vegetated Biofilter figure.

Example Vegetated Biofilter



Construction/Inspection Considerations

Vegetated biofilters should not be established until contributing watershed is stabilized.

Performance

Vegetated biofilters remove storm water pollutants through physical and biological processes, including adsorption, filtration, plant uptake, microbial activity, decomposition, sedimentation and volatilization (EPA, 1999). Adsorption is the process whereby particulate pollutants attach to soil (i.e., clay) or vegetation surfaces. Adequate contact time between the surface and pollutant must be provided for in the design of the system for this removal process to occur. Thus, the infiltration rate of the soils must not exceed those specified in the design criteria or pollutant removal may decrease. Pollutants removed by adsorption include metals, phosphorus, and hydrocarbons. Filtration occurs as runoff passes through the vegetated biofilter media, such as the sand bed, ground cover, and planting soil.

Common particulates removed from storm water include particulate organic matter, phosphorus, and suspended solids. Biological processes that occur in wetlands result in pollutant uptake by plants and microorganisms in the soil. Plant growth is sustained by the uptake of nutrients from the soils, with woody plants locking up these nutrients through the seasons. Microbial activity within the soil also contributes to the removal of nitrogen and organic matter. Nitrogen is removed by nitrifying and denitrifying bacteria, while aerobic bacteria are responsible for the decomposition of the organic matter. Microbial processes require oxygen and can result in depleted oxygen levels if the vegetated biofilter is not adequately aerated. The microbial activity and plant uptake occurring in the vegetated biofilter will likely result in higher removal rates than those determined for infiltration BMPs. Sedimentation occurs in the swale or ponding area as the velocity slows and solids fall out of suspension.

There is considerable variability in the effectiveness of vegetated biofilters, and it is believed that properly designing and maintaining these areas may help to improve their performance. The siting and design criteria presented in this sheet reflect the best current information and experience to improve the performance of vegetated biofilters.

Pollutant Removal

Little pollutant removal data has been collected on the pollutant removal effectiveness of bioretention areas. A field and laboratory analysis of vegetated biofilters conducted by Davis et al. (1997), showed very high removal rates (roughly 95% for copper, 98% for phosphorus, 20% for nitrate, and 50% for total Kjeldahl nitrogen (TKN). The table below shows data from two other studies of field vegetated biofilter sites in Maryland.

Pollutant Removal Effectiveness of Two (2) Vegetated Biofilters in Maryland

Pollutant	Pollutant Removal
Copper	43-97%
Lead	70%-95%
Zinc	64%-95%
Phosphorus	65%-87%
Total Kjedahl Nitrogen(TKN)	52%-67%
Ammonium (NH_4+)	92%
Nitrate (NO_3-)	15%-16%
Total Nitrgorgen	49%
Calcium	27%

Source: Davis et al., 1997

Siting Criteria

Vegetated biofilters are generally used to treat storm water from impervious surfaces at commercial, residential, and industrial areas (EPA, 1999). Implementation of vegetated biofilters for storm water management is ideal for median strips, parking lot islands, and swales. Moreover, the runoff in these areas can be designed to either divert directly into the vegetated biofilter or convey into the vegetated biofilter by a curb and gutter collection system.

The best location for vegetated biofilters is upland from inlets that receive sheet flow from graded areas and at areas that will be excavated (EPA, 1999). In order to maximize treatment effectiveness, the site must be graded in such a way that minimizes erosive conditions as sheet flow is conveyed to the treatment area. Locations where a vegetated biofilter can be readily incorporated into the site plan without further environmental damage are preferred. Furthermore, to effectively minimize sediment loading in the treatment area, vegetated biofilters only should be used in stabilized drainage areas.

Additional Design Guidelines

The layout of the vegetated biofilter is determined after site constraints such as location of utilities, underlying soils, existing vegetation, and drainage are considered (EPA, 1999). Sites with loamy sand soils are especially appropriate for vegetated biofilters because the excavated soil can be backfilled and used as the planting soil, thus eliminating the cost of importing planting soil.

The use of vegetated biofilters may not be feasible given an unstable surrounding soil stratum, soils with clay content greater than 25%, a site with slopes greater than 20%, and/or a site with mature trees that would be removed during construction of the BMP.

Vegetated biofilters can be designed to be off-line or on-line of the existing drainage system (EPA, 1999). The drainage area for a vegetated biofilter should be between 0.25 to 1.0 acres (0.1 to 0.4 hectares). Larger drainage areas may require multiple vegetated biofilters. Furthermore, the maximum drainage area for a vegetated biofilter is determined by the expected rainfall intensity and runoff rate. Stabilized areas may erode when velocities are greater than 5 feet/second (1.5 meter per second). The designer should determine the potential for erosive conditions at the site.

The size of the vegetated biofilter, which is a function of the drainage area and the runoff generated from the area, is sized to capture the water quality volume.

The recommended minimum dimensions of the vegetated biofilter are 15 feet (4.6 meters) wide by 40 feet (12.2 meters) long, where the minimum width allows enough space for a dense, randomly-distributed area of trees and shrubs to become established. Thus replicating a natural forest and creating a microclimate, thereby enabling the vegetated biofilter to tolerate the effects of heat stress, acid rain, runoff pollutants, and insect and disease infestations which landscaped areas in urban settings typically are unable to tolerate.

In order to provide adequate storage and prevent water from standing for excessive periods of time the ponding depth of the vegetated biofilter should not exceed 12 inches (30 centimeters). Water should not be left to stand for more than 48 hours. A restriction on the type of plants that can be used may be necessary due to some plants' water intolerance. Furthermore, if water is left standing for longer than 72 hours mosquitoes and other insects may start to breed.

The appropriate planting soil should be backfilled into the excavated vegetated biofilter. Planting soils should be sandy loam, loamy sand, or loam texture with a clay content ranging from 10 to 25%.

The pH of the soil should range between 5.5 to 6.5, where pollutants such as organic nitrogen and phosphorus can be absorbed by the soil and microbial activity can flourish. Additional requirements for the planting soil include a 1.5 to 3% organic content and a maximum 500 ppm concentration of soluble salts.

Soil tests should be performed for every 500 cubic yards (382 cubic meters) of planting soil, with the exception of pH and organic content tests, which are required only once per vegetated biofilter (EPA, 1999). Planting soil should be 4 inches (10.1 centimeters) deeper than the bottom of the largest root ball and 4 feet (1.2 meters) altogether. This depth will provide adequate soil for the plants' root systems to become established, prevent plant damage due to severe wind, and provide adequate moisture capacity. Most sites will require excavation in order to obtain the recommended depth.

Planting soil depths of greater than 4 feet (1.2 meters) may require additional construction practices such as shoring measures (EPA, 1999). Planting soil should be placed in 18 inches or greater lifts and lightly compacted until the desired depth is reached. Since high canopy trees may be destroyed during maintenance, the vegetated biofilter should be vegetated to resemble a terrestrial forest community ecosystem that is dominated by understory trees. Three species each of both trees and shrubs are recommended to be planted at a rate of 1000 trees and shrubs per acre (2,500 per hectare). For instance, a 15 foot (4.6 meters) by 40 foot (12.2 meters) vegetated biofilter (600 square feet or 55.75 square meters) would require 14 trees and shrubs. The shrub-to-tree ratio should be 2:1 to 3:1.

Trees and shrubs should be planted when conditions are favorable. Vegetation should be watered at the end of each day for 14 days following its planting. Plant species tolerant of pollutant loads and varying wet and dry conditions should be used in the vegetated biofilter.

The designer should assess aesthetics, site layout, and maintenance requirements when selecting plant species. Adjacent non-native invasive species should be identified and the designer should take measures, such as providing a soil breach to eliminate the threat of these species invading the vegetated biofilter. Regional landscaping manuals should be consulted to ensure that the planting of the vegetated biofilter meets the landscaping requirements established by the local authorities. The designers should evaluate the best placement of vegetation within the vegetated biofilter. Plants should be placed at irregular intervals to replicate a natural forest. Trees should be placed on the perimeter of the area to provide shade and shelter from the wind. Trees and shrubs can be sheltered from damaging flows if they are placed away from the path of the incoming runoff. In cold climates, species that are more tolerant to cold winds, such as evergreens, should be placed in windier areas of the site.

Following placement of the trees and shrubs, the ground cover and/or mulch should be established. Ground cover such as grasses or legumes can be planted at the beginning of the growing season. Mulch should be placed immediately after trees and shrubs are planted. 2 to 4 inches (5 to 10 cm) of commercially-available fine shredded hardwood mulch or shredded hardwood chips should be applied to the bioretention area to protect from erosion.

Maintenance

The primary maintenance requirement for vegetated biofilters is that of inspection and repair or replacement of the treatment area's components. Generally, this involves nothing more than the routine periodic maintenance that is required of any landscaped area. Plants that are appropriate for the site, climatic, and watering conditions should be selected for use in the vegetated biofilter. Appropriately selected plants will aide in reducing fertilizer, pesticide, water, and overall maintenance requirements. Vegetated biofilter system components should blend over time through plant and root growth, organic decomposition, and the development of a natural soil horizon. These biologic and physical processes over time will lengthen the facility's life span and reduce the need for extensive maintenance.

Routine maintenance should include a bi-annual health evaluation of the trees and shrubs and subsequent removal of any dead or diseased vegetation (EPA, 1999). Diseased vegetation should be treated as needed using preventative and low-toxic measures to the extent possible.

BMPs have the potential to create very attractive habitats for mosquitoes and other vectors because of highly organic, often heavily vegetated areas mixed with shallow water. Routine inspections for areas of standing water within the BMP and corrective measures to restore proper infiltration rates are necessary to prevent creating mosquito and other vector habitat. In addition, vegetated biofilters are susceptible to invasion by aggressive plant species such as cattails, which increase the chances of water standing and subsequent vector production if not routinely maintained.

In order to maintain the treatment area’s appearance it may be necessary to prune and weed.

Furthermore, mulch replacement is suggested when erosion is evident or when the site begins to look unattractive. Specifically, the entire area may require mulch replacement every two (2) to three (3) years, although spot mulching may be sufficient when there are random void areas. Mulch replacement should be done prior to the start of the wet season.

New Jersey's Department of Environmental Protection states in their vegetated biofilter systems standards that accumulated sediment and debris removal (especially at the inflow point) will normally be the primary maintenance function. Other potential tasks include replacement of dead vegetation, soil pH regulation, erosion repair at inflow points, mulch replenishment, unclogging the underdrain, and repairing overflow structures. There is also the possibility that the cation exchange capacity of the soils in the cell will be significantly reduced over time.

Depending on pollutant loads, soils may need to be replaced within 5 to 10 years of construction.

Cost

In general, Hawaii's unit prices are higher than California's unit prices.

Construction Cost

Construction cost estimates for a vegetated biofilter are slightly greater than those for the required landscaping for a new development (EPA, 1999). A general rule of thumb (Coffman, 1999) is that residential vegetated biofilters average about \$3 to \$4 per square feet, depending on soil conditions and the density and types of plants used. Commercial, industrial and institutional site costs can range between \$10 to \$40 per square feet, based on the need for control structures, curbing, storm drains and underdrains. A recent study (Brown and Schueler, 1997) estimated the cost for vegetated biofilters, adjusting for inflation, to be described by the following equation:

$$\mathbf{C = 7.30V^{0.99}}$$

Where:

C = construction, design, and permitting cost (\$)
V = volume of water treated by facility (cubic feet)

Retrofitting a site typically costs more, averaging \$6,500 per vegetated biofilter. The higher costs are attributed to the demolition of existing concrete, asphalt, and existing structures and the replacement of fill material with planting soil. The costs of retrofitting a commercial site in Maryland, Kettering Development, with 15 vegetated biofilters were estimated at \$111,600.

In any vegetated biofilter design, the cost of plants varies substantially and can account for a significant portion of the expenditures. While these cost estimates are slightly greater than those of typical landscaping treatment (due to the increased number of plantings, additional soil excavation, backfill material, use of underdrains etc.), those landscaping expenses that would be required regardless of the vegetated biofilter installation should be subtracted when determining the net cost.

Perhaps of most importance, however, the cost savings compared to the use of traditional structural storm water conveyance systems makes vegetated biofilters quite attractive financially. For example, the use of vegetated biofilters can decrease the cost required for constructing storm water conveyance systems at a site. A medical office building in Maryland was able to reduce the amount of storm drain pipe that was needed from 800 to 230 feet - a cost savings of \$24,000 (PGDER, 1993). And a new residential development spent a total of approximately \$100,000 using vegetated biofilters on each lot instead of nearly \$400,000 for the traditional storm water ponds that were originally planned (Rappahanock). Also, in residential areas, storm water management controls become a part of each property owner's landscape, reducing the public burden to maintain large centralized facilities.

Maintenance Cost

The operation and maintenance costs for a vegetated biofilter will be comparable to those of typical landscaping required for a site. Costs beyond the normal landscaping fees will include the cost for testing the soils and may include costs for a sand bed and planting soil.

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Green Roofs TC-33

Design Considerations		
•	Structural Load	
•	Slope	
•	Cost	
Target Constituents		
✓	Sediments	H
✓	Nutrients	M
✓	Trash	H
✓	Metals	M
✓	Bacteria	M
✓	Oil and Grease	H
✓	Organics	M
Legend (Removal Effectiveness)		
L	Low	
M	Medium	
H	High	

Description

Green roofs can be effectively used to reduce storm water runoff from commercial, industrial, and residential buildings. In contrast to traditional asphalt or metal roofing, green roofs absorb, store, and later evapotranspiration from initial precipitation, thereby acting as a storm water management system and reducing overall peak flow discharge to a storm sewer system. Furthermore, conventional roofing can act as a source for numerous toxic pollutants including lead, zinc, pyrene, and chrysene (Vane Metre and Mahler, 2003).

Green roofs have the potential to reduce discharge of pollutants such as nitrogen and phosphorous due to soil microbial processes and plant uptake. However, initial studies conflict as to the removal efficiency of nutrients, particularly nitrogen, by green roofs. If implemented on a wide scale, green roofs will reduce the volume of storm water entering local waterways resulting in less in-stream scouring, lower water temperatures and better water quality.

Advantages

These roofs are not just green, they're alive. Planted with grasses and succulents, low- profile green roofs reduce the urban heat island effect, storm water runoff, and cooling costs, while providing wildlife habitat and a connection to nature for building occupants. These roofs are widely used on industrial facilities in Europe and have been established as experimental installations in several locations in the US, including Portland, Oregon. Green roofs reduce the total volume and rate of runoff from individual lots and reduce pollutants that would have been picked up by replacing traditional roofing materials with vegetation. By absorbing, storing, and transpiring rainwater, it may act as an efficient storm water management system.

Green roofs offer additional benefits including reduction of urban heat island effects, increased thermal insulation and energy efficiency, increased acoustic insulation, and increased durability and lifespan compared to conventional roofs. Europeans, led by the Germans, have been using green roofs for decades and have found them to be a cost effective method to mitigate some environmental impacts of development.

Limitations

Single family residential structures, like all buildings with green roofs, must be able to support the loading from a saturated roof. Furthermore, the green roofs should be easily accessible and residents should understand the maintenance requirements necessary to keep the roof functional. A building must be able to support the loading of green roof materials under fully saturated conditions. These materials include a waterproofing layer, a soil or substrate layer, and a plant layer. Plants selected need to be suited for local climatic conditions and can range from sedums, grasses, and wildflowers on extensive roofs to shrubs and small trees on intensive roofs.

Design and Sizing Guidelines

Green roofs are classified as extensive, semi-intensive, or intensive. Generally, extensive green roofs have six inches or less of growing medium, whereas intensive green roofs have greater than six (6) inches of substrate. Semi-intensive green roofs can be defined as a hybrid between intensive and extensive green roofs, where at least 25% of the roof square footage is above or below the six (6) inch threshold. Extensive green roofs provide many of the environmental benefits of intensive green roofs, but they are designed to be very low-maintenance and are not typically designed for public access. Semi-intensive and intensive green roofs are designed to be used by the public or building tenants as a park or relaxation area. However, they also require greater capital and maintenance investments than extensive green roofs. Intensive green roofs are particularly attractive for developers, property owners, and municipalities, in areas where land prices command a premium, but property owners want to provide some of the amenities associated with parks. Due to increasing demand for green roofs, there is now commercial industry in many parts of the country. The industry organization Green Roofs for Healthy Cities website can provide additional information on green roofs and links to numerous companies that provide green roofing products and services.

The amount of storm water that a green roof mitigates is directly proportional to the area it covers, the depth and type of the growing medium, slope, and the type of plants selected. The larger the green roof area, the more storm water mitigated. Green roofs are appropriate for industrial and commercial facilities and large residential buildings such as condominiums or apartment complexes. Green roofs can also prove useful for small residential buildings under some circumstances. For instance, green roofs are commonly used on single family residential structures in Germany and other European countries.

Green roofs can be retrofitted to existing construction by making the same considerations as when designing for a new installation. A storm water retrofit is a storm water management practice (usually structural) put into place after development has occurred, to improve water quality, protect downstream channels, reduce flooding, or meet other specific objectives. Green roofs are a useful tool for retrofitting existing impervious area associated with building footprints. The construction of most existing flat-roofed buildings is such that they can accommodate the weight of an extensive green roof without structural modifications. Although retrofitting existing structures with green roofs can be more complex and expensive than on new facilities, technological advances are bringing that cost down.

Performance

Green roofs have been shown to be effective at removing some pollutants and reducing peak flows associated with storm events. As a general rule, developers can assume that extensive green roofs will absorb 50% of rainfall (Stephen Peck, 9/1/2005, personal communication). In a modeling study, Casey Trees and Limno-Tech (2005) assumed that extensive green roofs absorbed two (2) inches of rainfall and intensive green roofs stored four (4) inches of rainfall. Due to evapotranspiration and plant uptake, this storage is assumed to recharge once every four (4) days. A study by Moran (2005) found that monthly storm water retention rates varied between 40 and 100% on two (2) green roofs in the Neuse River watershed, North Carolina. The study showed a decrease in peak flow runoff and total storm water runoff, and a gradual and delayed release of the storm water that was ultimately discharged. The reduction of peak flow discharge potentially mitigates stream channel scouring, resulting in improved aquatic habitat and lessening the risk of downstream property damage and flooding.

Penn State Green Roof Research Center has also noted a decrease in both total storm water runoff and peak flow discharge. In a 1+ inch storm event, the green roofs captured approximately 25% of total runoff compared to the conventional roofs. Over the period from May 23 to June 1, 2003, 2.21 inches of rain fell, of which the green roof detained 1.05 inches (~47%). The center noted that the Spring of 2003 was wet and cool.

Siting Criteria

Green roofs can be applied to new construction or retrofitted to existing construction. They are applicable on residential, commercial, and industrial buildings and are easily constructed on roofs with up to a 20% slope. Many cities such as Chicago and Washington, DC are actively encouraging green roof construction as a means to reduce storm water runoff and combined sewer overflows. Other municipalities are encouraging green roof development with tax credits, density credits, or allowing a small impervious credit to be applied to other structural BMPs requirements.

Green roofs are applicable in all parts of the country. In climates with extreme temperatures, green roofs provide additional building insulation, which makes them more financially justifiable for many facility operators.

Ultra-urban areas are densely developed urban areas in which little pervious surface exists. Green roofs are ideal for ultra-urban areas because they provide storm water benefits and other valuable ecological services without consuming additional land. In a 2005 modeling study of Washington DC, Casey Trees and Limno-Tech found that green roofs on 20% of buildings over 10,000 square feet could add an additional 23 million gallons of storage and reduce outflow to the storm sewer or combined sewer systems by an average of just under 300 million gallons per year.

Design Guidelines

Green roofs can be designed to be; intensive, semi-intensive, or extensive green roofs. The type of design chosen will depend upon loading capacity, budget, design goals, and storm water retention desired. There will also be variations in the type of green roof selected depending upon climate, types of plants chosen, soil layer depth desired and feasibility and other design considerations. Green roofs can be constructed layer by layer, or can be purchased as a system. Some vendors offer modular trays containing the green roof components. In most climates, green roofs will need to have drought tolerant plant species or an irrigation system to sustain vegetation. The slope of green roofs can range from 0 to 40 degrees. In new construction, buildings should be designed to manage a potentially increased load associated with the green roof. When designing green roofs for existing structures, engineers must take the load restrictions of the building into account.

Maintenance

Immediately after construction, green roofs need to be monitored regularly to ensure the vegetation thrives. During the first season, green roofs may need to be watered periodically if there is not sufficient precipitation. After the first season, extensive green roofs may only need to be inspected and lightly fertilized approximately once per year. The roofs may need occasional weeding and may require some watering during exceptionally dry periods. If leaks should occur in the roof, they are relatively easy to detect and fix. Intensive green roofs need to be maintained as any other landscaped area. This can involve gardening and irrigation, in addition to other roof maintenance. Green roofs are less prone to leaking than conventional roofs. In most cases, detecting and fixing a leak under a green roof is no more difficult than doing the same for a conventional roof.

Cost

Extensive green roofs range in price from approximately $5/feet^2 to $20/feet^2. However, there are significant cost savings associated with reducing energy consumption and longer roof lifespan. For instance, the green roof on the Gap building in San Bruno, California more than covered the additional cost associated with construction, through energy savings, within a few years. Annualized costs should be lowered considerably by the roof's increased lifespan. Furthermore, some municipalities offer incentives to help defray the higher up-front costs of green roof construction.

Intensive green roofs can be considerably more expensive than extensive green roofs. Estimates range from $20 to $80/feet^2. Other benefits should be taken into account, however, such as recreational space provided and costs relative to the price of land in an area.

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Design Considerations		
•	Aesthetics	
•	Hydraulic Head	
Target Constituents		
✓	Sediments	H
✓	Nutrients	L/M
✓	Trash	H
✓	Metals	M/H
✓	Bacteria	M
✓	Oil and Grease	H
✓	Organics	M/H
Legend (Removal Effectiveness)		
L	Low	
M	Medium	
H	High	

Description

Storm water media filters are usually two-chambered including a pretreatment settling basin and a filter bed filled with sand or other absorptive filtering media. As storm water flows into the first chamber, large particles settle out, and then finer particles and other pollutants are removed as storm water flows through the filtering media in the second chamber. There are a number of design variations including the Austin sand filter, Delaware sand filter, and multi-chambered treatment train (MCTT).

Other Jurisdictions

Caltrans constructed and monitored five (5) Austin sand filters, two (2) MCTTs, and one (1) Delaware design in southern California. Pollutant removal was very similar for each of the designs; however operational and maintenance aspects were quite different. The Delaware filter and MCTT maintain permanent pools and consequently mosquito management was a critical issue, while the Austin style which is designed to empty completely between storms was less affected. Removal of the top few inches of sand was required at three (3) of the Austin filters and the Delaware filter during the third year of operation; consequently, sizing of the filter bed is a critical design factor for establishing maintenance frequency.

Advantages

- Relatively high pollutant removal, especially for sediment and associated pollutants.
- Widespread application with sufficient capture volume can provide significant control of channel erosion and enlargement caused by changes to flow frequency relationships resulting from the increase of impervious cover in a watershed.

Limitations

- More expensive to construct than many other BMPs.
- May require more maintenance that some other BMPs depending upon the sizing of the filter bed.
- Generally require more hydraulic head to operate properly (minimum four (4) feet).
- High solids loads will cause the filter to clog.
- Work best for relatively small, impervious watersheds.

- Filters in residential areas can present aesthetic and safety problems if constructed with vertical concrete walls.
- Certain designs (i.e., MCTT and Delaware filter) maintain permanent sources of standing water where mosquito and midge breeding is likely to occur.

Design and Sizing Guidelines

- Filter bed sized to discharge the capture volume over a period of 48 hours.
- Filter bed 18 inches thick above underdrain system.
- Include energy dissipation in the inlet design to reduce re-suspension of accumulated sediment.
- A maintenance ramp should be included in the design to facilitate access to the sedimentation and filter basins for maintenance activities (particularly for the Austin design).
- Designs that utilize covered sedimentation and filtration basins should be accessible to vector control personnel via access doors to facilitate vector surveillance and controlling the basins if needed.

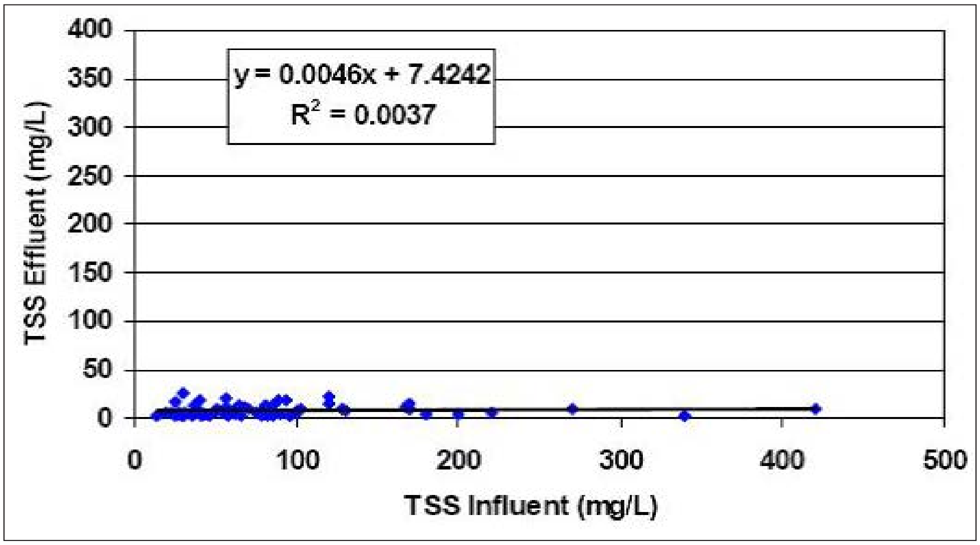
Construction/Inspection Considerations

Tributary area should be completely stabilized before media is installed to prevent premature clogging.

Performance

The pollutant removal performance of media filters and other storm water BMPs is generally characterized by the percent reduction in the influent load. This method implies a relationship between influent and effluent concentrations. For instance, it would be expected that a device that is reported to achieve a 75% reduction would have an effluent concentration equal to 25% of the influent concentrations. Recent work in California (Caltrans, 2002) on various sand filter designs indicates that this model for characterizing performance is inadequate. The figure that follows presents a graph relating influent and effluent Total Suspended Solids (TSS) concentrations for the Austin full sedimentation design.

Comparison of Influent and Effluent Concentrations for TSS



It is clearly evident that the effluent concentration is relative constant and independent of influent concentration. Consequently, the performance is more accurately characterized by the effluent concentration, which is about 7.5 mg/L. Constant effluent concentrations also are observed for all other particle related constituents such as particulate metals (total - dissolved) and particulate phosphorus.

The small uncertainty in the estimate of the mean effluent concentration highlights the very consistent effluent quality for TSS produced by sand filters. In addition, it demonstrates that a calculated percent reduction for TSS and other constituents with similar behavior for Austin sand filters is a secondary characteristic of the device and depends primarily on the specific influent concentrations observed. The distinction between a constant effluent quality and a percent reduction is extremely important to recognize if the results are to be used to estimate effluent quality from sand filters installed at other sites with different influent concentrations or for estimating compliance with water quality standards for storms with high concentrations of particulate constituents.

If the conventionally derived removal efficiency (90%) were used to estimate the TSS concentrations in the treated runoff from storms with high influent concentrations, the estimated effluent concentration would be too high. For instance, the storm with the highest observed influent concentration (420 mg/L) would be expected to have a concentration in the treated runoff of 42 mg/L, rather than the 10 mg/L that was measured. In fact, the TSS effluent concentrations for all events with influent concentrations greater than 200 mg/L were 10 mg/L or less.

The stable effluent concentration of a sand filter under very different influent TSS concentrations implies something about the properties of the influent particle size distribution. If one assumes that only the smallest size fraction can pass through the filter, then the similarity in effluent concentrations suggests that there is little difference in the total mass of the smallest sized particles even when the total TSS concentration varies greatly. Further, the difference in TSS concentration must then be caused by changes in the relative amount of the larger size fractions. Further research is necessary to determine the range of particle size that is effectively removed in the filter and the portion of the size fraction of suspended solids that it represents in urban storm water.

Sand filters are effective storm water management practices for pollutant removal. Conventional removal rates for all sand filters and organic filters are presented in the table below. With the exception of nitrates, which are always exported from filtering systems because of the conversion of ammonia and organic nitrogen to nitrate, they perform relatively well at removing pollutants.

Sand Filter Removal Efficiencies

	Sand Filter (Glick et al., 1998)	Compost Filter System		Multi-Chamber Treatment Train		
		Stewart, 1992	Leif, 1999	Pitt et al., 1997	Pitt, 1996	Greb et al., 1998
TSS	89	95	85	85	83	98
TP	59	41	4	80	-	84
TN	18	-	-	-	-	-
Nitrate	-76	-34	-95	-	14	-
Metals	72-86	61-88	44-75	65-90	91-100	83-89
Bacteria	65	-	-	-	-	-

From the few studies available, it is difficult to determine if organic filters necessarily have higher removal efficiencies than sand filters. The MCTT may have high pollutant removal for some constituents, although an evaluation of these devices by the California Department of Transportation indicated no significant difference for most conventional pollutants. (For more information on the MCTT, see TC-60, figure displaying “Schematic of a Multi-Chamber Treatment Train (MCTT) (Robertson et al., 1995)”).

In addition to the relatively high pollutant removal in media filters, these devices, when sized to capture the channel forming storm volume, are highly effective at attenuating peak flow rates and reducing channel erosion.

Siting Criteria

In general, sand filters are preferred over infiltration practices, such as infiltration trenches, when contamination of groundwater with conventional pollutants is of concern. This usually occurs in areas where underlying soils alone cannot treat runoff adequately - or ground water tables are high. In most cases, sand filters can be constructed with impermeable basin or chamber bottoms, which help to collect, treat, and release runoff to a storm drainage system or directly to surface water with no contact between contaminated runoff and groundwater. In regions where evaporation exceeds rainfall and a wet pond would be unlikely to maintain the required permanent pool, a sand filtration system can be used.

The selection of a sand filter design depends largely on the drainage area’s characteristics. For example, the Washington, D.C. and Delaware sand filter systems are well suited for highly impervious areas where land available for structural controls is limited, since both are installed underground. They have been used to treat runoff from parking lots, driveways, loading docks, service stations, garages, airport runways/ taxiways, and storage yards. The Austin sand filtration system is more suited for large drainage areas that have both impervious and pervious surfaces. This system is located at grade and is used to treat runoff from any urban land use.

It is challenging to use most sand filters in very flat terrain because they require a significant amount of hydraulic head (about 4 feet), to allow flow through the system. One exception is the perimeter sand filter, which can be applied with as little as 2 feet of head.

Sand filters are best applied on relatively small sites (up to 25 acres for surface sand filters and closer to 2 acres for perimeter or underground filters). Filters have been used on larger drainage areas, of up to 100 acres, but these systems can clog when they treat larger drainage areas unless adequate measures are provided to prevent clogging, such as a larger sedimentation chamber or more intensive regular maintenance.

When sand filters are designed as a stand-alone practice, they can be used on almost any soil because they can be designed so that storm water never infiltrates into the soil or interacts with the ground water. Alternatively, sand filters can be designed as pretreatment for an infiltration practice, where soils do play a role.

Additional Design Guidelines

Pretreatment is a critical component of any storm water management practice. In sand filters, pretreatment is achieved in the sedimentation chamber that precedes the filter bed. In this chamber, the coarsest particles settle out and thus do not reach the filter bed. Pretreatment reduces the maintenance burden of sand filters by reducing the potential for these sediments to clog the filter. When pretreatment is not provided designers should increase the size of the filter area to reduce the clogging potential. In sand filters, designers should select a medium sized sand as the filtering medium. A fine aggregate (ASTM C-33) that is intended for use in concrete is commonly specified.

Many guidelines recommend sizing the filter bed using Darcy's Law, which relates the velocity of fluids to the hydraulic head and the coefficient of permeability of a medium. The resulting equation, as derived by the city of Austin, Texas, (1996), is as follows:

$$A_f = \frac{(WQV)(d)}{kt(h+d)}$$

Where:

WQV = water quality volume (feet^2)
A_f = area of the filter bed (feet^2)
d = depth of the filter bed (feet; usually about 1.5 feet, depending on the design)
k = coefficient of permeability of he filtering medium (feet/day)
t = time for the water quality volume to filter through the system (days, usually assumed to be 1.67 days)
h = average water height above the sand bed (feet; assumed to be one-half of the maximum head)

Typical values for k, as assembled by CWP (1996), are shown in the following table.

Coefficient of Permeability Values for Storm Water Filtering Practices (CWP, 1996)

Filter Medium	Coefficient of Permeability (feet/day)
Sand	3.5
Peat/Sand	2.75
Compost	8.7

The permeability of sand shown in this table is extremely conservative, but is widely used since it is incorporated in the design guidelines of the City of Austin. When the sand is initially installed, the permeability is so high (over 100 feet/day) that generally only a portion of the filter area is required to infiltrate the entire volume, especially in a "full sedimentation" Austin design where the capture volume is released to the filter basin over 24 hours.

The preceding methodology results in a filter bed area that is oversized when new and the entire water quality volume is filtered in less than a day with no significant height of water on top of the sand bed. Consequently, the following simple rule of thumb is adequate for sizing the filter area. If the filter is preceded by a sedimentation basin that releases the water quality volume (WQV) to the filter over 24 hours, then:

$$A_f = \frac{WQV}{18}$$

If no pretreatment is provided then the filter area is calculated more conservatively as:

$$A_f = \frac{WQV}{10}$$

Typically, filtering practices are designed as "off-line" systems, meaning that during larger storms all runoff greater than the water quality volume is bypassed untreated using a flow splitter, which is a structure that directs larger flows to the storm drain system or to a stabilized channel. One exception is the perimeter filter; in this design, all flows enter the system, but larger flows overflow to an outlet chamber and are not treated by the practice.

The Austin design variations are preferred where there is sufficient space, because they lack a permanent pool, which eliminates vector concerns. Design details of this variation are summarized below.

Summary of Design Recommendations

- Capture Volume: The facility should be sized to capture the required water quality volume, preferably in a separate pretreatment sedimentation basin.
- Basin Geometry: The water depth in the sedimentation basin when full should be at least 2 feet and no greater than 10 feet. A fixed vertical sediment depth marker should be installed in the sedimentation basin to indicate when 20% of the basin volume has been lost because of sediment accumulation. When a pretreatment sedimentation basin is provided the minimum average surface area for the sand filter (A_f) is calculated from the following equation:

$$A_f = \frac{WQV}{18}$$

If no pretreatment is provided then the filter area is calculated as:

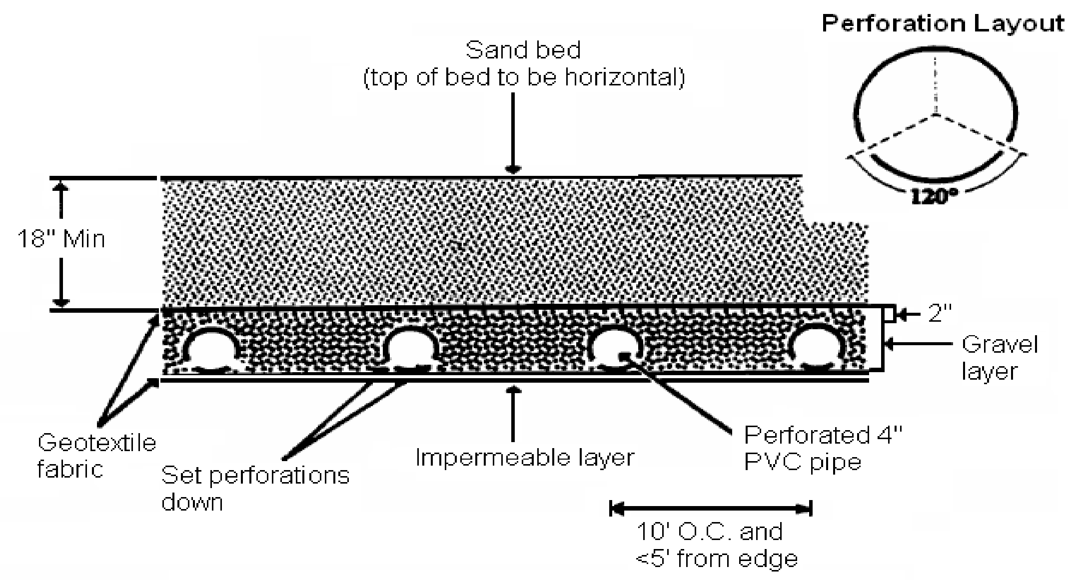
$$A_f = \frac{WQV}{10}$$

Sand and Gravel Configuration: The sand filter is constructed with 18 inches of sand overlying 6 inches of gravel. The sand and gravel media are separated by permeable geotextile fabric and the gravel layer is situated on geotextile fabric. Four-inch perforated PVC pipe is used to drain captured flows from the gravel layer. A minimum of 2 inches of gravel must cover the top surface of the PVC pipe. In a figure shown below, Schematic of a Delaware Sand Filter (Young et al., 1996), a schematic representation of a standard sand bed profile.

- Sand Properties: The sand grain size distribution should be comparable to that of “washed concrete sand,” as specified for fine aggregate in ASTM C-33.
- Underdrain Pipe Configuration: In an Austin filter, the underdrain piping should consist of a main collector pipe and two or more lateral branch pipes, each with a minimum diameter of 4 inches. The pipes should have a minimum slope of 1% (1/8 inch per foot) and the laterals should be spaced at intervals of no more than 10 feet. There should be no fewer than two lateral branch pipes. Each individual underdrain pipe should have a cleanout access location. All piping is to be Schedule 40 PVC. The maximum spacing between rows of perforations should not exceed 6 inches. See the Schematic of Sand Bed Profile (with gravel filter).
- Flow Splitter: The inflow structure to the sedimentation chamber should incorporate a flow-splitting device capable of isolating the capture volume and bypassing the peak flow due to the appropriate recurrence interval storm around the facility with the sedimentation/filtration pond full. Guidelines for selecting the recurrence interval are as follows:
  - For drainage areas of 100 acres or less, the recurrence interval shall be 10 years.
  - For drainage areas greater than 100 acres, the recurrence interval shall be 100 years.

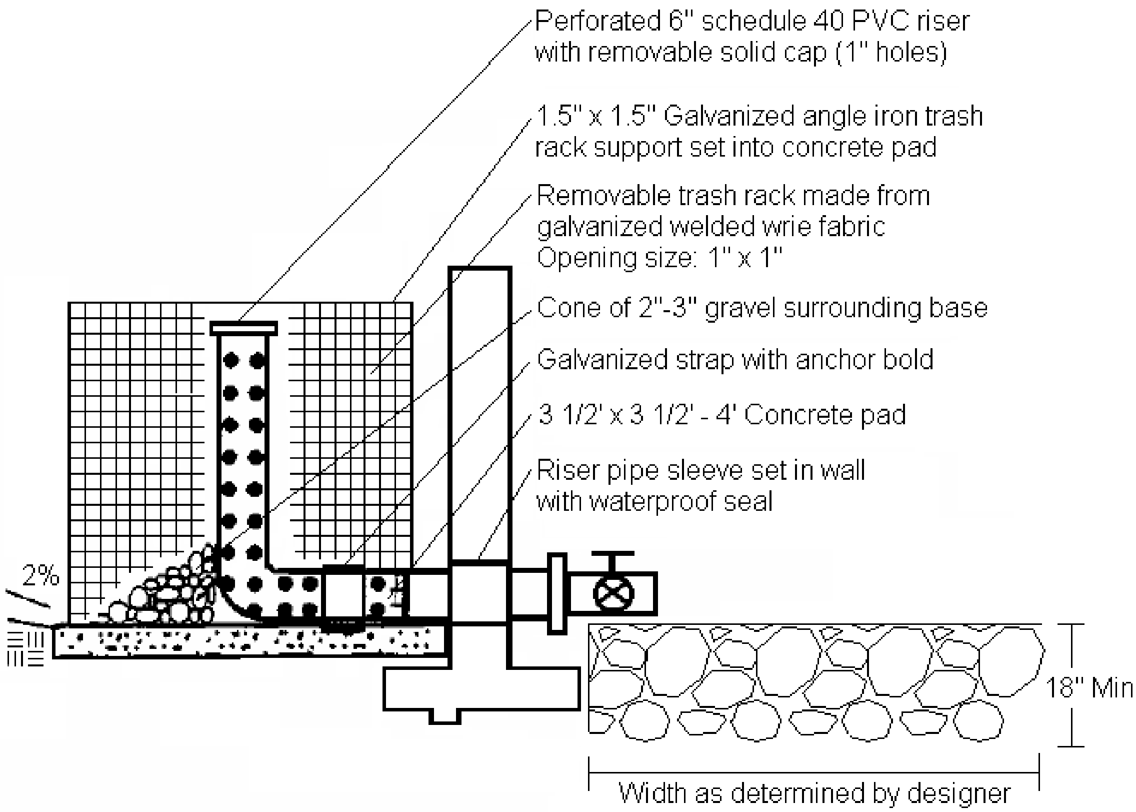
- Basin Inlet: Energy dissipation is required at the sedimentation basin inlet so that flows entering the basin should be distributed uniformly and at low velocity in order to prevent re-suspension and encourage quiescent conditions necessary for deposition of solids.
- Sedimentation Pond Outlet Structure: The outflow structure from the sedimentation chamber should be (1) an earthen berm; (2) a concrete wall; or (3) a rock gabion. Gabion outflow structures should extend across the full width of the facility such that no short circuiting of flows can occur. The gabion rock should be 4 inches in diameter. The receiving end of the sand filter should be protected (splash pad, riprap, etc.) such that erosion of the sand media does not occur. When a riser pipe is used to connect the sedimentation and filtration basins (see attached example figure Detail of Sedimentation Riser Pipe), a valve should be included to isolate the sedimentation basin in case of a hazardous material spill in the watershed. The control for the valve must be accessible at all times, including when the basin is full. The riser pipe should have a minimum diameter of 6 inches with four 1-inch perforations per row. The vertical spacing between rows should be 4 inches (on centers). Other examples are illustrated in the attached examples - Schematic of the "Full Sedimentation" Austin Sand Filter and Schematic of a Delaware Sand Filter (Young et al., 1996).
- Sand Filter Discharge: If a gabion structure is used to separate the sedimentation and filtration basins, a valve must be installed so that discharge from the BMP can be stopped in case runoff from a spill of hazardous material enters the sand filter. The control for the valve must be accessible at all times, including when the basin is full.

Schematic of Sand Bed Profile (with gravel filter)

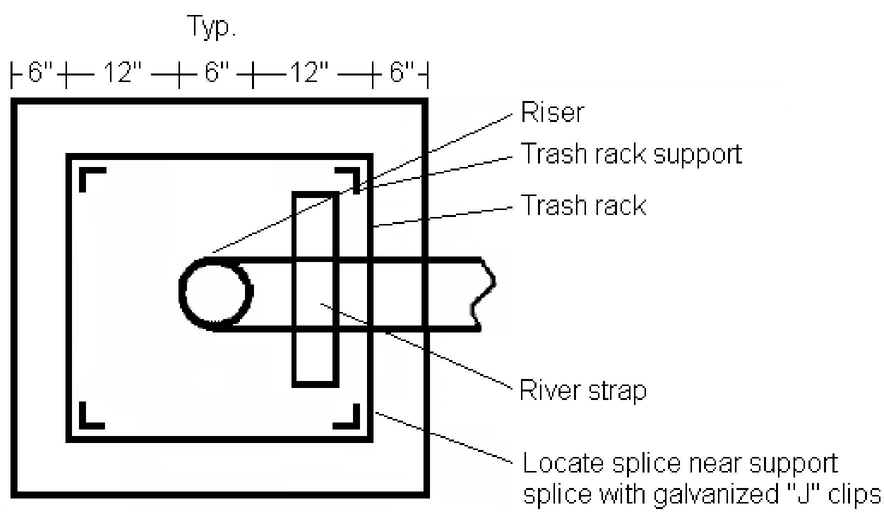


A. SAND BED PROFILE (with gravel filter)

Detail of Sedimentation Riser Pipe

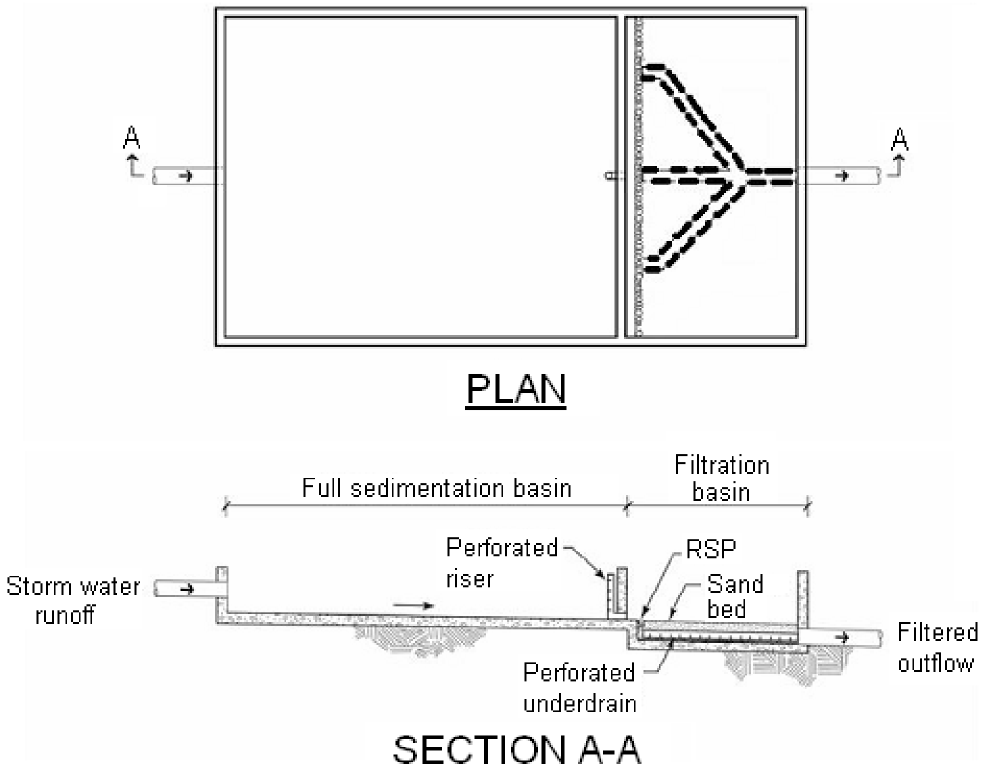


SIDE VIEW OF RISER

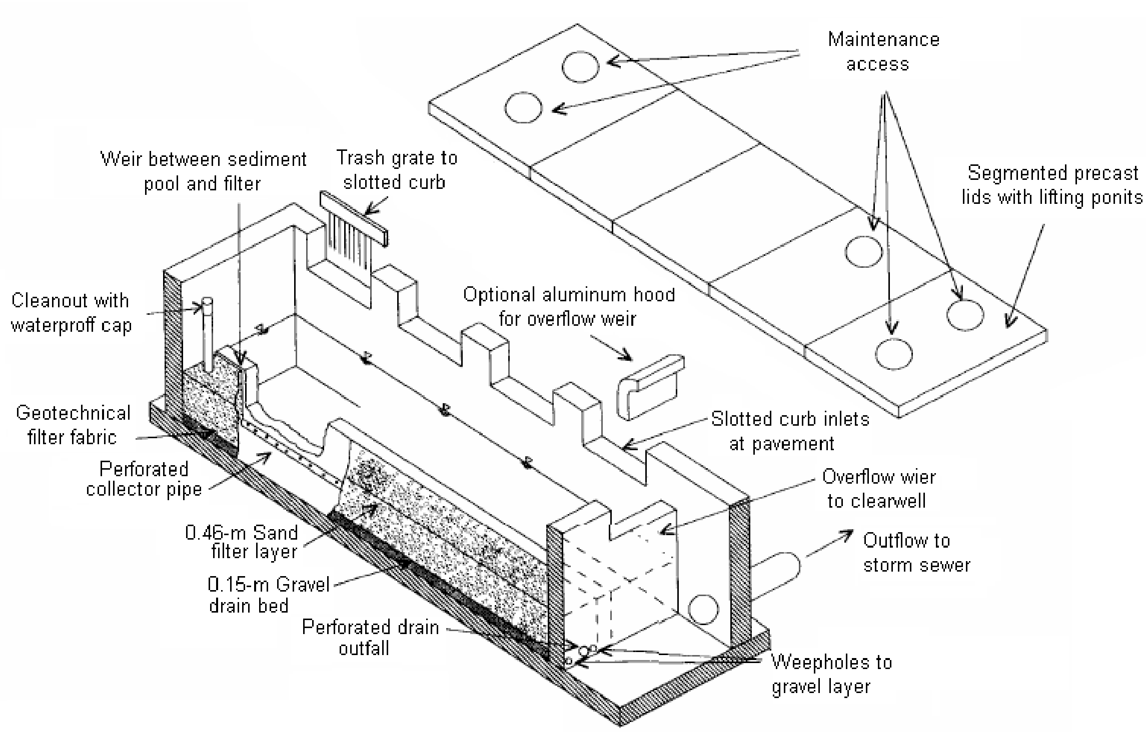


TOP VIEW OF RISER (SQUARE DESIGN)

Schematic of the "Full Sedimentation" Austin Sand Filter



Schematic of a Delaware Sand Filter (Young et al., 1996)



Maintenance

Even though sand filters are generally thought of as one of the higher maintenance BMPs, in a recent California study an average of only about 49 hours a year were required for field activities. This was less maintenance than was required by extended detention basins serving comparable sized catchments. Most maintenance consists of routine removal of trash and debris, especially in Austin sand filters where the outlet riser from the sedimentation basin can become clogged.

Most data (i.e. Clark, 2001) indicate that hydraulic failure from clogging of the sand media occurs before pollutant breakthrough. Typically, only the very top of the sand becomes clogged while the rest remains in relative pristine condition as shown in the picture below. The rate of clogging has been related to the TSS loading on the filter bed (Urbonas, 1999); however, the data are quite variable. Empirical observation of sites treating urban and highway runoff indicates that clogging of the filter occurs after 2 to 10 years of service. Presumably, this is related to differences in the type and amount of sediment in the catchment areas of the various installations. Once clogging occurs the top 2 to 3 inches of filter media is removed, which restores much, but not all, of the lost permeability. This removal of the surface layer can occur several times before the entire filter bed must be replaced. The cost of the removal of the surface layer is not cost prohibitive, generally ranging between $2,000 (EPA Fact Sheet) and $4,000 (Caltrans, 2002) depending on the size of the filter.

Formation of Clogging Crust on Filter Bed

Media filters can become a nuisance due to mosquito and midge breeding in certain designs or if not regularly maintained. “Wet” designs (i.e., MCTT and Delaware filter) are more conducive to vectors than others (i.e., Austin filters) because they maintain permanent sources of standing water where breeding is likely to occur. Caltrans successfully excluded mosquitoes and midges from accessing the permanent water in the sedimentation basin of MCTT installations through use of a tight-fitting aluminum cover to seal vectors out. However, typical wet designs may require routine inspections and treatments by local mosquito and vector control agencies to suppress mosquito production. Vector habitats may also be created in “dry” designs when media filters clog, and/or when features such as level spreaders that hold water over 72 hours are included in the installation. Dry designs such as Austin filters should dewater completely (recommended 72 hour residence time or less) to prevent creating mosquito and other vector habitats. Maintenance efforts to prevent vector breeding in dry designs will need to focus on basic housekeeping practices such as removal of debris accumulations and vegetation management (in filter media) to prevent clogs and/or pools of standing water.

Recommended maintenance activities and frequencies include:

- Inspections semi-annually for standing water, sediment, trash and debris, and to identify potential problems.
- Remove accumulated trash and debris in the sedimentation basin, from the riser pipe, and the filter bed during routine inspections.
- Inspect the facility once during the wet season after a large rain event to determine whether the facility is draining completely within 72 hour.
- Remove top 2 inches (50 mm) of sand and dispose of sediment if facility drain time exceeds 72 hour.
- Restore media depth to 18 inches (450 mm) when overall media depth drops to 12 inches (300 mm).
- Remove accumulated sediment in the sedimentation basin every 10 year or when the sediment occupies 10% of the basin volume, whichever is less.

Cost

In general, Hawaii's unit prices are higher than California's unit prices.

Construction Cost

There are few consistent data on the cost of sand filters due to their not having been used widely and they have such varied designs that it is difficult to assign a cost to filters in general. A study by Brown and Schueler (1997) was unable to find a statistically valid relationship between the volume of water treated in a filter and the cost of the practice, but typical total cost of installation ranged between $2.50 and $7.50 per cubic foot of storm water treated, with an average cost of about $5/feet^3. The cost per impervious acre treated varies considerably depending on the region and design used. It is important to note that, although underground and perimeter sand filters can be more expensive than surface sand filters, they consume no surface space, making them a relatively cost-effective practice in ultra-urban areas where land is at a premium.

Construction Cost for Various Sand Filters

Region (Design)	Cost/Impervious Acre
Delaware (Perimeter)	$10,000
Alexandria, VA (Perimeter)	$23,500
Austin. TX (>2 acres) (Surface)	$16,000
Austin, TX (>5 acres) (Surface)	$3,400
Washington, DC (underground)	$14,000
Denver, CO	$30,000-$50,000
Mutli-Chamber Treatment Train	$40,000-$80,000

Source: Schueler, 1994

Maintenance Cost

Annual costs for maintaining sand filter systems average about 5% of the initial construction cost (Schueler, 1992). Media is replaced as needed, with the frequency correlated with the solids loading on the filter bed. Currently the sand is being replaced in the D.C. filter systems about every 2 years, while an Austin design might last 3 to 10 years depending on the watershed characteristics. The cost to replace the gravel layer, filter fabric and top portion of the sand for D.C. sand filters is approximately $1,700 (1997 dollars).

Caltrans estimated future maintenance costs for the Austin design, assuming a device sized to treat runoff from approximately 4 acres. These estimates are presented in the table below and assume a fully burdened hourly rate of $44 for labor. This estimate is somewhat uncertain, since complete replacement of the filter bed was not required during the period that maintenance costs were recorded.

Expected Annual Maintenance Costs for an Austin Sand Filter

Activity	Labor Hours	Equipment and Materials ($)	Cost
Inspections	4	0	176
Maintenance	36	125	1,706
Vector Control	0	0	0
Administration	3	0	132
Direct Costs	-	888	888
Total	43	$1,013	$2,902

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Design Considerations		
•	Area Required	
Target Constituents		
✓	Sediments	L
✓	Nutrients	L
✓	Trash	M
✓	Metals	L
✓	Bacteria	L
✓	Oil and Grease	M
✓	Organics	L
Legend (Removal Effectiveness)		
L	Low	
M	Medium	
H	High	

Description

Water quality inlets (WQIs), also commonly called trapping catch basins, oil/grit separators or oil/water separators, consist of one or more chambers that promote sedimentation of coarse materials and separation of free oil (as opposed to emulsified or dissolved oil) from storm water. Some WQIs also contain screens to help retain larger or floating debris, and many of the newer designs also include a coalescing unit that helps promote oil/water separation. A typical WQI, as shown in the schematic, consists of a sedimentation chamber, an oil separation chamber, and a discharge chamber.

These devices are appropriate for capturing hydrocarbon spills, but provide very marginal sediment removal and are not very effective for treatment of storm water runoff. WQIs typically capture only the first portion of runoff for treatment and are generally used for pretreatment before discharging to other BMPs.

Other Jurisdictions

Caltrans investigated the use of coalescing plate oil/water separators at maintenance stations in Southern California. Twenty-two maintenance stations were originally considered for implementation of this technology; however, only one site appeared to have concentrations that were sufficiently high to warrant installation of an oil-water separator. Concentrations of free oil in storm water runoff observed during the course of the study even from this site were too low for effective operation of this technology, and no free oil was ever captured by the device.

Advantages

- Can provide spill control.

Limitations

- WQIs generally provide limited hydraulic and residuals storage. Due to the limited storage, WQIs do not provide substantial storm water improvement.
- Standing water in the devices can provide a breeding ground for mosquitoes.

Design and Sizing Guidelines

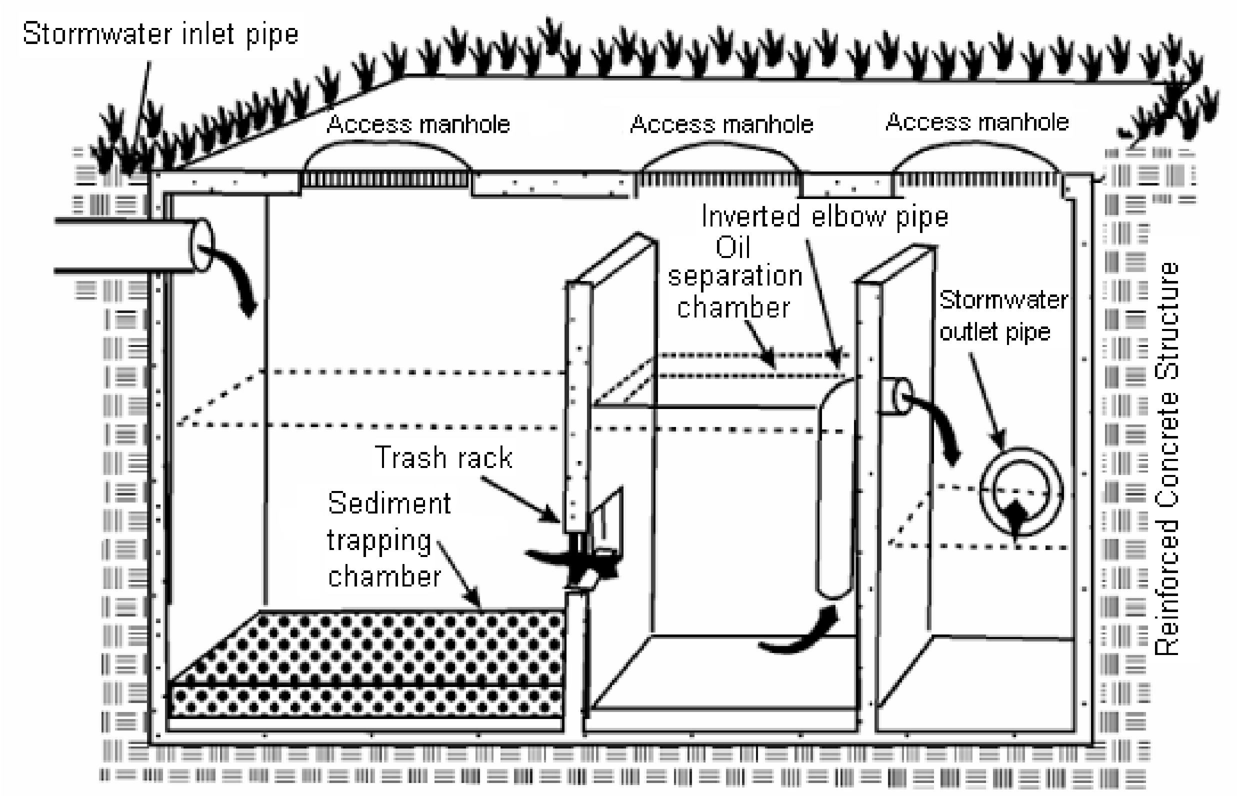
- Water quality inlets are most effective for spill control and should be sized accordingly.

- Designs that utilize covered sedimentation and filtration basins should be accessible to vector control personnel via access doors to facilitate vector surveillance and controlling the basins if needed.

Performance

WQIs are primarily utilized to remove sediment from storm water runoff. Grit and sediment are partially removed by gravity settling within the first two chambers. A WQI with a detention time of one (1) hour may expect to have 20 to 40% removal of sediments. Hydrocarbons associated with the accumulated sediments are also often removed from the runoff through this process. The WQI achieves slight, if any, removal of nutrients, metals and organic pollutants other than free petroleum products (Schueler, 1992). See the Example of a Water Quality Inlet figure.

Example of a Water Quality Inlet



A 1993 Metropolitan Washington Council of Governments (MWCOG) study found that an average of less than 2 inches (5 centimeters) of sediments (mostly coarse-grained grit and organic matter) was trapped in the WQIs. Hydrocarbon and total organic carbon (TOC) concentrations of the sediments averaged 8,150 and 53,900 ppm, respectively. The mean hydrocarbon concentration in the WQI water column was 10 ppm. The study also indicated that sediment accumulation did not increase over time, suggesting that the sediments become re-suspended during storm events. The authors concluded that although the WQI effectively separates oil and grease from water, re-suspension of the settled matter appears to limit removal efficiencies. Actual removal only occurs when the residuals are removed from the WQI (Schueler 1992).

A 1990 report by American Petroleum Institute (API) found that the efficiency of oil and water separation in a WQI is inversely proportional to the ratio of the discharge rate to the unit's surface area. Due to the small capacity of the WQI, the discharge rate is typically very high and the detention time is very short. For example, the MWCOG study found that the average detention time in a WQI is less than 0.5 hour. This can result in minimal pollutant settling (API, 1990). However, the addition of coalescing units in many current WQI units may increase oil/water separation efficiency. Most coalescing units are designed to achieve a specific outlet concentration of oil and grease (for example, 10-1 5m/L oil and grease).

Pollutant removal in storm water inlets can be somewhat improved using inserts, which are promoted for removal of oil and grease, trash, debris, and sediment. Some inserts are designed to drop directly into existing catch basins, while others may require extensive retrofit construction.

Siting Criteria

Oil/water separation units are often utilized in specific industrial areas, such as airport aprons, equipment wash down areas, or vehicle storage areas. Generally drains from industrial activities such as wash and equipment service areas are connected to an Oil Water Separator (OWS). Discharges are sent to the sewer collection system. Such non-storm water industrial discharges are not covered by the NPDES general permit and MS4 permit. However, nonpoint storm water runoff can be treated by OWS.

Additional Design Guidelines

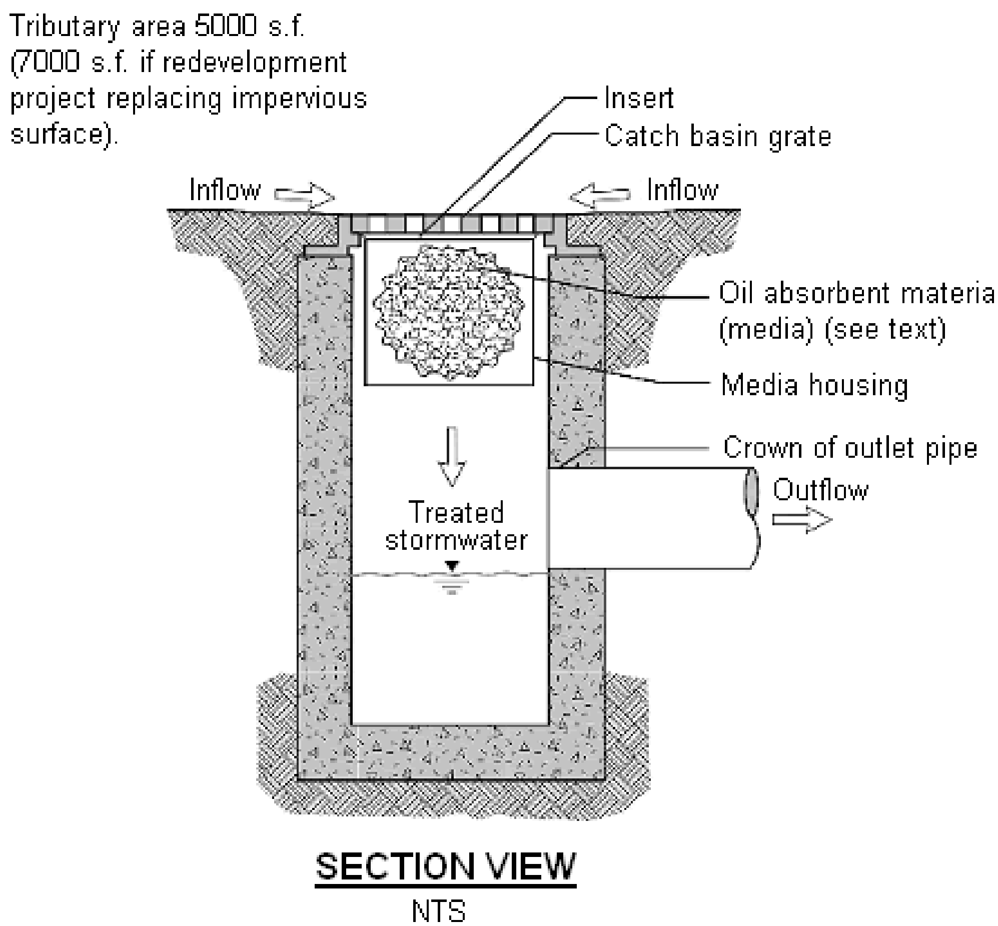
Prior to WQI design; the site should be evaluated to determine if another BMP would be more cost-effective in removing the pollutants of concern. WQIs should be used when no other BMP is feasible. The WQI should be constructed near a storm drain network so that flow can be easily diverted to the WQI for treatment (NVPDC, 1992). Any construction activities within the drainage area should be completed before installation of the WQI, and the drainage area should be revegetated so that the sediment loading to the WQI is minimized.

WQIs are most effective for small drainage areas. Drainage areas of 0.4 hectares (1 acre) or less are often recommended. WQIs are typically used in an off-line configuration (i.e., portions of runoff are diverted to the WQI), but they can be used as on-line units (i.e., receive all runoff). Generally, off-line units are designed to handle the first 1.3 centimeters (0.5 inches) of runoff from the drainage areas. Upstream isolation/diversion structures can be used to divert the water to the off-line structure (Schueler, 1992). On-line units receive higher flows that will likely cause increased turbulence and re-suspension of settled material, thereby reducing WQI performance.

Oil/water separation tanks are often fitted with diffusion baffles at the inlets to prevent turbulent flow from entering the unit and re-suspending settled pollutants. WQIs are available as pre-manufactured units or can be cast in place. Reinforced concrete should be used to construct below-grade WQIs. The WQIs should be water tight to prevent possible ground water contamination.

Another type of WQI is the grated inlet filter inserts. The Grated Inlet Filter figure illustrates a conceptual section view of a surface grated inlet with absorbent material to filter out pollutants. However frequent inspection and maintenance is needed.

Grated Inlet Filter



The typical design of a catch basin insert is a set of filters that are specifically chosen to address the pollutants expected at that site (Source: King County, Washington, 2000)

Maintenance

Typical maintenance of WQIs includes trash removal if a screen or other debris capturing device is used, and removal of sediment using a vactor truck. Operators need to be properly trained in WQI maintenance. Maintenance should include keeping a log of the amount of sediment collected and the date of removal. Some cities have incorporated the use of the Geographical Information System to track sediment collection and to optimize future catch basin cleaning efforts.

One study (Pitt, 1985) concluded that WQIs can capture sediments up to approximately 60% of the sump volume. When sediment fills greater than 60% of their volume, catch basins reach steady state. Storm flows can then re-suspend sediments trapped in the catch basin, and will bypass treatment. Frequent clean-out can retain the volume in the catch basin sump available for treatment of storm water flows.

At a minimum, these inlets should be cleaned at least twice during the wet season. Two studies suggest that increasing the frequency of maintenance can improve the performance of catch basins, particularly in industrial or commercial areas. One study of 60 catch basins in Alameda County, California, found that increasing the maintenance frequency from once per year to twice per year could increase the total sediment removed by catch basins on an annual basis (Mineart and Singh, 1994). Annual sediment removed per inlet was 54 pounds for annual cleaning, 70 pounds for semi-annual and quarterly cleaning, and 160 pounds for monthly cleaning. For catch basins draining industrial uses, monthly cleaning increased total annual sediment collected to six times the amount collected by annual cleaning (180 pounds versus 30 pounds).

These results suggest that, at least for industrial uses, more frequent cleaning of catch basins may improve efficiency.

BMPs designed with permanent water sumps, vaults, and/or catch basins (frequently installed below-ground) can become a nuisance due to mosquito and other vector breeding. Preventing mosquito access to standing water sources in BMPs (particularly below-ground) is the best prevention plan, but can prove challenging due to multiple entrances and the need to maintain the hydraulic integrity of the system. BMPs that maintain permanent standing water may require routine inspections and treatments by local mosquito and vector control agencies to suppress mosquito production. Standing water in oil/water separators may contain sufficient floating hydrocarbons to prevent mosquito breeding, but this is not a reliable control alternative to vector exclusion or chemical treatment.

Cost

A typical pre-cast catch basin costs between $2,000 and $3,000; however, oil/water separators can be much more expensive. The true pollutant removal cost associated with catch basins, however, is the long-term maintenance cost. A vactor truck, the most common method of catch basin cleaning, costs between $125,000 and $150,000. This initial cost may be high for smaller Phase II communities. However, it may be possible to share a vactor truck with another community. Typical vactor trucks can store between 10 and 15 cubic yards of material, which is enough storage for three to five catch basins. Assuming semi-annual cleaning, and that the vactor truck could be filled and material disposed of twice in one day, one truck would be sufficient to clean between 750 and 1,000 catch basins. Another maintenance cost is the staff time needed to operate the truck.

Note that Hawaii's unit prices are higher than California's unit prices.

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Photo Source: stormwater.ucf.edu

Design Considerations
• Area Required
• Slope
• Water Availability
• Hydraulic Head
• Environmental Side Effects

Target Constituents		
✓	Sediments	H
✓	Nutrients	L
✓	Trash	H
✓	Metals	H
✓	Bacteria	M
✓	Oil and Grease	H
✓	Organics	H

Legend (Removal Effectiveness)	
L	Low
M	Medium
H	High

Description

A multiple treatment system uses two or more BMPs in series. Some examples of multiple systems include: settling basin combined with a sand filter; settling basin or biofilter combined with an infiltration basin or trench; extended detention zone on a wet pond.

Advantages

- BMPs that are less sensitive to high pollutant loadings, especially solids, can be used to pretreat runoff for sand filters and infiltration devices where the potential for clogging exists.
- BMPs which target different constituents can be combined to provide treatment for all constituents of concern.
- BMPs which use different removal processes (sedimentation, filtration, biological uptake) can be combined to improve the overall removal efficiency for a given constituent.
- BMPs in series can provide redundancy and reduce the likelihood of total system failure.

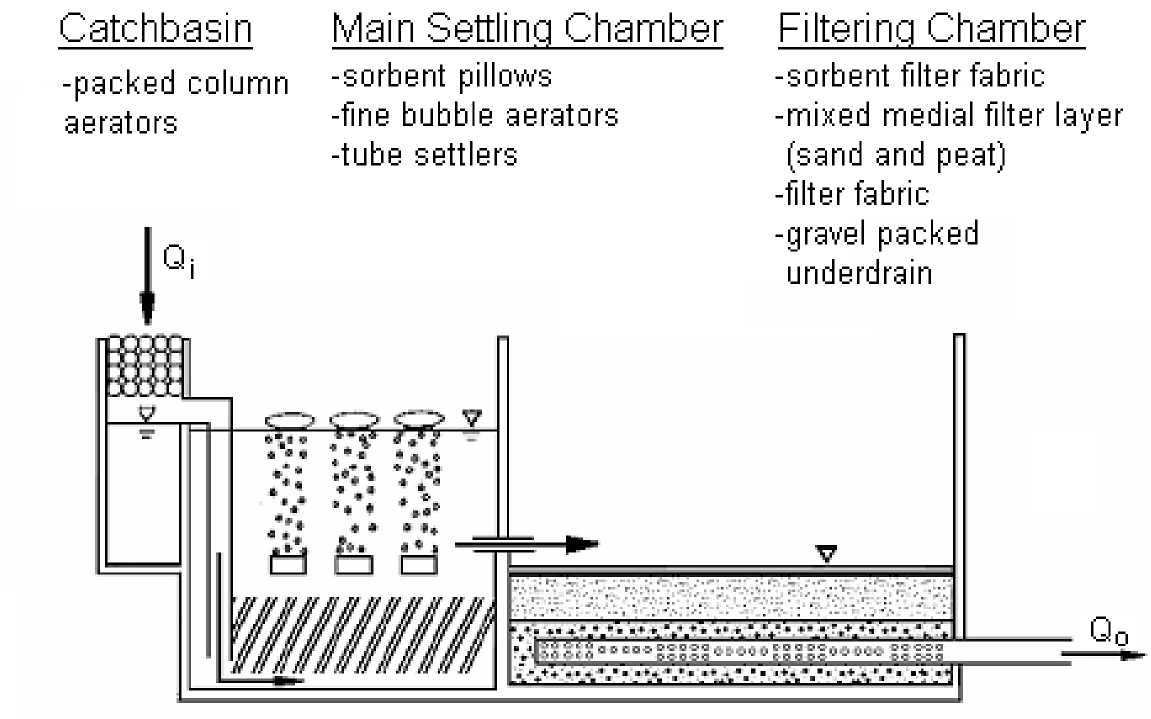
Limitations

- Capital costs of multiple systems are higher than for single devices.
- Space requirements are greater than that required for a single technology.

Design and Sizing Guidelines

Refer to individual treatment control BMP fact sheets. The Schematic of a Multi-Chambered Treatment Train (MCTT) figure illustrates a conceptual layout of a multiple treatment system.

Schematic of a Multi-Chambered Treatment Train (MCTT) (Robertson et al., 1995)



Performance

- Be aware that placing multiple BMPs in series does not necessarily result in combined cumulative increased performance. This is because the first BMP may already achieve part of the gain normally achieved by the second BMP. On the other hand, picking the right combination can often help optimize performance of the second BMP since the influent to the second BMP is of more consistent water quality, and thus more consistent performance, thereby allowing the BMP to achieve its highest performance.
- When addressing multiple constituents through multiple BMPs, one BMP may optimize removal of a particular constituent, while another BMP optimizes removal of a different constituent or set of constituents. Therefore, selecting the right combination of BMPs can be very constructive in collectively removing multiple constituents.

Siting Criteria

Refer to individual treatment control BMPs fact sheets.

Additional Design Guidelines

- When using two (2) or more BMPs in series, it may be possible to reduce the size of BMPs.
- Existing pretreatment requirements may be able to be avoided when using some BMPs combinations.

Maintenance

Refer to individual treatment control BMP fact sheets.

Cost

Refer to individual treatment control BMP fact sheets. Note that Hawaii’s unit prices are higher than California’s unit prices.

References

Individual Treatment Control BMPs fact sheets.

Photo Source. http://stormwater/ucf.edu/conferences/presentations/Pitt%20UpFlow%20Filtration%20for%20the%20Treatment%20of%20Stormwater.pdf.

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Treatment Control Manufactured Proprietary (MP) Fact Sheets

- MP-20 Wetland
- MP-40 Media Filter
- MP-50 Wet Vault
- MP-51 Vortex Separator
- MP-52 Drain Inlet

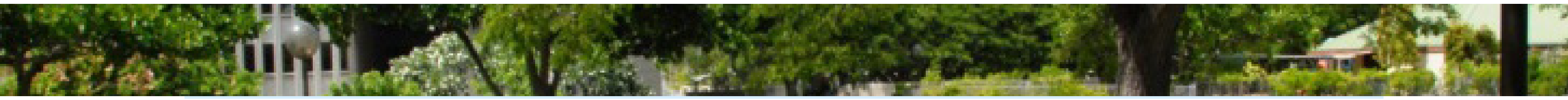

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Photo Source: Erie County, Ohio

Design Considerations	
•	Drainage Area Size
•	Potential Pre-treatment Requirements
Target Constituents	
✓	Sediments
✓	Nutrients
✓	Trash
✓	Metals
✓	Bacteria
✓	Oil and Grease
✓	Organics

Description

Modular wetlands or manufactured wetlands consist of two (2) concentric chambers that circulate storm water for an extended period of time to allow for contact and interaction with wetland vegetation. The inner chamber is a closed storage tank and the outer chamber is filled with fine gravel and wetland vegetation consists of cattails, reeds, and rushes. Storm water enters the center tank, moving in a circular motion, and then flows into the outer chamber via floating skimmers. A subsurface flow of storm water is routed through the gravel and wetland vegetation root system allowing for microbial utilization and plant uptake of pollutants. Pretreatment with an upstream treatment control can be added to remove litter, debris and coarse sediment loads. Supplemental media including activated carbon, iron wool and zeolite can also be added to increase pollutant removal efficiency. Modular wetlands are reportedly effective at removing dissolved and suspended solids, nutrients, pesticides, heavy metals and bacteria from urban runoff.

Advantages

- Gravel substrate and subsurface flow of the storm water through the root systems forces the vegetation to remove nutrients and dissolved pollutants from the storm water, which provides a good environment for bacteria, facilitating the removal of nitrogen and the degradation of oil and greases, and other organic compounds.
- The gravel substrate can also be augmented with media that is specifically effective at removing dissolved pollutants, increasing further the performance of the system.
- High removal efficiency of TSS, nutrients, pesticides, total metals, petroleum hydrocarbons and microbiological materials.
- Unlike standard constructed wetlands (TC-21), there is no standing water in the manufactured wetland between storms (after emptying with each storm). This minimizes but does not entirely eliminate the opportunity for mosquito breeding.
- Provides modest habitat for beneficial insects and other small invertebrates which in turn provide food for birds and other small animals.
- Can be incorporated into the landscaping of the development.
- Vegetation is more easily harvested in comparison to a wet pond or standard constructed wetland (TC-21).

Limitations

- Not likely suitable for drainage areas greater than an acre due to the number of units that are required for larger sites.
- Requires a perennial water source to maintain wetland vegetation (irrigation during dry season).
- Wetland vegetation requires annual maintenance.
- May attract invasive wetland species.
- With an emptying time as much as five (5) days, a breeding ground for mosquitoes may occur during and immediately following each storm.
- If site plan requires detention for flow control, the drawdown characteristics of the system must be compatible with the detention system.
- Where many units are required, the pattern of circular plastic covers of the center wells may not be appealing.
- Prefabricated wetland not readily available in Hawaii requires shipping from overseas manufacturer.
- Performance data not available.

Design and Construction Criteria

- The unit includes a burlap bag over the inlet to remove debris, and screens within the center well for the same purpose. However, the upstream drainage system is considered the primary remover of coarse solids and debris. If the drainage system lacks drain inlets with sumps where coarse sediments and floatables are removed, it is desirable to include a pretreatment unit for this purpose such as a manhole or wet vault of suitable size.
- Modular wetland should be sized to capture and treat the designated storm (for example the 2 year - 24 hour storm event); alternative sizing criteria may be acceptable if it is commonly used in other communities and performance data is available that demonstrates acceptable pollutant removal rates.
- A standard module is about 9.5 feet in diameter and 4 feet in height. Constructed of recycled polyethylene.
- Excavation depth of over 5 feet is typical.
- Refer to the manufacture's specifications for additional design and construction criteria.

Inspection and Maintenance Requirements

To maximize the benefits of wetland vegetation in its removal of pollutants:

- Inspect periodically and remove any invasive wetland plant species and to prevent water ponding standing longer than seven (7) days.
- Annual inspection and replacement of grit filter bag is required.
- Wetland vegetation should be harvested once a year during mid-summer before plants transferring phosphorus and metals from aboveground foliage to subsurface roots.
- The entire plant mass (foliage and roots) should be harvested and replaced every three to five years or more often as needed.

- Sediment should be removed for the center tank every three (3) to five (5) years or more often as needed. This is because the below ground biomass constitutes a significant reservoir (possibly half) of the nutrients and metals that are removed from the storm water by plants (Minton, 2002). Annual inspection maintenance and maintenance is typical.
- A vacuum truck or a septic tank service truck can conduct sediment removal.
- Crop vegetation near end of each growth season to capture the nutrients and pollutants removed by the wetland vegetation.

Performance

There is little operating data for the manufactured wetland, although these data indicate very high removal efficiencies, similar to created storm water wetlands. An advantage of wet ponds and standard constructed wetlands over most other treatment technologies is the removal of dissolved pollutants. However, this occurs only to the extent that the storm water pollutants are able to diffuse into the soil where they are removed by the soil or the plants. Except for non-rooted plants, pollutant uptake by vegetation does not occur in the overlying wet pool (Minton, 2002). Placement of wetland plants in gravel with the storm water flowing directly through the root system forces uptake by the vegetation. To maintain performance therefore requires annual or harvesting of the vegetation (See Inspection and Maintenance Requirements). However, the removal of dissolved phosphorus, metals, and complex organics like pesticides in earthen-lined ponds and wetlands is primarily by chemical sorption or precipitation with the soil, not uptake by plants (Minton, 2002). Gravel substrate does not provide ideal conditions for these chemical processes. There are currently limited operating data for the manufactured wetland with respect to the removal of dissolved pollutants and therefore whether uptake solely by plants is sufficient is unknown. It may be desirable to augment the gravel with media capable of removing dissolved pollutants. The supplemental media can be specific for the pollutant that is to be removed. The table below lists media that have been evaluated in either storm water or wastewater constructed wetlands or filtration systems.

The gravel substrate likely provides a good environment for bacteria, facilitating the removal of nitrogen (its primary mechanism of removal) and the degradation of petroleum and other organic compounds. While this has been confirmed to occur in the manufactured product discussed here, experience with constructed wetlands used for wastewater treatment (Minton, 2002) suggests that it likely occurs.

Supplemental Media

Target Pollutant	Alternative Media	References
Complex organics (i.e., pesticides)	Activated carbon	Metcalf and Eddy (2002), Minton (2002)
Petroleum hydrocarbons	Activated carbon, organoclay, granular polymer	Minton (2002)
Dissolved metals	zeolite, activated carbon	Minton (2002), Groffman et al. (1997), Netzer and Hughes (1984), Stormwater Management Inc. technical memos.
Dissolved phosphorous	Blast furnance slag, iron-ore, iron wool, limestone, aluminum oxide, dolomite, iron-infused resin	James, et al. (1992), Minton (2002), Shapiro(1999), Avoub et al. (2001), Storm-water Management Inc memos.

Siting Criteria

While not stated by the manufacturer, the system is likely most appropriate for small drainage areas of approximately an acre or less, given the number of units required per acre.

Additional Design Guidelines

As noted previously, the number of units installed is the function of the volume of water to be treated: multiple units are installed in parallel with incoming storm water split via a manifold.

The storage volume of one unit is approximately 185 ft3. The recommended emptying rate is 0.25 gallons per minute (average).

However, the emptying time must be considered with respect to the inter-event time between storms. If the emptying time is too great there is a statistical probability of some water being present in the units when the next storm occurs. If so, the full volume of the design event is not treated over the long term. The manufacturer currently does not provide a design method that considers this factor. The recommended approach is to use the method presented in TC-22 for Extended Detention systems inasmuch as the Storm Treat is a “fill-and-draw” system that functions like Extended Detention and should be expected to capture and treat the same storm water volume over time.

Fewer units are possible if the upstream drainage system is able to store water, although this extends the emptying time. If an upstream detention facility is required for flow control, it can provide the necessary storage and the number of wetland units is reduced, but not substantially given the need to drain the system in a timely fashion. Furthermore, if a detention facility is included it must control the release rate, not the manufactured wetland. This may require a more rapid release rate than recommended by the manufacturer. However, there are no data relating emptying rate with performance. Since the system also functions in effect as a horizontal filter, throughput rates higher than what is recommended by the manufacturer may be possible without a significant reduction in performance.

Cost

Manufacturers provide costs for the units including delivery, shipping and handling. Installation costs are generally on the order of 50 to 100% of the manufacturer’s cost.

Cost Considerations

- If the drainage system lacks drain inlets with sumps where coarse sediments and floatables are removed, it is desirable to include a pretreatment unit for this purpose such as a manhole or wet vault of suitable size. This should be factored in the cost-analysis when comparing to other treatment BMPs. If already a requirement of the local government, a detention facility for flow control can serve this purpose.
- In comparison to public domain wet ponds (TC-20) and constructed wetlands (TC-21), vegetation harvesting is simpler, and therefore less costly.

Note that Hawaii’s unit prices are higher than California’s unit prices.

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Design Considerations	
•	Design Storm
•	Media Type
•	Maintenance Requirement
Target Constituents	
✓	Sediments
✓	Nutrients
✓	Trash
✓	Metals
✓	Bacteria
✓	Oil and Grease
✓	Organics

Description

Manufactured storm water media filters are usually subsurface BMPs consisting of two (2) chambers including a pretreatment settling basin and a filter bed filled with sand or other absorptive filtering media. As storm water flows into the first chamber, large particles and floatables are removed, finer particles and other pollutants are then removed as storm water flows through the filtering media in the second chamber. Overflow weirs are typically incorporated to allow higher flows from larger storm events to bypass the device and flow directly into the storm drain system.

There are currently three (3) manufacturers of storm water filter systems. Two (2) are similar in that they use cartridges of a standard size. The cartridges are placed in vaults; the number of cartridges is a function of the design flow rate. The water flows laterally (horizontally) into the cartridge to a centerwell, then downward to an underdrain system. The third product is a flatbed filter, similar in appearance to sand filters.

Advantages

- Requires a smaller area than standard flatbed sand filters, wet ponds, and constructed wetlands.
- There is no standing water in the units between storms, minimizing but not entirely eliminating the opportunity for mosquito breeding.
- Media capable of removing dissolved pollutants can be selected.
- Removes sediment and any absorbed nutrients in the sediment, such as orthophosphates.
- One system utilizes media in layers, allowing for selective removal of pollutants.
- The modular concept allows the design engineer to more closely match the size of the facility to the design storm.

Limitations

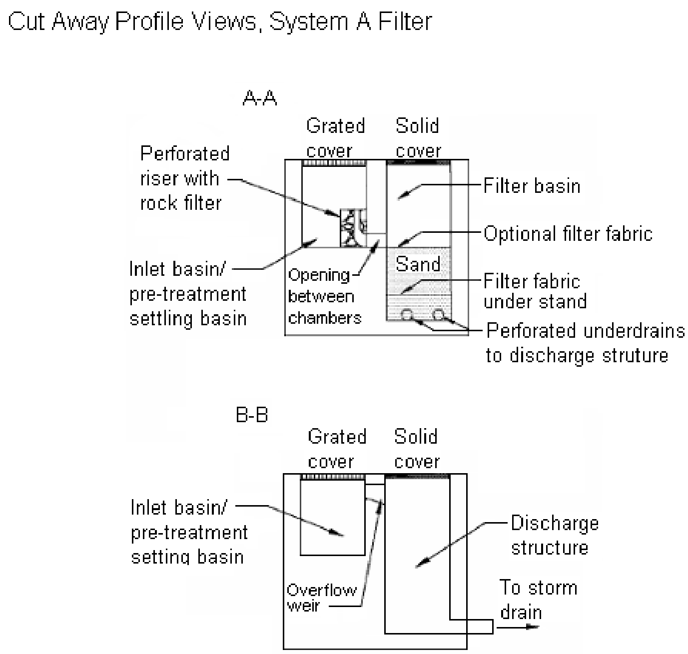
- Involves periodic inspections.
- Some manufactured media filters have reduced pollutant removal efficiencies at higher flow rates.
- Involves maintenance cleaning in a confined space.
- Headloss caused by overflow.
- Use in catchments that have significant areas of high sediment loads can lead to premature clogging.

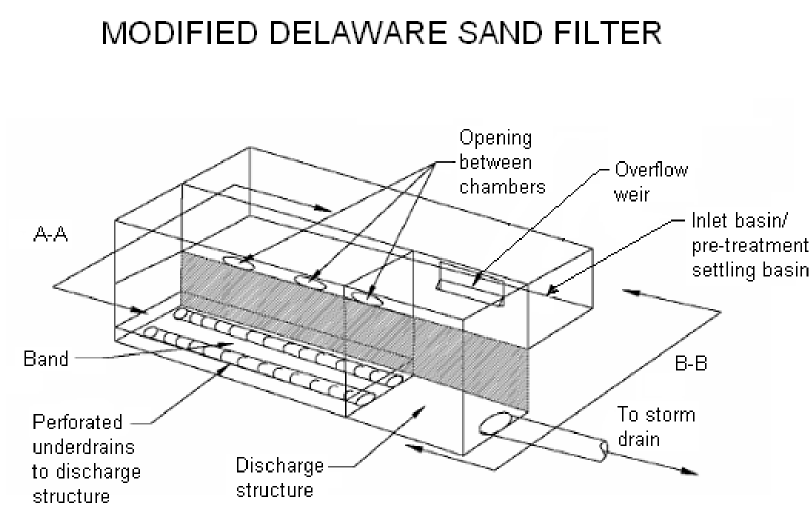
Design and Sizing Guidelines

There are currently three (3) storm water filter systems.

Filter System A: This system is similar in appearance to a slow-rate sand filter. However, the media is cellulose material treated to enhance its ability to remove hydrocarbons and other organic compounds. The media depth is 12 inches (30 centimeters). It operates at a very high rate, 20 gallon per minute/feet^2 at peak flows. Normal operating rates are much lower assuming that the storm water covers the entire bed at flows less than the peak rate. The system uses vortex separation for pretreatment. As the media is intended to remove sediments (with attached pollutants) and organic compounds, it would not be expected to remove dissolved pollutants such as nutrients and metals unless they are complexed with the organic compounds that are removed. See the Filter A System figure.

Filter System A





Filter System B: It uses a simple vertical filter consisting of 3-inch diameter, 30-inch high slotted plastic pipe wrapped with fabric. The standard fabric has nominal openings of 10 microns. The storm water flows into the vertical filter pipes and out through an underdrain system. Several units are placed vertically at 1 foot intervals to give the desired capacity. Pretreatment is typically a dry extended detention basin, with a detention time of about 30 hours. Storm water is retained in the basin by a bladder that is automatically inflated when rainfall begins. This action starts a timer which opens the bladder 30 hours later. The filter bay has an emptying time of 12 to 24 hours, or about 1 to 2 gallon per minute/feet^2 of filter area. This provides a total elapsed time of 42 to 54 hours. Given that the media is fabric, the system does not remove dissolved pollutants. It does remove pollutants attached to the sediment that is removed.

Filter System C: The system use vertical cartridges in which storm water enters radially to a center well within the filter unit, flowing downward to an underdrain system. Flow is controlled by a passive float valve system, which prevents water from passing through the cartridge until the water level in the vault rises to the top of the cartridge. Full use of the entire filter surface area and the volume of the cartridge are assured by a passive siphon mechanism as the water surface recedes below the top of the cartridge. A balance between hydrostatic forces assures a more or less equal flow potential across the vertical face of the filter surface. Hence, the filter surface receives suspended solids evenly. Absent the float valve and siphon systems, the amount of water treated over time per unit area in a vertical filter is not constant, decreasing with the filter height; furthermore, a filter would clog unevenly. Restriction of the flow using orifices ensures consistent hydraulic conductivity of the cartridge as a whole by allowing the orifice, rather than the media, whose hydraulic conductivity decreases over time, to control flow.

The manufacturer offers several media used singly or in combination (dual- or multi-media). Total media thickness is about 7 inches. Some media, such as fabric and perlite, remove only suspended solids (with attached pollutants). Media that also remove dissolved pollutants include compost, Zeolite and Iron-infused polymer. Pretreatment occurs in an upstream unit and/or the vault within which the cartridges are located.

Construction/Inspection Considerations

Inspect several times during the first year to establish loading and cleaning frequencies (typically cleaned once a year).

Performance

The mechanisms of pollutant removal are essentially the same as with public domain media filters (TC-40) if of a similar design. Removal of dissolved pollutants depends on the media. Perlite and filter are not effective at removal of dissolved pollutants, whereas filters with zeolites, compost, activated carbon, and peat have this capability.

As most manufactured filter systems function at higher flow rates and have larger media than found in flatbed filters, they may not provide the same level of performance as standard sand filters. However, the level of treatment may still be satisfactory.

Siting Criteria

- Can be placed under roadways, parking lots, sidewalks or landscaped areas and can treat drainage areas of up to five (5) acres (depending on manufacturer model).
- Do not install in drainage areas with highly erodible or unstable soils.

Additional Design Guidelines

Follow guidelines provided by the manufacturer.

Maintenance

- Manufactured filters, like standard filters (TC-40), require more frequent maintenance than most standard treatment systems like wet ponds and constructed wetlands, typically annually for most sites.
- Maintenance activities and frequencies are specific to each product. Annual maintenance is typical.
- Pretreatment systems that may precede the filter unit should be maintained at a frequency specified for the particular process.

Cost

Manufacturers provide costs for the units including delivery. Installation costs are generally on the order of 50 to 100% of the manufacturer's costs.

Cost Considerations

- Filters are generally more expensive to maintain than swales, ponds, and basins.
- The modularity of the manufactured systems allows the design engineer to closely match the capacity of the facility to the design storm, more so than with most other manufactured products.
- Note that Hawaii's unit prices are higher than California's unit prices.

References

California Stormwater Quality Association (CASQA) Best Management Practices Handbook New Development and Redevelopment, 2003.

Minton, G.R., 2002, Stormwater Treatment: Biological, Chemical, and Engineering Principles, RPA Press, 416 pages.

Wet Vault MP-50

Design Considerations	
•	Hydraulic Capacity
•	Sediment Accumulation
Target Constituents	
✓	Sediments
✓	Nutrients
✓	Trash
✓	Metals
✓	Bacteria
✓	Oil and Grease
✓	Organics

Description

A wet vault is a subterranean structure designed with baffles and chambers to promote settling of storm water particulates. They have a permanent water pool, generally 3 to 5 feet deep. The vault may also have a constricted outlet that causes a temporary rise of the water level (i.e., extended detention) during each storm. This additional volume generally drains within 12 to 48 hours after the end of each storm.

Advantages

- Internal baffling and other design features such as bypasses may increase performance over traditional wet vaults and/or reduce the likelihood of re-suspension and loss of sediments or floatables during high flows.
- Head loss is modest.

Limitations

- Concern about mosquito breeding in standing water.
- The area served is limited by the capacity of the largest models.
- As the products come in standard sizes, the facilities will be oversized in many cases relative to the design treatment storm, increasing the cost.
- Can be considerably more expensive than many other BMPs. However, the added cost may be offset by the value of continued use of the land surface.
- Ineffective in removing dissolved pollutants.
- A loss of dissolved pollutants may occur as accumulated organic matter (i.e., leaves) decomposes in the units.

Design and Sizing Guidelines

Water quality volume or flow rate (depending on the particular product) is determined by Figure 1 of the City Drainage Rules.

Manufactured vaults generally fall into three (3) categories:

- Vault System 1: This system consists of two (2) standard precast manholes that create an upstream (primary) chamber and a downstream (storage) chamber. The manholes are sized to capture a desired treatment volume. Storm water runoff enters the primary chamber where coarse-grained solids settle and collect. Storm water then flows to the storage chamber carrying floatable debris and trash where they are captured and retained. Further sedimentation occurs in the storage chamber and flows in excess of the design treatment flow rate are bypassed around the storage chamber to the storm drain system. The storage chamber serves as an off-line reservoir for floatables and finer-grained sediments and storm water flows through it at flow rates less than the design treatment flow rate of the device. The bypass prevents the re-suspension of sediments that have accumulated in the storage chamber. The manufacturer currently provides four (4) models with treatment flow rates ranging from 2.4 to 21.8 $feet^3$/second. The hydraulic capacities of the four (4) models range from 10 to 100 $feet^3$/second, respectively.

- Vault System 2: This system appears similar to a standard rectangular wet vault; however there are significant internal design differences. A series of baffles attached to the top and bottom function to reduce energy, aid in sedimentation and reduce the re-suspension of collected sediments. The vault includes a permanent pool and a constricted outlet that causes a temporary rise in the water level of the pool during storm events. The system consists of standard modular units that can be configured to provide the desired treatment volume. Floating absorbent pads can also be added for oil and grease.
- Vault System 3: This style of wet vault consists of one circular structure that can be constructed of a standard precast manhole. Larger drainage areas require the use of larger non-standard size manholes. A proprietary internal bypass weir structure routes all storm water flows up to the bypass rate into a center well where sedimentation occurs. Flows in excess of the treatment flow rate are diverted directly across the top of the center well and over the bypass weir to the storm drain system. Currently there are twelve models of Type C wet vault systems available. The manufacturer provides the capacity and efficiency of these systems. The hydraulic capacity of these systems ranges from a low flow model to more than 60 $feet^3$/second. The required amount of head is a function of the treatment capacity of the systems and ranges to a maximum of 21 inches.

Construction/Inspection Considerations

Refer to guidelines provided by the manufacturer.

Performance

A manufactured wet vault can be expected to perform similarly to large catch basins in that its wet volume (dead storage) is similar to that determined by methodology provided in TC-20 for wet ponds. Hence, the engineer should compare the volume of the model he/she intends to select to what the volume of a constructed wet vault would be for the site. Conceivably, manufactured vaults may give better performance than standard catch basins, given the inclusion of design elements that are intended to minimize re-suspension. Given this benefit, it could be argued that manufactured wet vaults can be smaller than traditional catch basins, to achieve similar performance. However, there is insufficient data indicating the incremental benefit of the particular design elements of each manufactured product.

Siting Criteria

There are no unique siting criteria. The size of the drainage area that can be served by a manufactured wet vault is directly related to the capacities of the largest models.

Additional Design Guidelines

Refer to guidelines of the manufacturers.

Maintenance

- Maintenance consists of the removal of accumulated material with a sump vacuum or a vacuum truck. It may be necessary to remove and dispose the floatables separately due to the presence of petroleum product.

- Units should be cleaned when sediment reaches 25% of the vault storage capacity.
- Annual maintenance is typical.

It is important to recognize that as storage of accumulated sediment occurs directly in the operating area of the wet vault, treatment efficiency will decline over time given the reduction in treatment volume. Whether this is significant depends on the design capacity. If the total volume of the wet pool is similar to that determined by the method on TC-20, the effect on performance is minor.

Maintenance Requirements

- Each manufacturer provides storage capacities with respect to sediments and floatables, with recommendations on the frequency of cleaning as a function of the percentage of the volume in the unit that has been filled by these materials.
- The recommended frequency of cleaning differs with the manufacturer, ranging from one (1) to two (2) years. It is prudent to inspect the unit twice during the first wet season of operation, setting the cleaning frequency accordingly.

Cost

Manufacturers provide costs for the units including delivery. Installation costs are generally on the order of 50 to 100% of the manufacturer's cost.

Cost Considerations

- The different geometries of the several manufactured separators suggest that when comparing the costs of these systems to each other, that local conditions (i.e., groundwater levels) may affect the relative cost-effectiveness.
- Subsurface facilities are more expensive to construct than surface facilities of similar size. However, the added cost of construction is in many developments offset by the value of continued use of the land.
- Some of the manufactured vaults may be less expensive to maintain than public domain vaults as the former may be cleaned without the need for confined space entry.
- Subsurface facilities do not require landscaping, reducing maintenance costs accordingly.

Note that Hawaii's unit prices are higher than California's unit prices.

References

California Stormwater Quality Association (CASQA) Best Management Practices Handbook New Development and Redevelopment, 2003.

Minton, G.R., 2002. Stormwater treatment, Biological, Chemical & Engineering Principles, Resource Planning Associates, Seattle, Washington.

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Vortex Separator MP-51

Design Considerations		
•	Service Area	
•	Setting Velocity	
•	Appropriate Sizing	
•	Inlet Pipe Diameter	
Target Constituents		
✓	Sediments	M
✓	Nutrients	L
✓	Trash	
✓	Metals	L
✓	Bacteria	
✓	Oil and Grease	
✓	Organics	
Legend (Removal Effectiveness)		
L	Low	
M	Medium	
H	High	

Description

Vortex separators: (alternatively, Hydrodynamic or swirl concentrators) are gravity separators, and in principle are essentially wet vaults. The difference from wet vaults, however, is that the vortex separator is round, rather than rectangular, and the water moves in a centrifugal fashion before exiting. By having the water move in a circular fashion, rather than a straight line as is the case with a standard wet vault, it is possible to obtain significant removal of suspended sediments and attached pollutants with less space. They are designed to remove trash, debris, and some amount of sediment, oil, and grease from urban runoff. Consisting of flow-through structures that have a settling or separation unit to remove sediment and other pollutants. Are best suited for heavy particulates (which settle) or floatables, rather than dissolved solids and pollutants that do not settle.

Advantages

- May provide the desired performance in less space and therefore less cost.
- May be more cost-effective pre-treatment devices than traditional wet or dry basins.
- Mosquito control may be less of an issue than with traditional wet basins.

Limitations

- As some of the systems have standing water that remains between storms, there is concern about mosquito breeding.
- It is likely that hydrodynamic/vortex separators are not as effective as wet vaults at removing fine sediments, on the order of 50 to 100 microns in diameter and less.
- The area served is limited by the capacity of the largest models.
- As the products come in standard sizes, the facilities will be oversized in many cases relative to the design treatment storm, increasing the cost.
- The non-steady flows of storm water decreases the efficiency of vortex separators from what may be estimated or determined from testing under constant flow.
- Will not significantly remove pollutants such as nutrients, which adhere to fine particulates or are dissolved.

- A loss of dissolved pollutants may occur as accumulated organic matter (i.e., leaves) decomposes in the units.
- Removal of debris and sediment require vacuum or manual cleaning.
- Annual inspection recommended. May require confined space entry for maintenance

Design and Sizing Guidelines

The storm water enters, typically below the effluent line, tangentially into the basin, thereby imparting a circular motion in the system. Due to centrifugal forces created by the circular motion, the suspended particles move to the center of the device where they settle to the bottom. There are two (2) general types of vortex separation: free vortex and dampened (or impeded) vortex. Free vortex separation becomes dampened vortex separation by the placement of radial baffles on the weir-plate that impede the free vortex-flow pattern.

It has been stated with respect to combined sewer overflows (CSOs) that the practical lower limit of vortex separation is a particle with a settling velocity of 12 to 16.5 feet per hour (0.10 to 0.14 cm/s). As such, the focus for vortex separation in CSOs has been with settleable solids generally 200 microns and larger, given the presence of the lighter organic solids. For inorganic sediment, the above settling velocity range represents a particle diameter of 50 to 100 microns. Head loss is a function of the size of the target particle. At 200 microns it is normally minor but increases significantly if the goal is to remove smaller particles. Note that the city's sewer and storm water collection systems are separate systems, and not CSOs. However, the performance of the vortex separation for storm water is expected to be similar, based upon the physical laws of sedimentation and hydraulics.

The commercial separators applied to storm water treatment vary considerably with respect to geometry, and the inclusion of radial baffles and internal circular chambers. At one extreme is the inclusion of a chamber within the round concentrator. Water flows initially around the perimeter between the inner and outer chambers, and then into the inner chamber, giving rise to a sudden change in velocity that purportedly enhances removal efficiency. The opposite extreme is to introduce the water tangentially into a round manhole with no internal parts of any kind except for an outlet hood. Whether the inclusion of chambers and baffles gives better performance is unknown. Some contend that free vortex, also identified as swirl concentration, creates less turbulence thereby increasing removal efficiency. One product is unique in that it includes a static separator screen.

- Size is based on the peak flow of the design treatment event as specified.
- If an in-line facility, the design peak flow is four times the peak of the design treatment event.
- If an off-line facility, the design peak flow is equal to the peak of the design treatment event.
- Head loss differs with the product and the model but is generally on the order of one foot or less in most cases.

Construction/Inspection Considerations

No special considerations.

Performance

Manufacturer's differ with respect to performance claims, but a general statement is that the manufacturer's design and rated capacity (feet^3/second) for each model is based on and believed to achieve an aggregate reduction of 90% of all particles with a specific gravity of 2.65 down to 150 microns, and to capture the floatables, and oil and grease. Laboratory tests of two (2) products support this claim. The stated performance expectation therefore implies that a lesser removal efficiency is obtained with particles less than 150 microns, and the lighter, organic settleables Laboratory tests of one of the products found about 60% removal of 50 micron sand at the expected average operating flow rate.

For vortex separation by particle size and velocities, see previous section Design and Sizing Guidelines.

Traditional treatment technologies such as wet ponds and extended detention basins are generally believed to be more effective at removing very small particles, down to the range of 10 to 20 microns. Hence, it is intuitively expected that vortex separators do not perform as well as the traditional wet and dry basins, and filters. Whether this matters depends on the particle size distribution of the sediments in storm water. If the distribution leans towards small material, there should be a marked difference between vortex separators and, say, traditional wet vaults.

There are little data to support this conjecture.

In comparison to other treatment technologies, such as wet ponds and grass swales, there are few studies of vortex separators. Two (2) field studies have been conducted. Both achieved in excess of 80% removal of TSS. However, the test was conducted in the Northeast (New York state and Maine) where it is possible the storm water contained significant quantities of de-icing sand. Consequently, the influent TSS concentrations and particle size are both likely considerably higher than is found in Hawaii storm water. These data suggest that if the storm water particles are for the most part fine (i.e., less than 50 microns), vortex separators will not be as efficient as traditional treatment BMPs such as wet ponds and swales, if the latter are sized according to the recommendations of this manual.

Siting Criteria

There are no particularly unique siting criteria. The size of the drainage area that can be served by vortex separators is directly related to the capacities of the largest models.

Additional Design Guidelines

Vortex separators have two (2) capacities if positioned as in-line facilities, a treatment capacity and a hydraulic capacity. Failure to recognize the difference between the two (1) may lead to significant under sizing; i.e., too small a model is selected. This observation is relevant to three of the five (5) products. These three (3) technologies all are designed to experience a unit flow rate of about 24 gallons/feet^2 of separator footprint at the peak of the design treatment event. This is the horizontal area of the separator zone within the container, not the total footprint of the unit. At this unit flow rate, laboratory tests by these manufacturers have established that the performance will meet the general claims previously described. However, the units are sized to handle 100 gallons/square foot at the peak of the hydraulic event. Hence, in selecting a particular model the design engineer must be certain to match the peak flow of the design event to the stated treatment capacity, not the hydraulic capacity. The former is one-fourth the latter. If the unit is positioned as an off-line facility, the model selected is based on the capacity equal to the peak of the design treatment event.

Maintenance

Maintenance consists of the removal of accumulated material either manually or with a vacuum truck. It may be necessary to remove and dispose the floatables separately due to the presence of petroleum product.

Maintenance Requirements

Remove all accumulated sediment, and litter and other floatables, annually, unless experience indicates the need for more or less frequent maintenance.

Cost

Manufacturers provide costs for the units including delivery. Installation costs are generally on the order of 50 to 100% of the manufacturer's cost. For most sites the units are cleaned annually.

Cost Considerations

The different geometry of the several manufactured separators suggests that when comparing the costs of these systems to each other, that local conditions (i.e., groundwater levels) may affect the relative cost-effectiveness.

Note that Hawaii's unit prices are higher than California's unit prices.

References and Sources of Additional Information

California Stormwater Quality Association (CASQA) Best Management Practices Handbook New Development and Redevelopment, 2003.

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Drain Inlet Inserts MP-52

Design Considerations		
•	Use with other BMPs	
•	Fit and Seal Capacity within Inlet	
Target Constituents		
✓	Sediments	M
✓	Nutrients	L
✓	Trash	
✓	Metals	L
✓	Bacteria	
✓	Oil and Grease	
✓	Organics	
Legend (Removal Effectiveness)		
L	Low	
M	Medium	
H	High	

Description

Drain inlet inserts (a.k.a. catch basin inserts or grate inlet inserts) filters placed in drop inlets to help remove sediment and debris from storm water runoff. They are used to increase a catch basin's efficiency at removing trash, debris and sediment and some oil and grease, organics, and metals. There are many varieties of catch basin inserts; however they typically fall into one of three main types of inserts: trays, boxes or socks. The tray insert option consists of a series of trays, with the top tray serving as an initial sediment trap. Underlying trays often contain filters composed of a variety of different types of media including polypropylene, porous polymers, treated cellulose, and activated carbon. The box option is typically constructed of plastic or wire mesh with filtering medium that fits directly into the box within the catch basin. Hydrocarbons are removed as the storm water passes through the adsorbent filters while trash, debris and sediment remains in the box as the storm water exits. Both tray and box type catch basin inserts typically provide overflow features and reportedly do not reduce the original hydraulic capacity of the catch basin. The sock option uses filter fabric (usually polypropylene) to remove pollutants from vertical drop inlets. The fabric is either attached to a frame or directly to the catch basin or grated inlet. Each of these options provides very little volume; therefore frequent sediment removal and maintenance is required. Some models allow for sediment removal with a vacuum truck while others require physically removing the insert for cleaning.

Other Jurisdictions Experience

Some users have reported that these systems require considerable maintenance to prevent plugging and bypass.

Advantages

- Does not require additional space in inserts as the drain inlets are already a component of the standard drainage systems.
- Easy access for inspection and maintenance.
- As there is no standing water, there is little concern for mosquito breeding.
- A relatively inexpensive capitol cost retrofit option.

Limitations

- Performance is likely significantly less than treatment systems that are located at the end of the drainage system such as ponds and vaults.
- Usually not suitable for large areas or areas with trash or leaves than can plug the insert.
- Requires frequent inspection.
- Additional cost to clean and or replace inserts.
- May reduce the hydraulic capacity of a catch basin, particularly when full of debris.
- Studies have found that a variety of inserts showed little removal of total suspended solids (TSS), partially due to scouring and re-suspension from relatively small (6-month) storm events.

Design and Sizing Guidelines

- Refer to manufacturer's guidelines.
- Drain inserts come in many configurations but can be placed into three general groups: socks, boxes, and trays. The sock consists of a fabric, usually constructed of polypropylene. The fabric may be attached to a frame or the grate of the inlet holds the sock. Socks are meant for vertical (drop) inlets. Boxes are constructed of plastic or wire mesh. Typically a polypropylene "bag" is placed in the wire mesh box. The bag takes the form of the box. Most box products are one box; that is, the setting area and filtration through media occurs in the same box.
- One manufacturer has a double-box. Storm water enters the first box where setting occurs. The storm water flows into the second box where the filter media is located. Some products consist of one or more trays or mesh grates. The trays can hold different types of media. Filtration media vary with the manufacturer: types include polypropylene, porous polymer, treated cellulose, and activated carbon.
- The diameter of the catch basin should be equal to four (4) times the diameter of the outlet pipe.

Construction/Inspection Considerations

- Be certain that installation is done in a manner that makes certain that the storm water enters the unit and does not leak around the perimeter. Leakage between the frame of the insert and the frame of the drain inlet can easily occur with vertical (drop) inlets.
- Inspect several times within the first year to establish cleaning frequencies.
- At a minimum, inserts should be cleaned or replaced once or twice per year.
- "Ultra Urban" brand filters recommend replacement of filter box every one (1) to three (3) years.

Performance

Few products have performance data collected under field conditions. The University of California, Los Angeles has tested "Ultra Urban" brand filters in low flow situations. The results of these tests indicate up to 80% removal rate of the petroleum hydrocarbons. The captured oil is then permanently bonded with the "Smart Sponge," which eliminates leaching.

Siting Criteria

It is recommended that inserts be used only for retrofit situations or as pretreatment where other treatment BMPs presented in this section area used.

Additional Design Guidelines

Follow guidelines provided by individual manufacturers.

Maintenance

Likely require frequent maintenance, on the order of several times per year.

Cost

- The initial cost of individual inserts ranges from less than $100 to about $2,000. The cost of using multiple units in curb inlet drains varies with the size of the inlet.
- The low cost of inserts may tend to favor the use of these systems over other, more effective treatment BMPs. However, the low cost of each unit may be offset by the number of units that are required, more frequent maintenance, and the shorter structural life (and therefore replacement).

Note that Hawaii's unit prices are higher than California's unit prices.

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6. LONG-TERM MAINTENANCE OF BMPS

6.1. Introduction

The long-term performance of BMPs hinges on ongoing and proper maintenance. In order for this to occur, detailed maintenance plans are needed that include specific maintenance activities and frequencies for each type of BMP. In addition, these should include indicators for assessing when "as needed" maintenance activities are required. The fact sheets included in this manual contain the basic information needed to develop these maintenance plans. The following discussion is based primarily on data developed by Horner et al. (1994) and information available at http://www.stormwatercenter.net.

6.2. Critical Regulatory Components

Critical regulatory components identified by Horner et al. (1994) include:

- Regulations should officially designate a responsible party, frequently the development site owner, to have ultimate responsibility for the continued maintenance of storm water facilities. This official designation provides the opportunity for appropriate preparation and budgeting prior to actually assuming responsibilities. It also facilitates enforcement or other legal remedies necessary to address compliance or performance problems once the facility has been constructed.
- Regulations should clearly state the inspection and maintenance requirements. Inspection and maintenance requirements should also comply with all applicable statutes and be based on the needs and priorities of the individual measure or facility. A clear presentation will help owners and builders comply, and inspectors enforce requirements.
- Regulations should contain comprehensive requirements for documenting and detailing maintenance. A facility operation and maintenance manual should be prepared containing accurate and comprehensive drawings or plans of the completed facility and detailed descriptions and schedules of inspection and maintenance.
- The regulations should delineate the procedure for maintenance noncompliance. This process should provide informal, discretionary measures to deal with periodic, inadvertent noncompliance and formal and severe measures to address chronic noncompliance or performance problems. In either case, the primary goal of enforcement is to maintain an effective BMP – the enforcement action should not become an end in itself.
- Regulations should also address the possibility of total default by the owner or builder by providing a way to complete construction and continue maintenance. For example, the public might assume maintenance responsibility. If so, the designated public agency must be alerted and possess the necessary staffing, equipment, expertise, and funding to assume this responsibility. Default can be addressed through bonds and other performance guarantees obtained before the project is approved and construction begins. These bonds can then be used to fund the necessary maintenance activities.
- The regulations must recognize that adequate and secure funding is needed for facility inspection and maintenance, and provide for such funding.

6.3. Enforcement Options

A public agency will sometimes need to compel those responsible for facility construction or maintenance to fulfill their obligations. Therefore, the maintenance program must have enforcement options for quick corrective action. Rather than a single enforcement measure, the program should have a variety of techniques, each with its own degree of formality and legal weight. The inspection program should provide for nonconforming performance and even default, and contain suitable means to address all stages.

Prior to receiving construction approval, the developer or builder can be forced to provide performance guarantees. The public agency overseeing the construction can use these guarantees, usually a performance bond or other surety in an amount equal to some fraction of the facility's construction cost, to fund maintenance activities.

Enforcement of maintenance requirements can be accomplished through a storm water maintenance agreement, which is a formal contract between a local government and a property owner designed to guarantee that specific maintenance functions are performed in exchange for permission to develop that property (http://www.stormwatercenter.net). Local governments benefit from these agreements in that responsibility for regular maintenance of the BMPs can be placed upon the property owner or other legally recognized party, allowing agency staff more time for plan review and inspection.

6.4. Maintenance Agreements

Maintenance agreements can be an effective tool for ensuring long-term maintenance of on-site BMPs. The most important aspect of creating these maintenance agreements is to clearly define the responsibilities of each party entering into the agreement. Basic language that should be incorporated into an agreement includes the following:

1. **Performance of Routine Maintenance**

   Local governments often find it easier to have a property owner perform all maintenance according to the requirements of a Design Manual. Other communities require that property owners do aesthetic maintenance (i.e., mowing, vegetation removal) and implement pollution prevention plans, but elect to perform structural maintenance and sediment removal themselves.

2. **Maintenance Schedules**

   Maintenance requirements may vary, but usually require that all BMP owners perform at least an annual inspection and document the maintenance and repairs performed. An annual report must then be submitted to the government, who may then choose to perform an inspection of the facility.

3. **Inspection Requirements**

   Local governments may obligate themselves to perform an annual inspection of a BMP, or may choose to inspect when deemed necessary instead. Local governments may also wish to include language allowing maintenance requirements to be increased if deemed necessary to ensure proper functioning of the BMP.

4. Access to BMPs

The agreement should grant permission to a local government or its authorized agent to enter onto property to inspect BMPs. If deficiencies are noted, the government should then provide a copy of the inspection report to the property owner and provide a timeline for repair of these deficiencies.

5. Failure to Maintain

In the maintenance agreement, the government should repeat the steps available for addressing a failure to maintain situation. Language allowing access to BMPs cited as not properly maintained is essential, along with the right to charge any costs for repairs back to the property owner. The government may wish to include deadlines for repayment of maintenance costs, and provide for liens against property up to the cost of the maintenance plus interest.

6. Recording of the Maintenance Agreement

An important aspect to the recording of the maintenance agreement is that the agreement be recorded into local deed records. This helps ensure that the maintenance agreement is bound to the property in perpetuity.

Finally, some communities elect to include easement requirements into their maintenance agreements. While easement agreements are often secured through a separate legal agreement, recording public access easements for maintenance.

Examples of maintenance agreements include several available on the web at http://www.stormwatercenter.net.

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7. GLOSSARY

303(d) Listed: Water bodies listed as impaired as per Section 303(d) of the 1972 Clean Water Act.

Best Management Practices (BMPs): Includes schedules of activities, prohibitions of practices, maintenance procedures, and other management practices to prevent, eliminate, or reduce the pollution of waters of the receiving waters. BMPs also include treatment requirements, operating procedures, and practices to control plant site runoff spillage or leaks, sludge or waste disposal, or drainage from raw material storage.

Catch Basin (Also known as Inlet): Box-like underground concrete structure with openings in curbs and gutters designed to collect runoff from streets and pavement.

Check Dams: Small temporary dams constructed across a swale or drainage ditch. Check dams reduce the velocity of concentrated storm water flows, thereby reducing erosion of the swale or ditch. The dams also decrease water velocity to increase sediment capture.

City: City & County of Honolulu.

Clean Water Act (CWA): (33 U.S.C. 1251 et seq.) requirements of the NPDES program are defined under Sections 307, 402, 318 and 405 of the CWA.

Construction Activity: Includes clearing, grading, excavation, and contractor activities that result in soil disturbance. Construction activities are regulated by the NPDES General Permit Coverage Hawaii Administrative Rules (HAR) Chapter 11-55 Water Pollution Control, Appendix C-Storm Water Associated with Construction Activities, effective October 22, 2007.

Denuded: Land stripped of vegetation or land that has had its vegetation worn down due to the impacts from the elements or humans.

Detention: The capture and subsequent release of storm water runoff from the site at a slower rate than it is collected, the difference being held in temporary storage.

Discharge: A release or flow of storm water or other substance from a conveyance system or storage container. Broader–includes release to storm drains, etc.

Effluent Limits: Limitations on amounts of pollutants that may be contained in a discharge. Can be expressed in a number of ways including as a concentration, as a concentration over a time period (i.e., 30-day average must be less than 20 mg/l), or as a total mass per time unit, or as a narrative limit.

Erosion: The wearing away of land surface by wind or water. Erosion occurs naturally from weather or runoff but can be intensified by land-clearing practices related to farming, new development, redevelopment, road building, or timber cutting.

Facility: Is a collection of industrial processes discharging storm water associated with industrial activity within the property boundary or operational unit.

Grading: The cutting or filling of the land surface to a desired slope or elevation.

Hazardous Waste: A waste or combination of wastes that, because of its quantity, concentration, or physical, chemical or infectious characteristics, may either cause or significantly contribute to an increase in mortality or an increase in serious irreversible illness; or pose a substantial present or potential hazard to human health or the environment when improperly treated, stored, transported, disposed of or otherwise managed. Possesses at least one of four characteristics (ignitability, corrosivity, reactivity, or toxicity) or appears on special EPA or state lists. Regulated under the federal Resource Conservation and Recovery Act and the California Health and Safety Code.

Illicit Discharges: Any discharge to a municipal separate storm sewer that is not in compliance with applicable laws and regulations as discussed in this document.

Industrial General Permit: A National Pollutant Discharge Elimination System (NPDES) Permit issued by the State of Hawaii Department of Health Clean Water Branch for discharge of storm water associated with industrial activity.

Inlet: An entrance into a ditch, storm drain, or other waterway.

Integrated Pest Management (IPM): An ecosystem-based strategy that focuses on long-term prevention of pests or their damage through a combination of techniques such as biological control, habitat manipulation, modification of cultural practices, and use of resistant varieties. Pesticides are used only after monitoring indicates they are needed according to established guidelines, and treatments are made with the goal of removing only the target organism.

Municipal Separate Storm Sewer System (MS4): A conveyance or system of conveyances (including roads with drainage systems, municipal streets, catch basins, curbs, gutters, ditches, man-made channels, or storm drains): (i) designed or used for collecting or conveying storm water; (ii) which is not a combined sewer; and (iii) which is not part of a Publicly Owned Treatment Works (POTW) as defined at Title 40 of the Code of Federal Regulations (CFR) 122.2. A "Small MS4" is defined as an MS4 that is not a permitted MS4 under the Phase I regulations. This definition of a Small MS4 applies to MS4 operated within cities and counties as well as governmental facilities that have a system of storm sewers.

Non-Storm Water Discharge: Any discharge to municipal separate storm sewer that is not composed entirely of storm water.

Nonpoint Source Pollution: Pollution that does not come from a point source. Nonpoint source pollution originates from aerial diffuse sources that are mostly related to land use.

Notice of Intent (NOI): A formal notice to the State of Hawaii Clean Water Branch submitted by the owner of an industrial site or construction site that said owner seeks coverage under a General Permit for discharges associated with industrial and construction activities. The NOI provides information on the owner, location, type of project, and certifies that the owner will comply with the conditions of the construction General Permit.

Notice of Cessation (NOC): Formal notice to the State of Hawaii Clean Water Branch submitted by owner/ developer that a construction project is complete.

NPDES Permit: NPDES is an acronym for National Pollutant Discharge Elimination System. NPDES is the national program for administering and regulating Sections 307, 318, 402, and 405 of the Clean Water Act (CWA). In Hawaii, the Department of Health Clean Water Branch has issued a permit to discharge storm water runoff from the City and County of Honolulu's Municipal Separate Storm Sewer System (MS4) into state waters in and around the Island of Oahu for storm water discharges.

Outfall: The end point where storm drains discharge water into a waterway.

Point Source: Any discernible, confined, and discrete conveyance from which pollutants are or may be discharged. This term does not include return flows from irrigated agriculture or agricultural storm water runoff.

Pollutant: Generally, any substance introduced into the environment that adversely affects the usefulness of a resource.

Pollution Prevention (P2): Practices and actions that reduce or eliminate the generation of pollutants.

Precipitation: Any form of rain.

Pretreatment: Treatment of waste stream before it is discharged to a collection system.

Reclaim (water reclamation): Planned use of treated effluent that would otherwise be discharged without being put to direct use.

Retention: The storage of storm water to prevent it from leaving the development site.

Reuse (water reuse): (see Reclaim)

Runoff: Water originating from rainfall and other sources (i.e., sprinkler irrigation) that flows over the land surface to drainage facilities, rivers, streams, springs, seeps, ponds, lakes, and wetlands.

Run-on: Offsite storm water surface flow or other surface flow which enters your site.

Scour: The erosive and digging action in a watercourse caused by flowing water.

Secondary Containment: Structures, usually dikes or berms, surrounding tanks or other storage containers, designed to catch spilled materials from the storage containers.

Sedimentation: The process of depositing soil particles, clays, sands, or other sediments that were picked up by runoff.

Sediments: Soil, sand, and minerals washed from land into water, usually after rain, that collect in reservoirs, rivers, and harbors, destroying fish nesting areas and clouding the water, thus preventing sunlight from reaching aquatic plants. Farming, mining, and building activities without proper implementation of BMPs will expose sediment materials, allowing them to be washed off the land after rainfalls.

Significant Materials: Includes, but not limited to, raw materials; fuels; materials such as solvents, detergents, and plastic pellets; finished materials such as metallic products; raw materials used in food processing or production; hazardous substances designed under Section 10 1(14) of CERLCA; any chemical the facility is required to report pursuant to Section 313 of Title III of SARA; fertilizers; pesticides; and waste products such as ashes, slag, and sludge that have the potential to be released with storm water discharges.

Significant Quantities: The volume, concentrations, or mass of a pollutant in storm water discharge that can cause or threaten to cause pollution, contamination, or nuisance that adversely impact human health or the environment and cause or contribute to a violation of any applicable water quality standards for receiving water.

Source Control BMPs: Operational practices that reduce potential pollutants at the source.

Source Reduction (also source control): The technique of stopping and/ or reducing pollutants at their point of generation so that they do not come into contact with storm water.

Storm Drains: Above- and below-ground structures for transporting storm water to streams or outfalls for flood control purposes.

Storm Water: Defined as urban runoff consisting only of those discharges, which originate from precipitation events. Storm water is the portion of precipitation that flows across a surface to the storm drain system or receiving waters.

Storm Water Discharge Associated with Industrial Activity: Discharge from any conveyance which is used for collecting and conveying storm water from an area that is directly related to manufacturing, processing, or raw materials storage activities at an industrial plant.

Storm Water Hotspots: Storm water hotspots are areas where land use or activities generate highly contaminated runoff, with concentrations of pollutants exceeding those typically found in storm water.

Storm Water Pollution Control Plan (SWPCP): A written plan that documents the series of phases and activities that, first, characterizes your site, and then prompts you to select and carry out actions which prevent the pollution of storm water discharges. For construction activities NOI, the Department of Health Clean Water Branch has renamed SWPCP to site-specific BMPs plan.

Storm Water Retrofit: A storm water retrofit is a storm water management practice (usually structural) put into place after development has occurred, to improve water quality, protect downstream channels, reduce flooding, or meet other specific objectives.

Treatment Control BMPs: Treatment methods to remove pollutants from storm water.

Toxicity: Adverse responses of organisms to chemicals or physical agents ranging from mortality to physiological responses such as impaired reproduction or growth anomalies.

Turbidity: Describes the ability of light to pass through water. The cloudy appearance of water caused by suspended and colloidal matter (particles).