A-7.0 NEW DEVELOPMENT/REDEVELOPMENT

A-7.1 Introduction

One of the most important responsibilities of the City is to provide a decision making and approval processing framework for new development and redevelopment that occurs within the City's boundaries. This framework ensures that both development and redevelopment occur in an organized and orderly fashion that reflects the vision and needs of the community, assesses the environmental issues associated with the proposed changes, and provides a regulatory framework to ensure that standards set by the City are implemented.

The Third Term MS4 Permits required the Permittees to initiate a comprehensive assessment of their planning and development processes with the intent of providing a greater focus on the protection of water bodies and a more rigorous application of BMPs in development and significant redevelopment projects. The Co-Permittees collaborated on the development of a model program to guide compliance with these requirements (see **DAMP, Section 7**).

The model program links BMP design, construction and operation to the earlier phases of project planning encompassed by the City's General Plan, environmental review process and development application approval processes. The General Plan specifies policies that guide new development. The environmental review process examines impacts from proposed new development /significant redevelopment with respect to the General Plan policies and many environmental issues, including water quality, and includes consideration of mitigation measures to reduce any identified significant impacts.

The development project application approval process carries forward mitigation requirements in the form of conditions of approval, design specifications, tracking, inspection and enforcement actions. These early planning processes must be coordinated and linked to the later phases of BMP design, construction and operation for new development/significant redevelopment to help ensure water quality protection features are planned, designed and evaluated in accordance with goals for the protection of water quality and other environmental resources.

The City used the model program in forming the new development/significant redevelopment plan contained within this section of the LIP. Subsequent sections describe:

- An organization structure for new development/redevelopment in the City;
- An assessment of the General Plan and the need for amendment;
- An assessment of the CEQA environmental review process;
- An assessment of the development project review, approval and permitting process;
- The City's requirement for Water Quality Management Plan (WQMP [also know as a Jurisdictional Runoff Management Plan]) preparation;
- The program for post construction BMP inspection and verification;
- Education and training programs; and,
- Program assessment.

It is important to note that this section of the City's LIP will not be fully updated to meet the requirements of the Fourth Term MS4 Permits of Orange County until such time as the Model Water Quality Management Plan (Santa Ana Region) and Local Water Quality Management Plan (San Diego Region) are adopted for implementation. The Model WQMP is anticipated to be adopted in May of 2011 and the Local WQMP is anticipated to take effect in December of 2011.

A-7.2 General Plan Assessment and Amendment

The City is required by the Santa Ana Region and San Diego Region Fourth Term MS4 Permits to minimize short and long-term impacts on receiving water quality from new development and significant redevelopment to the maximum extent practicable. The permits require a review and update, as necessary, of the City's General Plan to ensure watershed and stormwater quality and quantity management are considered as specified in Section XII of the Santa Ana Region Fourth Term MS4 Permit and Section F.1 of the San Diego Region Fourth Term MS4 Permit. In accordance with these requirements the City completed a review of the City's General Plan. The most recent environmental update to the General Plan was completed on December 15, 2009, with the adoption of the Water Efficient Landscape Ordinance.

A-7.3 Development Project Review, Approval and Permitting

A-7.3.1 Project Review, Approval, and Permitting Process Overview

During project review, approval, and permitting, the City will require new development and significant redevelopment projects to address the quality and quantity of stormwater runoff through the incorporation of permanent (post-construction) BMPs in project design. The City will require project-specific Water Quality Management Plans (WQMPs) for all private and public projects that:

- Qualify as one of the Priority Project Categories listed in **Figure A-7.1**
- Do not qualify as one of the Priority Project Categories but meet one of the following criteria:
    - Require discretionary action that will include a precise plan of development, except for those projects specified by the City's Water Quality Management Ordinance
    - Require issuance of a non-residential plumbing permit, where a non residential plumbing permit is defined as a plumbing permit authorizing the construction and installation of facilities for the conveyance of liquids other than stormwater, potable water, reclaimed water or domestic sewage.

The WQMP contains all the information specified for the Standard Urban Stormwater Mitigation Plan (SSMP) in the San Diego Region Fourth Term MS4 Permit and should therefore be considered a SSMP.

New development and significant redevelopment projects requiring a WQMP will be categorized as a Priority Project or a Non-Priority Project. The primary difference between a Priority Project and a Non-Priority Project is that Priority Projects will be required to include Treatment Control BMPs in project design. The detailed requirements for preparation of a WQMP are included in **Section A-7.4** and a template/user guide for preparing a WQMP is provided as **Exhibit A-7.I.**

"Significant Redevelopment" in the Santa Ana Regional Board area means:

Projects that include the addition or replacement of 5,000 square feet or more of impervious surface on a developed site.

Redevelopment does not include routine maintenance activities that are conducted to maintain original line and grade, hydraulic capacity, original purpose of the facility, or emergency redevelopment activity required to protect public health and safety.

Where redevelopment results in the addition or replacement of less than fifty percent of the impervious surfaces of a previously existing developed site, the treatment requirements apply only to the addition or replacement, and not to the entire developed site.

Where redevelopment results in the addition or replacement of more than fifty percent of the impervious surfaces of a previously existing developed site, the treatment requirements apply to the entire development.

"Significant Redevelopment" in the San Diego Regional Board area means:

Redevelopment projects that will create, add or replace at least 5,000 square feet of impervious surfaces on an already developed site and/or redevelopment project meet any of the project categories listed in **Figure A-7.1.**

These priority redevelopment projects include, but are not limited to: the 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; and land disturbing activities related to structural or impervious surfaces. Replacement of impervious surfaces includes any activity that is not part of a routine maintenance activity where impervious material(s) are removed, exposing underlying soil during construction.

Where priority redevelopment projects result in an increase of less than fifty percent of the impervious surfaces of a previously existing development, and the existing development was not subject to WQMP requirements, the treatment control BMP numeric-sizing criteria described in Section 6.3 of the City's Model WQMP (**Exhibit A-7.I**) shall only apply to the addition or replacement. Where priority redevelopment projects result in an increase of more than fifty percent of the impervious surfaces, the criteria shall apply to the entire development.

Redevelopment does not include trenching and resurfacing associated with utility work; resurfacing existing roadways; new sidewalk construction, pedestrian ramps, or bike lanes on existing roads, and; routine replacement of damaged pavement, such as pothole repair.

If the redevelopment activity would not result in a Priority Project and would not require discretionary action that will include a precise plan of development or issuance of a non-residential plumbing permit. The project would not require a WQMP.

The City will require project applicants to submit a WQMP at one or both points in the project planning and permitting stage:

- During the discretionary approval process (land use permit) of a proposed project, when the City must exercise judgment or deliberation in order to approve or disapprove a new development or significant redevelopment project, or
- During the ministerial approval process of issuing a grading, building, demolition, or similar "construction" permits in which only fixed standards or objective measures are applied.

A-7.3.2 Public Agency Projects

The City intends to incorporate the requirement for a WQMP into the process of planning, design, approval, and construction oversight of its public agency projects. Depending upon the type of public agency project being planned or designed, the Engineering Division or the Maintenance Division project manager will require their design architect/engineering contractors to prepare the WQMP for a public facility project.

A WQMP is not required for public agency projects consisting of routine maintenance or emergency construction activities required to protect public health and safety; interior remodeling with no outside exposure of construction materials or construction waste to stormwater; mechanical permit work; electrical permit work; and sign permit work.

The City uses the categories of Priority Projects that are listed in **Figure A-7.1.** Although the City does not plan and design some of the types of project categories listed in **Figure A-7.1**, some public agency projects may have similar functions or characteristics or may conduct similar activities after construction is completed. Therefore, some of the City's public agency projects will be considered Priority Projects requiring Treatment Control BMPs.

For other public agency projects that are not Priority Projects, the City may decide on a project specific basis to identify and incorporate routine structural source control BMPs applicable to the project features, and consider Site Design BMPs where applicable. Project types include, but are not limited to:

- Parks and recreation facilities
- Public buildings
- Streets and roadways
- Above ground drainage facilities (e.g. channels, basins)

A-7.3.3 Conditions of Approval

The City has reviewed its standard conditions of approval to ensure that the existing standard conditions are not in conflict with any provisions of the Santa Ana and San Diego Region Permits, the DAMP, California's General Permit for Stormwater Discharges Associated with Construction Activity, California's General Permit for Stormwater Discharges Associated with Industrial Activity and adopted Total Maximum Daily Load (TMDL) allocations that apply to the City.

A-7.3.4 Review and Approval of WQMPs

The requirements for preparation of a WQMP are described in **Section A-7.4**. The City will require all new development and significant redevelopment private projects that meet the minimum requirements described in **Sections A-7.3.1 and A-7.3.2** to select appropriate permanent (post-construction) non-structural and structural BMPs, prepare a project-specific WQMP, and submit the WQMP for review and approval. Prior to issuance of grading or building permits, the City shall require the project applicant to have an approved final WQMP. The City will require public projects that are considered Priority Projects to complete a WQMP as part of the design review and may require Non-Priority Projects to identify and include all applicable routine structural and non-structural source control BMPs and consider site design BMPs in the project.

The City will use a checklist to document the identification of a project as a Priority Project or as a Non-Priority Project. A checklist to be used by the City for categorizing new development and significant redevelopment projects as Priority or Non-Priority is shown in **Figure A-7.1**.

Figure A-7.1. Checklist for Categorizing Development and Significant Redevelopment[1] Projects as Priority or Non-Priority

Project File No.	
Project Name:	
Project Location:	
Project Description	

Proposed Project Includes:	**Yes**	**No**
1. Projects that create 10,000 square feet or more of impervious surface		
2. Automotive repair shops (SIC codes 5013, 5014, 5541, 7532-7534, and 7536-7539)		
3. Restaurant involving development of 5,000 square feet or more including parking areas (SIC code 5812)		
4. Hillside developments that create 5,000 square feet or more of impervious surface in areas with known erosive soil conditions or involving grading on a natural slope of 25 percent greater		
5. Projects that create 2,500 square feet or more of impervious surface located within, directly adjacent to (within 200 feet), or discharging directly to receiving water within Environmentally Sensitive Areas[2].		
6. Parking lot area of 5,000 square feet or more, or with 15 or more parking spaces, and potentially exposed to urban runoff		
7. ***For San Diego Region -*** Streets, roads, highways, and freeways that would create a new paved surface that is 5,000 square feet or greater ***For Santa Ana Region –*** Streets, roads, highways and freeways of 5,000 square feet or more of paved surface shall incorporate USEPA guidance, "Managing Wet Weather with Green Infrastructure: Green Streets" in a manner consistent with the maximum extent practicable.		
8. **For Santa Ana Region** – All significant redevelopment projects, where significant redevelopment is defined as the addition or replacement of 5,000 or more square feet of impervious surface on an already developed site		
9. Retail gasoline outlets 5,000 square feet or more with projected Average Daily Traffic (ADT) of 100 or more vehicles per day		

[1] For definitions of *"Significant Redevelopment for the San Diego and Santa Ana Regional Board permit areas see **Section A-7.3.1** of this LIP"*

[2] Environmentally Sensitive Areas are shown in maps in Section A-1 of this LIP.

Priority Project: <u>Any</u> question answered "YES."

Non-Priority Project: <u>All</u> questions are answered "NO."

DETERMINATION: This project is considered a <u>PRIORITY / NON-PRIORITY</u> project.
(Circle appropriate answer.)

Although both Priority and Non-Priority projects require the preparation of a WQMP, the scope of the WQMP differs. The WQMP for a Priority Project must address:

- Regional or watershed programs (if applicable) – Santa Ana Regional Board area only
- Site design BMPs (as appropriate)
- Routine structural and non-structural BMPs,
- Treatment Control BMPs
- Interim Hydromodification Controls – San Diego Regional Board area only
- The mechanism(s) by which long-term operation and maintenance of all structural BMPs will be provided.

The WQMP for a Non-Priority Project must address:

- Routine structural and non-structural BMPs,
- Site design BMPs (as appropriate), and
- The mechanism(s) by which long-term operation and maintenance of all structural BMPs will be provided.

To assure thorough and consistent reviews of WQMPs, the City will utilize a checklist as its initial tool in reviewing WQMPs and approve in writing appropriately completed WQMPs.

When reviewing WQMPs submitted for approval, the City will assess the potential project impacts on receiving waters and ensure that the WQMP adequately identifies such impacts. The City will examine all identified BMPs to ensure that they address the pollutants and conditions of concern identified in the WQMP.

A-7.3.5 Plan Check: Issuance of Grading or Building Permits

The construction plans submitted by the applicant for plan check must incorporate all of the structural BMPs identified in a project's WQMP.

General or Special Notes for Plan Sheets

Prior to the issuance of a grading or building permit, the City shall require the permit applicant to include the following as general or special notes on the plan sheets for new development or significant redevelopment projects:

1. In the case of emergency, call ______________________________________
   at Work Phone # ____
   or Home Phone # ____.

2. Sediment from areas disturbed by construction shall be retained on site using structural controls to the maximum extent practicable.

3. Stockpiles of soil shall be properly contained to minimize sediment transport from the site to streets, drainage facilities or adjacent properties via runoff, vehicle tacking, or wind.

4. Appropriate BMPs for construction-related materials, wastes, spills shall be implemented to minimize transport from the site to streets, drainage facilities, or adjoining properties by wind or runoff.

5. Runoff from equipment and vehicle washing shall be contained at construction sites unless treated to reduce or remove sediment and other pollutants.

6. All construction contractor and subcontractor personnel are to be made aware or the required Best Management Practices and good housekeeping measures for the project site and any associated construction staging areas.

7. At the end of each day of construction activity all construction debris and waste materials shall be collected and properly disposed in trash or recycle bins.

8. Construction sites shall be maintained in such a condition that an anticipated storm does not carry wastes or pollutants off the site. Discharges of material other than stormwater only when necessary for performance and completion of construction practices and where they do not: cause or contribute to a violation of any water quality standard; cause or threaten to cause pollution, contamination, or nuisance; or contain a hazardous substance in a quantity reportable under Federal Regulations 40 CFR Parts 117 and 302.

9. Potential pollutants include but are not limited to: solid or liquid chemical spills; wastes from paints, stains, sealants, glues, limes, pesticides, herbicides, wood preservatives and solvents; asbestos fibers, paint flakes or stucco fragments; fuels, oils, lubricants, and hydraulic, radiator or battery fluids; fertilizers, vehicle/equipment wash water and concrete wash water; concrete, detergent or floatable wastes; wastes from any engine/equipment steam cleaning or chemical degreasing and superchlorinated potable water line flushing.

10. During construction, permittee shall dispose of such materials in a specified and controlled temporary area on-site, physically separated from potential stormwater runoff, with ultimate disposal in accordance with local, state and federal requirements.

11. Dewatering of contaminated groundwater, or discharging contaminated soils via surface erosion is prohibited. Dewatering of non-contaminated groundwater requires a National Pollutant Discharge Elimination System Permit from the respective California Regional Water Quality Control Board.

12. Graded areas on the permitted area perimeter must drain away from the face of slopes at the conclusion of each working day. Drainage is to be directed toward desilting facilities.

13. The permittee and contractor shall be responsible and shall take necessary precautions to prevent public trespass onto areas where impounded water creates a hazardous condition.

14. The permittee and contractor shall inspect the erosion control work and insure that the work is in accordance with the approved plans.

15. The permittee shall notify all general contractors, subcontractors, material suppliers, lessees, and property owners: that dumping of chemicals into the storm drain system or the watershed is prohibited.

16. Equipment and workers for emergency work shall be made available at all times during the rainy season. Necessary materials shall be available on site and stockpiled at convenient locations to facilitate rapid construction of temporary devices when rain is imminent.

17. All removable erosion protective devices shall be in place at the end of each working day when the 5-Day Rain Probability Forecast exceeds 40%.

18. Sediments from areas disturbed by construction shall be retained on site using an effective combination of erosion and sediment controls to the maximum extent practicable, and stockpiles of soil shall be properly contained to minimize sediment transport from the site to streets, drainage facilities or adjacent properties via runoff, vehicle tracking, or wind.

19. Appropriate BMPs for construction-related materials, wastes, spills or residues shall be implemented and retained on site to minimize transport from the site to streets, drainage facilities, or adjoining property by wind or runoff.

Plan Check for Private Projects

For projects with entitlements, the City will review the conditions of approval and the submitted WQMP for an understanding of the water quality issues and structural BMPs required. The City will review construction plans for conformity with the project's WQMP. No grading or building permits are issued prior to approval of the WQMP. If the selected BMPs were approved in concept during the land use entitlement process, the City will require the applicant to submit detailed construction plans showing locations and design details of all BMPs that are in substantial conformance with the preliminary approvals. The City will review a project's construction plans to assure that the plans are consistent with the BMP design criteria and guidance provided in **DAMP Section 7, Exhibit 7.II.**

Plan Check for Projects with By-Right Zoning (Ministerial Projects)

For projects with by-right zoning or projects that do not need discretionary review but are required to prepare a WQMP, the City will first review the project's proposed WQMP for conformity with the requirements described in **DAMP Section 7.7** and **DAMP Section 7,**

Exhibit 7.II. The WQMP will then be used in reviewing the construction plans for consistency with the BMP design criteria and guidance provided in **DAMP Section 7, Exhibit 7.II**.

Design Review for Public Agency Projects

Prior to initiating grading or construction activities, the City will confirm that the construction plans for its public works projects reflect the structural BMPs described in the project's approved final WQMP. In conducting the design review process for its public agency projects, the City will review the construction plans and specifications for conformity with the approved final WQMP and for consistency with the BMP design criteria and guidance provided in **DAMP Section 7, Exhibit 7.II**.

Plan Check for Projects with Alternative Treatment Control BMPs (See **DAMP Section 7, Exhibit 7.II Section 3.3.3.**)

If an applicant elected to utilize Alternative Treatment Control BMPs in a project's construction plans, the City will require the project's engineer of record to certify that the Alternative Treatment Control BMPs are equally or more effective in pollutant reduction than comparable BMPs found in the Model WQMP.

A-7.3.6 Permit Closeout, Certificates of Use and Certificates of Occupancy

Private Sector Projects

The WQMP continues with the property (it "runs with the land") after the completion of the construction phase and the City will require that the terms, conditions and requirements be recorded with the County Recorder's office by the property owner or any successive owner as authorized by the City's Water Quality Management Ordinance. The end of the construction phase therefore represents a transition from the New Development/Redevelopment Program to the Existing Development Program (**Section A-9**). Accompanying this is a close out of permits and issuance of certificates of use and occupancy. The City will use this juncture to assure satisfactory completion of all conditions applied to the project and all requirements in the WQMP by requiring the applicant to:

- Demonstrate that all structural BMPs described in the project's WQMP have been constructed and installed in conformance with approved plans and specifications
- Demonstrate that the WQMP and the Operations and Maintenance (O&M) Plan have been recorded with the Orange County Clerk-Recorder
- Demonstrate that an adequate number of copies of the WQMP are available onsite

The O&M Plan for structural BMPs that is prepared by the applicant for private sector projects shall include:

- Description of structural BMPs

- Description of employee responsibilities and training for BMP operation and maintenance
- Operating schedule
- Inspection/maintenance frequency and schedule
- Specific maintenance activities
- Required permits from resource agencies, if any
- Forms to be used in documenting maintenance activities
- Recordkeeping requirements (at least 5 years)

At a minimum, the City will require the annual inspection and maintenance of all structural BMPs including inspection and performance of any required maintenance in the late summer/early fall, prior to the start of the rainy season.

Following satisfactory inspection, those structural BMPs proposed during the planning process to be within City right-of-ways, or on land to be dedicated to City ownership will be offered for acceptance. Upon acceptance, responsibility for operation and maintenance will transfer from the developer or contractor to the City, including the funding mechanism identified in the project's approved WQMP.

If a property owner or a private entity, such as a homeowners association (HOA), retains or assumes responsibility for operation and maintenance of structural BMPs, the City will require access for inspection through an agreement. If the City will be responsible for operating and maintaining structural BMPs on private property, an easement will be established to allow for entry and proper management of the BMPs. Such access easements shall be binding throughout the life of the project, or until the BMPs requiring access are acceptably replaced with a BMP not requiring access. Funding for the long-term operation and maintenance of structural BMPs transferred to the City will be front-funded or otherwise guaranteed via mechanisms such as approved assessment districts, or other funding mechanisms.

Public Agency Projects

For the City's public agency projects, upon completion of construction when contract close-out occurs the responsibility for operation and maintenance of the structural BMPs will transfer from the contractor to the City and become part of the Municipal Activities Program (**Section A-5**).

A-7.4 Water Quality Management Plan (WQMP) Preparation

In accordance with the requirements in the Development Project Review, Approval and Permitting process described previously, the City will require WQMPs to be prepared using the guidelines set forth in **DAMP Section 7** and the model WQMP **DAMP Section 7, Exhibit 7.II**, and the submittal template/user guide provided as **Exhibit A-7.I** of this LIP. Elements of WQMP development are illustrated in the following figures:

Figure A-7.2 (1 of 2)

Development Planning and WQMP Preparation Steps for the Santa Ana Regional Board Area

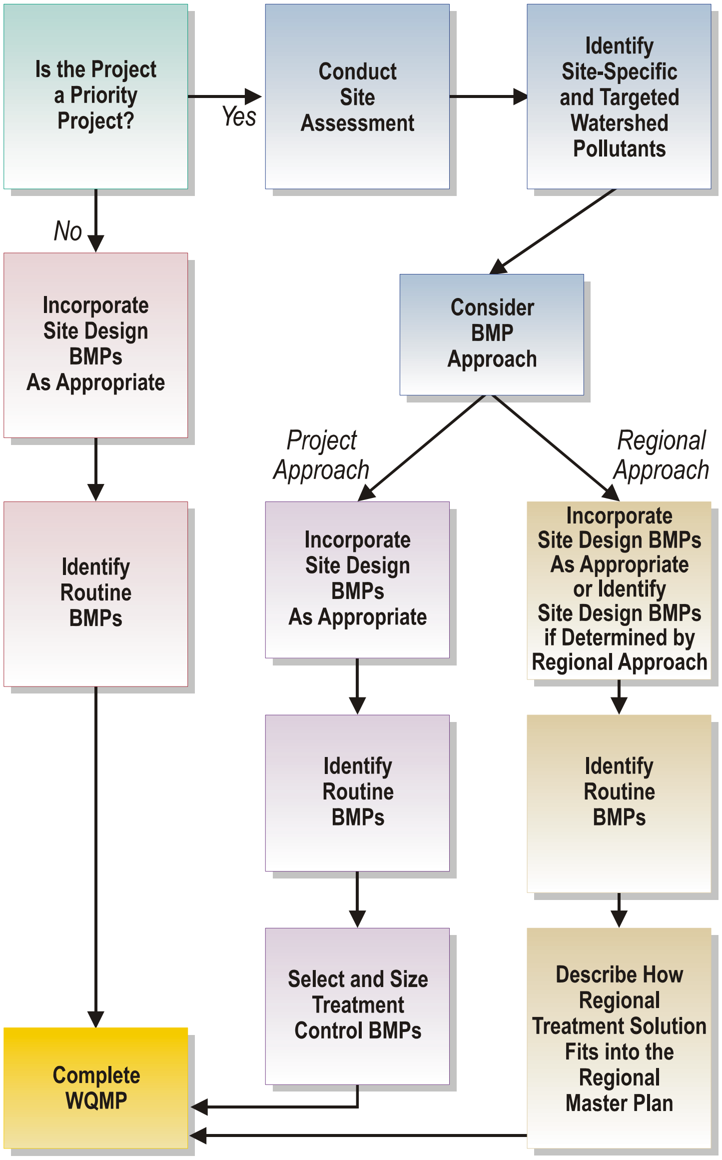
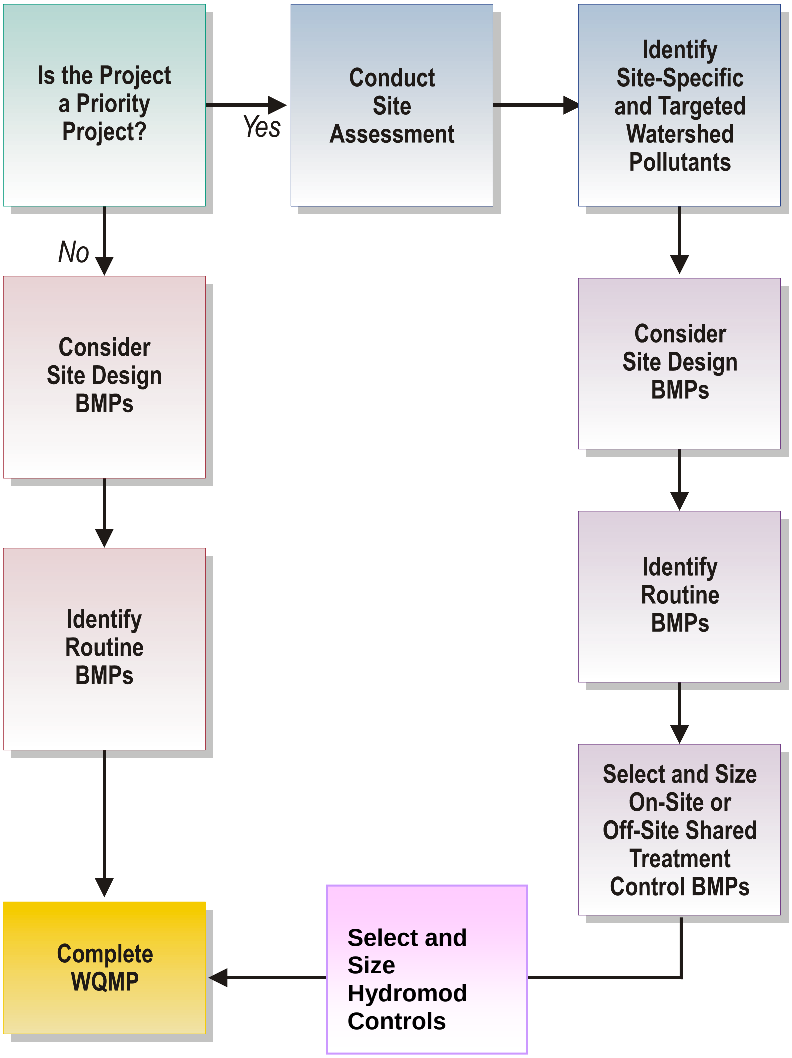


Figure A-7.2 (2 of 2)
Development Planning and WQMP Preparation Steps for the San Diego Regional Board Area



BMP Implementation

Consistent with the Model WQMP, the City will require Priority Projects to:

- Incorporate and implement Source Control BMPs (routine non-structural and routine structural) unless not applicable to the project due to project characteristics, and document why any applicable Source Control BMP was not included;
- Incorporate and implement Site Design BMPs as appropriate; and

- Either:
    - Implement treatment control BMPs including a selection of such BMPs into the project design, (unless a waiver is granted for infeasibility of all treatment control BMPs, see Model WQMP, **DAMP Section 7, Exhibit 7.II, Section 6.0** for details);

  or:
    - Participate in or contribute to an acceptable regional or watershed management program – Santa Ana Regional Board area only.
- Implement Hydromodification Controls – San Diego Regional Board area only.
- The combination of Source Control, Site Design and Treatment Control BMPs, Hydromodification Controls or regional or watershed based-programs must adequately address all identified pollutants and hydrologic conditions of concern.

The City will require all Non-Priority projects to incorporate and implement Source Control BMPs as above and incorporate, implement and document Site Design BMPs as appropriate. Once a project reaches the plan check phase, the applicant will be required to submit the approved WQMP together with construction plans that incorporate the selected BMPs.

A combination of Source Control BMPs (routine non-structural and routine structural BMPs) and Site Design BMPs is generally the most effective means of pollution prevention because they minimize the need for treatment. The City will require Treatment Control BMPs to be considered for all Priority Projects in addition to Source Controls to meet the requirements of the Fourth Term Permits to minimize, to the maximum extent practicable, the discharge of pollutants to the storm drain system or receiving waters.

The categories of stormwater pollution control BMPs are summarized in **Table A-7.1**, together with the applicable projects and primary pollution prevention objectives of the BMPs.

Routine Source Control BMPs

Routine structural Source Control BMPs are low-technology practices designed to prevent pollutants from contacting stormwater runoff or to prevent discharge of contaminated runoff to the storm drainage system. Routine non-structural Source Control BMPs are listed in **Table A-7.2**. Routine structural Source Control BMPs are listed in **Table A-7.3**. WQMPs for Public Agency projects are not required to include routine non-structural BMPs if they are already included as part of the Municipal Activities Program (see **Section A-5**).

Table A-7.1
Summary of BMPs for Development/Significant Redevelopment Projects

BMP Category		Applicable Projects	Pollution Prevention Objective
Source Control BMPs	**Routine Non-Structural BMPs**	Required for all projects – as applicable (see **Table A-7.2**)	Prevent pollution by educating the public on proper disposal of hazardous or toxic wastes, regulatory approaches, street sweeping and facility maintenance, and detection and elimination of illicit connections and illegal dumping.
	Routine Structural BMPs	Required for project features (see **Table A-7.3**)	Prevent potential pollutants from contacting rainwater or stormwater runoff or to prevent discharge of contaminated runoff to the storm drain system or receiving waters. Reduce the creation or severity of potential pollutant sources or to reduce the alteration of the project site's natural flow regime.
Site Design BMPs		All projects shall incorporate as appropriate	Minimize or prevent potential pollutants from contacting rainwater or stormwater runoff or to prevent discharge of contaminated runoff to the storm drain system or receiving waters.
Treatment Control BMPs or Regional Program		All priority projects – at least one treatment control BMP required	Remove pollutants from stormwater runoff prior to discharge to the storm drain system or receiving waters
Interim Hydromodification Controls		All priority projects in San Diego Region not draining directly or via a concrete conveyance system all the way to a harbor, lake, pond, lagoon, basin, or the ocean) – until adoption of Model WQMP/ Hydromodification Management Plan	Match post-development hydrologic regime with pre-development for all flows between 10% of the 2 year event, up to the 10 year storm even.

Table A-7.2
Routine Non-Structural Source Control BMPs

Identifier	Name
N1	Education for Property Owners, Tenants and Occupants
N2	Activity Restrictions
N3	Common Area Landscape Management
N4	BMP Maintenance
N5	Title 22 CCR Compliance (How the development will comply)
N6	Local Water Quality Permit Compliance
N7	Spill Contingency Plan
N8	Underground Storage Tank Compliance
N9	Hazardous Materials Disclosure Compliance
N10	Uniform Fire Code Implementation
N11	Common Area Litter Control
N12	Employee Training
N13	Housekeeping of Loading Docks
N14	Common Area Catch Basin Inspection
N15	Street Sweeping Private Streets and Parking Lots
N16	*BMP has been removed*
N17	Retail Gasoline Outlets

Table A-7.3
Routine Structural Source Control BMPs

Provide storm drain system stenciling and signage
Design and construct outdoor material storage areas to reduce pollution introduction
Design and construct trash and waste storage areas to reduce pollution introduction
Use efficient irrigation systems & landscape design, water conservation, smart controllers, and source control
Protect slopes and channels and provide energy dissipation
Required for the following project features: • Private roads • Residential driveways and guest parking • Loading dock areas • Maintenance bays • Vehicle wash areas • Outdoor processing areas • Equipment wash areas • Parking areas • Roadways • Fueling areas • Hillside landscaping • Wash water control for food preparation areas • Community car wash racks

Site Design BMPs

The principal objective of Site Design BMPs is to prevent pollution of stormwater by minimizing the introduction of pollutants and conditions of concern that may result in significant impacts generated from site runoff to the stormwater conveyance system. One approach to achieve this objective is to reduce stormwater runoff flows and volumes and reduce pollutants through appropriate Site Design BMPs.

Start at the Source (Bay Area Stormwater Management Association 1999) provides design guidance and techniques for implementing site design BMPs. Benefits derived from this approach include:

- Reduced size of downstream treatment controls and conveyance systems;
- Reduced pollutant loading to treatment controls; and
- Reduced hydraulic impact on receiving streams

Site Design BMPs should be incorporated and implemented as appropriate. Site Design BMPs include the design techniques listed in **Table A-7.4**.

Table A-7.4
Site Design BMP Techniques

Minimize Impervious Area/Maximize Permeability (C-Factor Reduction)
Minimize Directly Connected Impervious Areas (DCIAs) (C-Factor Reduction)
Create Reduced or “Zero Discharge” Areas (Runoff Volume Reduction)
Conserve Natural Areas (C-Factor Reduction)

Fact sheets for routine structural Source Control BMPs and Site Design BMPs are presented in **Exhibit A-7.II**. The fact sheets include design criteria established to ensure effective implementation of the required Site Design BMPs and will be made available by the City.

Treatment Control BMPs

Treatment Control BMPs are engineered technologies designed to remove pollutants from stormwater runoff and are required to augment Source Control and Site Design BMPs to reduce pollution from stormwater discharges as required by the Fourth Term Permits. The type of Treatment Control BMP(s) to be implemented at a site depends on a number of factors including: type of pollutants in the stormwater runoff, volume or flow of stormwater runoff to be treated, project site conditions, receiving water conditions, and General Industrial Permit requirements, when applicable. Land requirements, and costs to design, construct and maintain Treatment Control BMPs vary by Treatment Control BMP.

Unlike flood control measures that are designed to handle peak flows, stormwater Treatment Control BMPs are designed to treat the more frequent, lower-flow storm events, or the first flush portions of runoff from larger storm events (typically referred to as the first-flush events). Small, frequent storm events represent most of the total average annual rainfall for the area. The flow and volume from such small events is targeted for treatment.

The primary control strategy for designing BMPs is to treat the Stormwater Quality Design Flow (SQDF) or the Stormwater Quality Design Volume (SQDV) of the stormwater runoff. **Table A-7.5** lists BMPs along with the basis of design, SQDF or SQDV, to be used for designing the BMP. The Model WQMP (**DAMP Section 7, Exhibit 7.II**) shows the approach that should be used to calculate the SQDF and/or SQDV.

Table A-7.5
Basis of Design for Treatment Control BMPs

Treatment Control BMP	Design Basis
Vegetated (Grass) Strips	SQDF
Vegetated (Grass) Swales	
Proprietary Control Measures	
Dry Detention Basin	SQDV
Wet Detention Basin	
Constructed Wetland	
Detention Basin/Sand Filter	
Porous Pavement Detention	
Porous Landscape Detention	
Infiltration Basin	
Infiltration Trench	
Media Filter	
Proprietary Control Measures	

BMP fact sheets for Treatment Control BMPs from the CASQA New Development Handbook are presented for guidance in **Exhibit A-7.II**. These fact sheets include specific design criteria established to ensure effective implementation of the required Treatment Control BMPs.

Regional or Watershed Programs

For the Santa Ana Regional Board area, if a regional or watershed-based program is selected, the regional or watershed BMPs selected must be designed to have the capacity to treat more than the cumulative volume (or flow rate) of runoff from all new development or significant redevelopment projects included in the regional or watershed plan. More detailed analysis (such as detailed planning and modeling) should be employed and cross-jurisdictional issues must be clearly defined and coordinated (see **DAMP Section 7 and Section 7.II. 3.3.3** for a more detailed discussion of the applicability of regional or watershed programs).

Regional and/or watershed management programs, as described in this Local WQMP, are not allowed within the San Diego Regional Board permit area. However, under certain conditions within the San Diego Regional Board permit area, offsite shared controls can be considered.

Interim Hydromodification Controls
(Applicable in the San Diego Region beginning December 16, 2010 until the Model WQMP and Hydromodification Plan for Orange County are adopted)

On December 16, 2010, Interim Hydromodification Control requirements, as required in Section F.1.h.(5) of the San Diego Region Fourth Term MS4 Permit, became effective. The City will apply these Interim Hydromodification Control (IHC) requirements to all priority projects in the San Diego Region until such time as the Hydromodification Management Plan for the San Diego Region of Orange County is adopted for implementation in December of 2011. A Copy of the City's Interim Hydromodification BMP Sizing Tool Technical Guidance Document, as well as the City's IHC BMP Sizing Tool can be found on the City's website at: http://www.lakeforestca.gov/services/forms.asp. A copy of the Technical Guidance Document is also provided in **Exhibit A-7.III** of this LIP.

Within the Santa Ana Region of Orange County, hydromodification control will be a function of the Model WQMP which is anticipated to be adopted in May of 2011.

A-7.5 Post Construction BMP Inspection and Verification

The City will conduct verifications to assure that implementation and appropriate maintenance described in the WQMP is taking place at structural and non-structural BMPs during the post construction phase. Assessment of BMP effectiveness will take place during verification. Verification of BMP implementation and ongoing maintenance will be conducted by inspection, self-certifications, surveys, or other equally effective approaches, in compliance with the Fourth Term MS4 requirements. A summary of the inspections conducted and any assessments of effectiveness will be provided in the annual Program Effectiveness Assessment, within Section C-9, Existing Development.

An inventory of approved WQMPs has been developed and will be included as part of Section A-9, Existing Development, of this LIP.

A-7.6 Education and Training

To assist responsible City and contract staff in understanding the New Development/Significant Redevelopment Program, annual training sessions will be conducted. In addition to Permittee sponsored training, staff may also attend training seminars or workshops related to general water quality and stormwater management during construction, conducted by other organizations.

A-7.8.1 Training Modules

Two training modules have been prepared that cover different aspects of the New Development/Significant Redevelopment Program. These modules are provided in **DAMP Appendix B-7**.

New Development/Significant Redevelopment Program Management (**DAMP Appendix B, Exhibit B-7.I**)

This training module is for Permittee Stormwater Program managers and the managers of a Permittee's planning and building departments. It provides an overview of the Stormwater Program as it pertains to a Permittee's General Plan, the preparation and review of environmental documents (Initial Studies, Environmental Impact Reports, Environmental Impact Statements, Negative Declarations, Mitigated Negative Declarations, etc.), conditions of approval for projects, the review of WQMPs, plan check, and permit closeout. The training module also briefly describes a Permittee's responsibility for verifying and inspecting permanent BMPs and for assessing the effectiveness of the New Development/Significant Redevelopment program element.

Project Planning and Design: Environmental Review, Planning and Permitting, and WQMP Development (**DAMP Appendix B, Exhibit B.7.II**)

This training module is targeted to planners, plan checkers, developers and engineers, and will address: the laws and regulations applicable to new development/significant redevelopment; the connection between new development/significant redevelopment and water quality; how to review and prepare California Environmental Quality (CEQA) compliance documents with regard to stormwater/urban runoff effects, how to develop and review a WQMP; and how to design and incorporate into a project Source Control, Site Design and Treatment Control BMPs to minimize impact to receiving waters.

A-7.8.2 Record Keeping

Records of training provided to City staff will be maintained to allow a determination of:

- Which staff require which training;
- When training sessions were conducted;
- Compliance with the permit requirements.

In addition to the Permittee-sponsored training, City staff may also attend various other workshop or training events as they take place throughout the year. These types of events may include local or national organization sponsored training.

A-7.9 Program Effectiveness Assessment (PEA)

The City will prepare an annual PEA (see **DAMP Appendix C-7**). This report will provide the basis for evaluating the City's efforts towards the reduction of pollutants from new development and significant redevelopment. The PEA will demonstrate a commitment to pollution prevention and source reduction processes in new development/redevelopment projects in the City. The annual PEA will include:

- Changes made to the General Plan, CEQA and development review processes;
- Information on WQMPs approved and verified by the City;
- Documentation of training received by the City staff.

Exhibit A-7.I

WQMP Template/User Guide

CITY OF LAKE FOREST

DECEMBER 20, 1991

Water Quality Management Plan (WQMP) Template/User Guide

Introduction

The preparation of a development project WQMP is a requirement of the City's Urban Runoff Management Program. This program was developed by the City to comply with State and Federal regulations to control and eliminate runoff pollution into receiving waters such as creeks, lakes and the ocean. In any case where a WQMP is required, a draft WQMP must be submitted with the application for a development permit. In this initial phase of development approval, the structural BMPs are the principal element of concern. Therefore, the concept grading plan as part of the initial development application must clearly show all proposed structural BMPs in conformance to Section 7 herein. The draft WQMP submitted at that time must address all aspects related to the determination of the structural BMPs. Other aspects may be considered later in the final WQMP document that must be submitted for review and approval prior to grading or building permit approval.

This template is to be used in preparing WQMPs for development projects in the City of Lake Forest. The template is a simplified document that generally follows the structure of the more comprehensive Orange County Drainage Area Management Plan (DAMP) and the City's Local Implementation Plan (LIP) for water quality. Therefore, the Orange County DAMP and the City's LIP should be used as a reference when more specific guidance is necessary. **The City requires Project WQMPs to be prepared using the guidelines set forth in the Model WQMP, provided in DAMP, Section 7, Exhibit 7.II**. The LIP can be accessed by contacting the City Public Works Department. The Orange County DAMP can be reviewed at www.ocwatersheds.com. Another useful reference document is the California Stormwater Quality Association New development and Redevelopment handbook. The handbook is available at www.cabmphandbooks.com. This handbook provides direct and practical in-depth information in all areas related to developing a WQMP. In general, the DAMP and LIP summarize the regulations, and the handbook explains ways to attain conformance to the regulations.

It is recommended that project applicants follow this WQMP template as much as possible, as it will help facilitate preparation and the corresponding City review process. However, use of this specific template is not required.

Determination of Need/Extent of WQMP

Most types of projects require a WQMP, and requirements are more extensive for certain types of projects. Any application for a project that requires discretionary action and includes a precise plan of development (Site Development Permit, Use Permit or Variance Permit), requires a WQMP to be submitted with the initial development permit application. Further, any project involving construction and installation of facilities for the conveyance of liquids other than stormwater, potable water, reclaimed water or domestic sewage, are required to submit a WQMP with the application for a project. There are also some types of projects that are considered "Priority Projects", which require a WQMP to be submitted regardless of the type of application, as listed in the following table:

Proposed Project Includes:	**Yes**	**No**
1. Projects that create 10,000 square feet or more of impervious surface		
2. Automotive repair shops (SIC codes 5013, 5014, 5541, 7532-7534, and 7536-7539)		
3. Restaurant involving development of 5,000 square feet or more including parking areas (SIC code 5812)		
4. Hillside developments that create 5,000 square feet or more of impervious surface in areas with known erosive soil conditions or involving grading on a natural slope of 25 percent greater		
5. Projects that create 2,500 square feet or more of impervious surface located within, directly adjacent to (within 200 feet), or discharging directly to receiving water within Environmentally Sensitive Areas[2].		
6. Parking lot area of 5,000 square feet or more, or with 15 or more parking spaces, and potentially exposed to urban runoff		
7. ***For San Diego Region -*** Streets, roads, highways, and freeways that would create a new paved surface that is 5,000 square feet or greater ***For Santa Ana Region –*** Streets, roads, highways and freeways of 5,000 square feet or more of paved surface shall incorporate USEPA guidance, "Managing Wet Weather with Green Infrastructure: Green Streets" in a manner consistent with the maximum extent practicable.		
8. **For Santa Ana Region** – All significant redevelopment projects, where significant redevelopment is defined as the addition or replacement of 5,000 or more square feet of impervious surface on an already developed site		
9. Retail gasoline outlets 5,000 square feet or more with projected Average Daily Traffic (ADT) of 100 or more vehicles per day		

[1] For definitions of *"Significant Redevelopment for the San Diego and Santa Ana Regional Board permit areas see **Section A-7.3.1** of this LIP"*

[2] Environmentally Sensitive Areas are shown in maps in Section A-1 of this LIP.

Further details of required WQMP components can be reviewed in Appendix A-7 of the City's LIP or Section 7.II-1.0 of Exhibit 7.II of the Orange County DAMP,OC Model WQMP .

How to Use this Template

This template was created in Microsoft Word and should be edited using Microsoft Word 98 or later version or a compatible program. To use this template simply rename and save this file to your computer and begin editing. Prior to submitting the WQMP for City review, add all necessary figures and attachments, complete the table of contents, and convert all text to black text.

This template is an outline of a WQMP. It also provides directions for completing the WQMP, as well as text and tables to assist you in the WQMP preparation. These different elements of the template are identified in different colors of text as described below.

- The Black text is intended to provide language to be incorporated into your WQMP (it can remain as part of your WQMP submittal).
- The Red text includes instructions and notes. Please insert the required information and delete all Red text from the final document.
- The Blue text identifies required information that may or may not be applicable to the project. If applicable, edit the Blue text as necessary for applicability and project specifics. If not applicable, delete the Blue text.

Purpose of the WQMP

The main purpose of the Water Quality Management Plan (WQMP) is to identify the potential development hydrologic and water quality impacts that could result from a project and to specify the Best Management Practice (BMP) measures that will be incorporated into the project reduce or eliminate identified impacts to the maximum extent practicable.

Water Quality Management Plan (WQMP)

for:

Insert Project Name

Insert Project Address Insert City Name

Insert APN, Tract Numbers, City Project Number, and Permit Numbers (as available)

Prepared for:

Insert Owner/developer
Address City, State, Zip, Telephone number, Email address

Prepared by:

Insert Engineer/Consultant Company Name
Contact Person Address City, State, Zip Telephone number, Email address

Insert Date

Owner's Certification Water Quality Management Plan (WQMP)

Insert Project Name: ________________
Insert Tract/Parcel Map Number:
____

This Water Quality Management Plan (WQMP) has been prepared for Owner/Developer Name. The WQMP is intended to comply with the requirements of the City of Lake Forest Urban Runoff Management Program and Stormwater Ordinance, as well as the Municipal Stormwater Permit which requires the preparation of WQMPs for priority development projects.

The undersigned, while it owns the subject property, is responsible for the implementation of the provisions of this WQMP. The undersigned will ensure that this plan is carried out and amended as appropriate to reflect up-to-date conditions on the site consistent with the current City of Lake Forest Urban Runoff Management Program and the intent of the NPDES/MS4 Permit for Waste Discharge Requirements as authorized by the State and EPA. Once the undersigned transfers its interest in the property, its successors-in-interest shall bear the aforementioned responsibility to implement and amend the WQMP. An appropriate number of approved and signed copies of this document shall be available on the subject site in perpetuity.

To be completed by the Owner or Developer.

Signed: ________________________________

Name: ______________________________

Title: ______________________________

Company: __________________________

Address: ___________________________

Telephone #: ___________________

Date: __________________________

Email Address: __________________________

Table of Contents

Tables

Figures

Section 1 Project Description

Complete the following table.

1. **Detailed development description:** Please include a detailed development project description. The description should include the proposed structure/s to be removed and/or built on the property including external hardscape areas, garages, property yard drains, stormdrains system, drainage lines, landscape areas, retaining walls, pools/spas and other external features.
2. **Project location and site address:** Provide the project location and site address
3. **Property size:** Describe the size of the property parcel and the size of proposed development project in acres and sq ft.
4. **Existing use:** Describe the existing use of site.
5. **Type of development:** Describe the type of development such as residential, commercial, etc.
6. **Impervious/pervious surface areas:** Describe the existing and final developed impervious and pervious surface areas in acres and sq ft. Calculate and describe the increase or decrease in impervious area for existing versus the final developed condition.
7. **Property ownership:** Describe the property Ownership – is it a private development, planned community with a homeowners association, is any infrastructure planned to be transferred to City.
8. **Other:** Include any other relevant details about the project.

Section 2 Project Location Map

The location of the project site is illustrated in Figures 2.1 and 2.2.

Insert a local vicinity map and provide the Thomas Bros. Map number.

Section 3 Project Site Assessment

This project site assessment section provides important information that is used when considering the potential water quality and hydrologic impacts that could be caused by the proposed project. This information is important when considering the appropriate BMPs to reduce identified potential impacts as well as when developing measures to reduce those impacts.

Complete the following table.

1. **Zoning and land use designation:** Provide the zoning and land use designation.

2. **Existing and proposed drainage:** Describe the existing and proposed drainage of site and surrounding property.

3. **Will the drainage system be modified by the development?** Answer Yes or No. If Yes, please describe.

4. **Will drainage coincide with City's system or flow to a creek or ocean?** Answer Yes or No. If Yes, please describe.

5. **Watershed and receiving waters:** Include the name of the watershed and receiving waters referencing the City's Urban Runoff Management Program or Water Quality Environmentally Sensitive Areas map available at the Counter or at County Stormwater Program .

6. 303(d) listed receiving waters: Identify receiving waters that this project drains to that are listed on the most recent Clean Water Act 303(d) and list pollutants for which the receiving waters are impaired (the 303(d) list can be found at the SWRCB website: 303(d) List

7. **Total Maximum Daily Loads (TMDLs):** Identify applicable pollutant Total Maximum Daily Loads (TMDLs). See also TMDLs.

8. **Environmentally Sensitive Areas (ESAs) and/or Areas of Special Biological Significance (ASBS):** Identify the Environmentally Sensitive Areas (ESAs) and/or Areas of Special Biological Significance (ASBS) the project is either located in or in close proximity to as shown on the ESA Watershed Maps. San Diego Creek Watershed Map; Aliso Creek Watershed Map

9. **Soil type(s) and condition:** Describe the site's soil type(s) and condition.

Section 4 Pollutants of Concern

This section of the water quality management plan identifies primary and secondary pollutants of concern. Pollutants of concern are those that are anticipated to be generated by the proposed project. Pollutants of concern are differentiated between primary and secondary depending on the condition of downstream receiving waters. If the project will drain to a receiving water that is impaired for a pollutant anticipated from that project, that pollutant is a primary pollutant of concern. Pollutants frequently identified on the 303(d) list of California impaired water bodies include metals, nitrogen, nutrients, indicator bacteria, pesticides and trash (see 303(d) List). In some cases, there may be specific conditions (i.e. other known water quality problems) that warrant identifying an anticipated pollutant as a primary pollutant of concern. If there is no corresponding impairment or other water quality problem in the receiving waters for an anticipated pollutant, the pollutant is a secondary pollutant of concern.

Complete the following table.

1. **Project categories and features:** Identify the project categories and features from Table 7.II-2 of Orange County DAMP, Exhibit 7.II, that apply to this project. (See Exhibit 7.II)

2. **Primary pollutants of concern:** List the anticipated pollutants for the project (identified using Table 7.II-2) that have also been identified in 303(d) as causing impairment of receiving waters.

3.	**Secondary pollutants of concern:** List all other anticipated pollutants for the project (identified using Table 7.II-2).
4.	**Project water quality analyses:** Provide information from any completed CEQA documents, site approvals, permits or analyses related to project's potential pollutants and environmental impacts.
5.	**Project watershed information:** Provide information from any relevant watershed planning documents (i.e. biological assessments, City's general plan) regarding water quality problems on or downstream of the project site, and relevant plans, policies, or water quality improvement projects.

Section 5 Hydrologic and Geotechnical Conditions of Concern/Drainage Report

This section of the water quality management plan identifies hydrologic and geotechnical conditions of concern related to the proposed project. Hydrologic or geotechnical conditions of concern are identified through a review of on-site and downstream drainage paths. If the proposed project would cause or contribute flows to problems along on-site or downstream drainage paths, these problems or future problems are considered conditions of concern. Conditions of concern can include problems such as flooding, erosion, scour, and other impacts that can adversely affect channel and habitat integrity.

In order to identify conditions of concern, a comprehensive understanding of flow volume, rate, duration, energy, and peak flow is necessary. Often, a formal drainage study is necessary which 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. 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

If the downstream channel(s) is fully natural or partially improved with a significant potential for erosive conditions or alteration of habitat integrity to occur as a result of upstream development, a drainage study report, prepared by a registered civil engineer in the State of California, with experience in fluvial geomorphology and water resources management is required to be included in the WQMP. The drainage report may be referenced and a detailed summary provided that addresses the items above.

If a drainage report is required, use the following paragraph:

A drainage report was prepared for the proposed project by insert name of engineer, as required by the City, and is included as Attachment B. A summary of the drainage report is provided below. Complete the table and provide a detailed summary after the table of the required elements of the drainage report bulleted above.

If a drainage report is not required, use the following paragraph:

A drainage report was not prepared for the proposed project; however, a State of California registered civil engineer (insert name of engineer and engineering firm) reviewed the project for potential conditions of concern. The following is a summary of that review.

If a geotechnical report was required, also include the following sentence:

A geotechnical report was also prepared for the proposed project by insert name of engineer, as required by the City, and is included as Attachment C.

Complete the following table.

1. **Project location:** Describe the project's location within the larger watershed perspective.
2. **Topography, soil and vegetation:** Describe topography, soil and vegetation conditions of the project site.
3. **Impervious area:** Provide percent impervious area on existing site and percent after development.
4. **Drainage features:** Describe natural and infrastructure drainage features.
5. **Relevant hydrologic and environmental factors:** Include other relevant hydrologic and environmental factors either on-site, in the project's vicinity, adjacent property or downstream of the site such as sensitive biological areas, areas prone to flooding, areas with erosion problems, etc.
6. **Proposed hydrologic conditions:** Summarize changes in the hydrologic system resulting from proposed development (i.e. increased runoff volume, reduced infiltration, increased flow frequency).
7. **Significant impact on downstream channels and habitat integrity:** Identify any changes resulting from the project that will have significant impact on downstream channels and habitat integrity. If off-site flows will be increased, this assessment requires a review of downstream areas. Areas with existing or future potential for flooding, erosion, and/or scour should be discussed.
8. **Project hydrology analyses:** Provide information from any previous analyses related to project's potential hydrologic impacts such as reports prepared for previous CEQA documents, site approvals, or permits.
9. **Project watershed information:** Provide information from any relevant watershed planning documents (i.e. drainage master plans, City's general plan) regarding hydrologic problems on or downstream of the project site, and relevant plans, policies, or water quality improvement projects.

Hydrology Report Summary (include if applicable)

Provide a detailed summary of the required elements of the drainage report including a table of pre- and post-development peak flow rate, flow velocity, runoff volume, time of concentration and retention volume.

Section 6 Best Management Practices (BMPs)

Minimizing a development's effects on water quality and the environment can be most effectively achieved by using a combination of BMPs which include Site Design, Source Control and Treatment Control measures. These design and control measures employ a multi-level strategy. The strategy consists of: 1) reducing or eliminating post-project runoff; 2) controlling sources of pollutants; and 3) treating stormwater runoff before discharging it to the stormdrain system or to receiving waters.

This WQMP and the proposed BMPs for the proposed project have been developed to minimize drainage impacts identified in Section 5 and the introduction of pollutants identified in Section 4 into the municipal stormdrain system and/or ultimate drainage receiving water body.

For more detailed information on the use and design of BMPs please see the California Stormwater Quality Association New development and Redevelopment handbook. The handbook is available at www.cabmphandbooks.com. Additional information is also available in the City's LIP.

6.1 Site Design BMPs

The most effective means of avoiding or reducing water quality and hydrologic impacts is through incorporation of measures into the project design. These measures should be taken into consideration early in the planning of a project as they can affect the overall design of a project.

The design of the proposed project has considered and incorporated site design concepts as described below.

Complete the following tables. Describe in detail how your project incorporates each of the concepts below (or provide an explanation as to why your project could not incorporate the concept). All concepts should be considered and incorporated where practicable. For more information, please refer to the City's LIP.

SITE DESIGN CONCEPT 1: MINIMIZE STORMWATER RUNOFF, MINIMIZE PROJECT'S IMPERVIOUS FOOTPRINT AND CONSERVE NATURAL AREAS

1.	**Minimizing impervious footprint:** Describe how your project minimizes impervious footprint.
2.	**Conservation of natural areas:** Describe where and how your project conserves natural areas.
3.	**Use of permeable paving or other surfaces:** Your project should include construction of low-traffic areas with open-jointed paving materials or permeable surfaces. Describe where these techniques have been implemented.

4. **Designing to minimum widths necessary:** Streets, sidewalks and parking lot aisles should be designed to the minimum widths necessary, while complying with ADA regulations and other life safety requirements. Please verify that minimum widths have been implemented and provide an explanation where they are not.

5. **Incorporation of landscaped buffers:** If the project has private streets, incorporation of landscaped buffer areas between sidewalks and streets should be provided. Please describe where this has been incorporated.

6. **Reduced street widths:** Your project should include reduced street widths where off-street parking is available. (Street widths must still comply with life safety requirements for fire and emergency vehicle access.) Please describe if this conditions applies and where it has been incorporated.

7. **Maximize canopy interception:** Describe how your project maximizes landscaping canopy interception of precipitation.

8. **Use of native or drought tolerant trees/shrubs:** Describe how your project maximizes water conservation by preserving existing native trees/shrubs and planting additional native or drought tolerant trees/shrubs.

9. **Minimizing impervious surfaces in landscaping:** Describe how your project minimizes the use of impervious surfaces in the landscape design.

10. **Use of natural drainage systems:** Describe how your project uses natural drainage systems.

11. **Low flow infiltration:** Your project should use perforated pipe or gravel filtration pits for low flow infiltration, where applicable and practicable. However, projects must also comply with hillside grading ordinances that limit or restrict infiltration of runoff. Please describe any low flow infiltration features of the project or reasons for not including them.

12. **Onsite ponding areas or retention facilities:** Your project should include onsite ponding areas or retention/detention facilities, where applicable and practicable.

13. **Other site design features:** Describe any other site design features that are incorporated into the project.

SITE DESIGN CONCEPT 2: MINIMIZE DIRECTLY CONNECTED IMPERVIOUS AREAS (DCIAs)

1. **Draining rooftops into adjacent landscaping:** Your project should drain rooftops into adjacent landscaping prior to discharging to the stormdrain. Please describe where this features have been implemented and if it has not, explain why.

2. **Draining to adjacent landscaping:** Your project should drain impervious sidewalks, walkways, trails, and patios into adjacent landscaping. Please describe where these features have been implemented and if it has not, explain why.

3. **Vegetated drainage swales:** Vegetated drainage swales should be used were possible in lieu of underground piping or imperviously lined swales. Please describe where these features have been implemented and if it has not, explain why.

4. **Site drainage system:** Where practicable, your project should use one or a combination of the following systems for its drainage: rural swale system, urban curb/swale system, dual drainage system, or other comparable design concepts. (for further guidance, see Start at the Source [1999]) Please describe how these types of systems are incorporated into the site's drainage and if not, explain why.

5. **Residential driveways:** Your project should use one of the following features for design of residential driveways: shared access, flared driveways, wheel strips, or drain driveway into adjacent landscaping. Please describe what feature is incorporated and if none, explain why.

6. **Residential parking areas:** Your project should use the following features for design of residential parking areas:
    - Uncovered temporary or guest parking on private residential lots paved with permeable surface; and
    - Drainage into landscaping prior to discharging to the municipal stormdrain system.

   Please describe how these features are incorporated and if not, explain why and any comparable design concepts incorporated.

7. **Non-residential parking areas:** Your project should use the following features for design of non-residential parking areas:
    - Incorporate landscape areas into the drainage design; and
    - Construct overflow parking constructed with permeable paving.

   Please describe how these features are incorporated and if not, explain why and any comparable design concepts incorporated.

6.2 Source Control BMPs

Source Control BMPs are measures focusing on reducing or eliminating post-project runoff and controlling sources of pollutants. Source Control BMPs must be included in all projects and can be represented in structural measures such as landscape, irrigation, signage considerations, materials, and design of areas; and non-structure measures such as requirements, cleaning, education, and maintenance.

Complete the following table. Indicate Y (Yes – included) or N (No – not included) in the Included box for the listed BMPs. If not included or not applicable, provide an explanation. If included, provide a specific description in sections following the table. Include frequency of implementation and responsible party.

Table 6.1 Source Control Non-Structural BMPs		
Number	**BMP and Objective**	**Included**
Routine Non-Structural BMPs (numbers correspond to those in City's WQMP)		
N1	**Education for Property Owners, Tenants and Occupants:** Practical informational materials are provided to residents, occupants, or tenants to increase the public's understanding of stormwater quality, sources of pollutants, and what they can do to reduce pollutants in stormwater. *Explanation/Description:* Add either explanation if not included or detailed description if included. Include educational materials as Appendix A.	Y/N
N2	**Activity Restrictions:** Rules or guidelines for developments are established within appropriate documents (i.e. CC&Rs, lease terms, etc.) which prohibit activities that can result in discharges of pollutants. *Explanation/Description:* Add either explanation if not included or detailed description if included.	Y/N
N3	**Common Area Landscape Management:** Specific practices are followed and ongoing maintenance is conducted to minimize erosion and over-irrigation, conserve water, and reduce pesticide and fertilizer applications. *Explanation/Description:* Add either explanation if not included or detailed description if included.	Y/N
N4	**BMP Maintenance:** In order to ensure adequate and comprehensive BMP implementation, all responsible parties are identified for implementing all non-structural BMPs and for structural BMPs, cleaning, inspection, and other maintenance activities are specified including responsible parties for conducting such activities. *Explanation/Description:* Add either explanation if not included or detailed description if included.	Y/N
N5	**Title 22 CCR Compliance:** Hazardous waste is managed properly through compliance with applicable Title 22 regulations. *Explanation/Description:* Add either explanation if not included or detailed description of applicable requirements and compliance activities if included.	Y/N

N6	**Local Water Quality Permit Compliance:** The project complies with water quality permits issued by the City to ensure clean stormwater discharges. *Explanation/Description:* Add either explanation if not included or detailed description of permit conditions and compliance activities if included.	Y/N
N7	**Spill Contingency Plan:** A Spill Contingency Plan is implemented to ensure that spills are managed properly by requiring stockpiling of cleanup materials, notification of responsible agencies, disposal of cleanup materials, documentation, etc. *Explanation/Description:* Add either explanation if not included or detailed description if included.	Y/N
N8	**Underground Storage Tank Compliance:** Because of the known or potential presence of underground storage tanks (USTs) on the project site, applicable UST regulations apply and are adhered to in order to avoid harm to humans or the environment. *Explanation/Description:* Add either explanation if not included or detailed description if included.	Y/N
N9	**Hazardous Materials Disclosure Compliance:** Because hazardous materials or wastes will be generated, handled, transported, or disposed of in association with the project, measures are taken to comply with applicable local, state, and federal regulation to avoid harm to humans and the environment. *Explanation/Description:* Add either explanation if not included or detailed description if included.	Y/N
N10	**Uniform Fire Code Implementation:** The project includes a hazardous material storage facility or other area regulated by Article 80 and therefore implements measures to comply with this section of the Uniform Fire Code. *Explanation/Description:* Add either explanation if not included or detailed description if included.	Y/N
N11	**Common Area Litter Control:** Trash management and litter control procedures are specified, including responsible parties, and implemented to reduce pollution of drainage water. *Explanation/Description:* Add either explanation if not included or detailed description if included.	Y/N
N12	**Employee Training:** Practical informational materials and/or training are provided to employees to increase their understanding of stormwater quality, sources of pollutants, and their responsibility for reducing pollutants in stormwater. *Explanation/Description:* Add either explanation if not included or detailed description if included.	Y/N
N13	**Housekeeping of Loading Docks:** Cleaning and clean up procedures are specified and implemented for loading dock areas to keep the area free for pollutants and reduce associated pollutant discharges. *Explanation/Description:* Add either explanation if not included or detailed description if included.	Y/N
N14	**Drainage Facility Inspection:** Inspection procedures, schedules, and responsibilities are established for drainage facilities to ensure regular cleaning, inspection, and maintenance. *Explanation/Description:* Add either explanation if not included or detailed	Y/N

	description if included.	
N15	**Street Sweeping Private Streets and Parking Lots:** Street sweeping frequency and responsible parties are identified and regular sweeping is conducted to reduce pollution of drainage water. *Explanation/Description:* Add either explanation if not included or detailed description if included.	Y/N
N17	**Retail Gasoline Outlets:** Specific operational and maintenance BMPs are implemented to the extent feasible to reduce potential for pollutant discharge from wash off by runoff, leaks, and spills. *Explanation/Description:* Add either explanation if not included or detailed description if included. Include educational materials as Appendix A.	Y/N

Number	**BMP and Objective**	**Included**
Source Control Structural BMPs (numbers correspond to the California BMP Handbook)		
SC-10	**Site Design and Landscape Planning:** Landscape planning methodologies are incorporated into project design to maximize water storage and infiltration opportunities and minimize surface and groundwater contamination from stormwater. *Explanation/Description:* Add either explanation if not included or detailed description if included.	Y/N
SC-11	**Roof Runoff Controls:** Direct roof runoff away from paved areas and to pervious areas, cisterns, infiltration trenches, and/or storage areas for reuse to reduce total volume and rate of site runoff and retain pollutant on site. *Explanation/Description:* Add either explanation if not included or detailed description if included.	Y/N
SC-12	**Efficient Irrigation:** Project plans include application methods to minimize irrigation water discharged into stormwater drainage systems. *Explanation/Description:* Add either explanation if not included or detailed description if included.	Y/N
SC-13	**Stormdrain System Signs:** Stencils or affixed signs a placed adjacent to stormdrain inlets to prevent waste dumping at stormdrain inlets. *Explanation/Description:* Add either explanation if not included or detailed description if included.	Y/N
SC-20	**Pervious Pavements:** Porous concrete or asphalt, blocks with pervious spaces or joints, or grass or gravel surfaces are employed to reduce runoff volume and provides treatment. *Explanation/Description:* Add either explanation if not included or detailed description if included.	Y/N

SC-21	**Alternative Building Materials:** Specialized building materials are employed that have lower potential to leach pollutants, and reduce need for future painting or other pollutant generating maintenance activities. For example, some treated wood contains pollutants that can leach our to the environment and some metal roofs and roofing materials result in high metal content in runoff. *Explanation/Description:* Add either explanation if not included or detailed description if included.	Y/N
SC-30	**Fueling Areas:** Project plans are developed for cleaning, spill cleanup, containment, leak prevention, and incorporation of design to reduce rain and runoff that could come in contact with fueling areas. *Explanation/Description:* Add either explanation if not included or detailed description if included.	Y/N

SC-31	**Maintenance Bays and Docks:** Project design incorporates measures to cover or otherwise eliminate run-on and off from bays and docks, and direct connections to stormdrain are eliminated. *Explanation/Description:* Add either explanation if not included or detailed description if included.	Y/N

SC-32	**Trash Enclosures:** Trash storage areas are covered and enclosed to prevent introduction of trash and debris to site runoff. *Explanation/Description:* Add either explanation if not included or detailed description if included.	Y/N
SC-33	**Vehicle and Equipment Washing Areas:** Designated wash areas or facilities are contained and wash water is reused, treated, or otherwise properly disposed of. *Explanation/Description:* Add either explanation if not included or detailed description if included.	Y/N
SC-34	**Outdoor Material Storage Areas:** Outdoor storage areas for materials containing pollutants, especially hazardous materials, are covered and enclosed, on impervious surfaces, and include secondary containment when applicable. *Explanation/Description:* Add either explanation if not included or detailed description if included.	Y/N
SC-35	**Outdoor Work Areas:** Outdoor work areas are covered, contained, and treated as necessary to reduce opportunity of pollutants from work activities to enter stormwater. *Explanation/Description:* Add either explanation if not included or detailed description if included.	Y/N
SC-36	**Outdoor Processing Areas:** Outdoor processing areas are covered, contained, and treated as necessary to reduce opportunity of pollutants from work activities to enter stormwater. *Explanation/Description:* Add either explanation if not included or detailed description if included.	Y/N

6.3 Treatment Control BMPs

Treatment control BMPs utilize treatment mechanisms to remove pollutants that have entered stormwater runoff and consist of public domain BMPs (identified in the following table with as TC-##) and manufactured or proprietary BMPs (identified in the following table with as MP-##). BMP numbers correspond to the California BMP Handbook.

The following table identifies the treatment control BMPs included in the proposed project.

Complete the following table. Indicate Y (Yes – included) or N (No – not included) in the Included box for the listed BMPs. If not included or not applicable, provide an explanation. If included, briefly state the location(s).

Table 6.2 Treatment Control BMPs

Number	BMP and Objective	Included
	Infiltration	
TC-10	**Infiltration Trench:** A long narrow rock filled trench with no outlet receives water and stores it until it infiltrates into the underlying soil. Its effective are removing most pollutants but can get clogged with sediment. *Explanation/Description:* If not included, provide explanation. If included, describe location and design.	Y/N
TC-11	**Infiltration Basin:** A shallow impoundment designed to capture and hold stormwater until it infiltrates into underlying soil. Effective at removing most pollutants but requires large areas and may be constrained by soil types. *Explanation/Description:* If not included, provide explanation. If included, describe location and design.	Y/N
TC-12	**Retention/Irrigation:** Stormwater is captured in cistern, basin, trench, or other storage area and is subsequently used for irrigation of site landscaping. *Explanation/Description:* If not included, provide explanation. If included, describe location and design.	Y/N
	Detention and Settling	
TC-20	**Wet Pond:** A constructed basin with a permanent pool of water throughout the year. Differ from wetlands because it is of greater depth. Treats stormwater runoff by settling and biological uptake. *Explanation/Description:* If not included, provide explanation. If included, describe location and design.	Y/N
TC-21	**Constructed Wetland:** A constructed basin with permanent pool of shallow water throughout most of year with substantial vegetative coverage. *Explanation/Description:* If not included, provide explanation. If included, describe location and design.	Y/N
TC-22	**Extended Detention Basin:** A constructed basin with an outlet designed to detain stormwater for at least 48 hours to allow particles and pollutants to settle.	Y/N

	Explanation/Description: If not included, provide explanation. If included, describe location and design.	
MP-20	**Wetland:** Similar to a constructed wetland but a self contained, manufactured module with vegetation that mimics natural wetland processes. *Explanation/Description:* If not included, provide explanation. If included, describe location and design.	Y/N
Biofiltration		
TC-30	**Vegetated Swale:** Open, shallow, vegetated channels that collect and slowly convey runoff through the property. Filters runoff through vegetation, subsoil matrix, and/or underlying soils; traps pollutants, promotes infiltration and reduce flow velocity. *Explanation/Description:* If not included, provide explanation. If included, describe location and design.	Y/N
TC-31	**Vegetated Buffer Strip:** Vegetated surfaces that are designed to treat sheet flow from adjacent surfaces. Removes pollutants by deceleration, settling, and infiltration. *Explanation/Description:* If not included, provide explanation. If included, describe location and design.	Y/N
TC-32	**Bioretention:** A soil and plant based filtration strategy that involved capturing stormwater in depressed landscaped areas. Bioretention practices are flexible strategies for using landscaping as treatment. *Explanation/Description:* If not included, provide explanation. If included, describe location and design.	Y/N
Filtration		
TC-40	**Media Filter:** Usually two-chambered with a pretreatment settling basin and a filter bed filled with sand or other absorptive filter media. *Explanation/Description:* If not included, provide explanation. If included, describe location and design.	Y/N
MP-40	Media Filter: Similar to constructed media filter but manufactured as self-contained filtering vaults, units, or cartridges. *Explanation/Description:* If not included, provide explanation. If included, describe location and design.	Y/N
Flow Through Separation		
TC-50	**Water Quality Inlet:** Vaults with chambers including screens, settling areas, and/or filter media to promote settling and/or separation of pollutants from stormwater. *Explanation/Description:* If not included, provide explanation. If included, describe location and design.	Y/N
MP-50	**Wet Vault:** A vault with a permanent water pool and internal features to promote settling and/or separation of pollutants from stormwater. *Explanation/Description:* If not included, provide explanation. If included, describe location and design.	Y/N

MP-51	**Vortex Separator:** Similar to wet vaults but round and use centrifugal action as primary separation mechanism. *Explanation/Description:* If not included, provide explanation. If included, describe location and design.	Y/N
MP-52	**Drain Inserts:** Boxes, trays, or socks with screens or filter fabric and may also include filter media. They are installed in inlets or catch basins and removal effectiveness for pollutants is generally low except for large sediment. *Note: Drain inserts cannot be the sole Treatment Control BMP selection for Priority Projects.* *Explanation/Description:* If not included, provide explanation. If included, describe location and design.	Y/N
Other		
TC-60	**Multiple Systems:** A system that uses two or more BMPs in series to increase treatment. Useful when one BMP does not provide sufficient treatment alone. *Explanation/Description:* If not included, provide explanation. If included, describe location and design.	Y/N

6.3.1 SELECTION

Provide a discussion supporting the selection of the proposed treatment control BMPs. The section should be based on achieving the highest removal possible of the primary pollutants of concern association with the project. Use Table 7-II-6 provided in DAMP, Exhibit 7.II, along with the primary pollutants of concern identified in Section 4 of this WQMP template to select treatment control BMP categories with the highest pollutant removal efficiencies. Include discussion regarding all BMPs that were considered for the project, but were not selected with detailed explanation(s) on why they were not feasible for the project.

6.3.2 SIZING

Sizing is required for all treatment control BMPs to demonstrate that the BMPs will provide adequate treatment for the flows or volumes of water that will be generated by the site. Separate sizing calculations and design specifications should be provided for each individual treatment control BMP and each treatment control BMP location identified for use in a project. The following information should be included in this section of the WQMP:

- Indicate whether the treatment control BMPs were designed using the Stormwater Quality Design Volume (SQDV) or the Stormwater Quality Design Flow (SQDF) – see Section 7 of the City's LIP and Exhibit 7.II of the DAMP for more information.
- Show calculations and provide key design criteria to demonstrate that the selected BMPs will provide adequate treatment. Please refer to the California Stormwater Quality Association (CASQA) BMP Handbook for New Development/Redevelopment or reference www.cabmphandbooks.com.
- Provide cross sections and details, as appropriate.

6.3.3 LOCATION

Project-based (on-site) structural Treatment Control BMPs should be implemented as close to pollutant sources as possible to minimize costs and maximize pollutant removal prior to runoff entering receiving waters.

- Include verbal description of BMP location(s) and describe the relationship/flow scenario between BMPs if more than one BMP is proposed (e.g. treatment train concept).
- Refer to the BMP Map.

6.3.4 RESTRICTIONS ON USE OF INFILTRATION BMPS

Restrictions on the use of infiltration BMPs are provided in Section 3.3.4 of the DAMP, Exhibit 7.II.

Include the following text if no infiltration BMPs are included:

The proposed project does not include infiltration BMPs.

Include the following text regarding restrictions of infiltration BMPs only if you are proposing an infiltration BMP such as infiltration trench or basin or porous pavement. Swales, biofilters, buffer strips, detention basins and constructed wetlands are not considered infiltration BMPs. Describe in detail how your project meets the restrictions.

The proposed project includes infiltration BMPs (BMPs that are designed to primarily function as infiltration devices) and meets the minimum restrictions on the use of infiltration BMPs as described below.

No.	**Condition**	**Yes**	**No**
1	Does use of structural infiltration Treatment Control BMPs contribute to groundwater quality objectives being surpassed?		X
Explain:			
2	Are pollution prevention and Source Control BMPs implemented at a level that protects groundwater quality?	X	
Explain:			
3	Do structural infiltration Treatment Control BMPs cause a nuisance or pollution (as defined in Water Code Section 13050)?		X
Explain:			
4	Does urban runoff from commercial developments undergo pretreatment to remove physical and chemical contaminants prior to infiltration?	X	
Explain:			
5	Are dry weather flows diverted from infiltration devices except for non-stormwater discharges authorized according to 40 CFR 122.26(d)(2)(iv)(B)(1)?	X	

Explain:			
6	Is the vertical distance from the base of any structural infiltration Treatment Control BMP to the seasonal high groundwater mark at least 10 feet? (Vertical distance criterion may be determined by the City)	X	
Explain:			
7	Does the infiltration soil have adequate physical and chemical characteristics to support proper infiltration durations and treatment of urban runoff for the protection of groundwater?	X	
Explain:			
8	Are structural infiltration Treatment Control BMPs used in areas of industrial activity, light industrial activity or other land uses posing a threat to water quality?		X
Explain:			
9	Is the horizontal distance between the base of any structural infiltration Treatment Control BMP and any water supply well at least 100 feet? (Horizontal distance criterion may be determined by the City)	X	
Explain:			
10	Does any entity implementing a structural infiltration Treatment Control BMP also mitigate any groundwater contamination caused by the infiltration system?	X	
Explain:			

Where infiltration Treatment Control BMPs are authorized, their performance has been evaluated for impacts on groundwater quality.

Section 7 Project Plan and BMP Location Map

Figure 7.1 illustrates the proposed project and the Source Control structural and Treatment BMPs that will be implemented pursuant to this WQMP. The following checklist identifies the required information that is included in the BMP map.

Include a BMP project map, 50 scale minimum size, including the elements listed in the following checklist and complete the checklist.

Included	**Requirement**
X	Legend, north arrow, scale
X	Show drainage arrows, and drainage areas
X	Entire property on one map (provided sufficient detail is shown)
X	Show structures to be constructed and removed
X	Show proposed and existing stormdrain systems
X	Show all external hardscape surfaces such as walkways, driveways, pools, spas, patio areas etc.
X	Indicate the landscape areas and planters
X	Show nearby waterbodies by name, if available
X	Identify site outlet and/or connection to municipal stormdrain system
X	Identify locations of all source control structural and treatment BMPs on the Map. Indicate the BMP location using the BMP number.
X	Differentiate/identify pervious and impervious surfaces, buildings, activity areas, etc.
X	Identify areas of potential soil erosion

Section 8 Stormwater BMP Maintenance

The City does not accept stormwater structural BMPs as meeting the WQMP requirements standard, unless an Operations and Maintenance (O&M) Plan is prepared and a mechanism is in place that will ensure ongoing long-term maintenance of all structural and non-structural BMPs. Select the appropriate Maintenance Mechanism for your project (delete all others).

The _________________________ project will implement the following maintenance mechanism to ensure ongoing long-term maintenance of all structural and non-structural BMPs.

1. **Public entity maintenance**: The City may approve a public or acceptable quasi-public entity (e.g., the County Flood Control District, or annex to an existing assessment district, an existing utility district, a state or federal resource agency, or a conservation conservancy) to assume responsibility for operation, maintenance, repair and replacement of the BMP. Unless otherwise acceptable to the City, public entity maintenance agreements shall ensure estimated costs are front-funded or reliably guaranteed, (e.g., through a trust fund, assessment district fees, bond, letter of credit or similar means). In addition, the City may seek protection from liability by appropriate releases and indemnities.

The City shall have the authority to approve stormwater BMPs proposed for transfer to any other public entity within its jurisdiction before installation. The City shall be involved in the negotiation of maintenance requirements with any other public entities accepting maintenance responsibilities within their respective jurisdictions; and in negotiations with the resource agencies responsible for issuing permits for the construction and/or maintenance of the facilities. The City must be identified as a third party beneficiary empowered to enforce any such maintenance agreement within their respective jurisdictions.

2. **Project proponent agreement to maintain stormwater BMPs**: The City may enter into a contract with the project proponent obliging the project proponent to maintain, repair and replace the stormwater BMP as necessary into perpetuity. Security or a funding mechanism with a “no sunset” clause may be required. Include name, Title Company, address and phone number of responsible party.
3. **Assessment districts**: The City may approve an Assessment District or other funding mechanism created by the project proponent to provide funds for stormwater BMP maintenance, repair and replacement on an ongoing basis. Any agreement with such a District shall be subject to the Public Entity Maintenance Provisions above.
4. **Lease provisions**: In those cases where the City holds title to the land in question, and the land is being leased to another party for private or public use, the City may assure stormwater BMP maintenance, repair and replacement through conditions in the lease.
5. **Conditional development permits**: For discretionary projects only, the City may assure maintenance of stormwater BMPs through the inclusion of maintenance conditions in the conditional development permit. Security may be required.
6. **Alternative mechanisms**: The City may accept alternative maintenance mechanisms if such mechanisms are as protective as those listed above.

8.1 Operation and Maintenance (O&M) Plan

An O&M Plan will be prepared for the proposed project and must be approved by the City prior to construction approvals, permit close out and issuance of certificates of use and occupancy. The O&M Plan describes the designated responsible party to manage the stormwater BMP(s), employee's training program and duties, operating schedule, inspection and maintenance frequencies, routine service schedule, specific maintenance activities, copies of resource agency permits, and any other necessary activities. At a minimum, maintenance agreements shall require the inspection and servicing of all structural BMPs per manufacturer or engineering specifications. Parties responsible for the O&M plan shall retain records for at least 5 years. These documents shall be made available to the City for inspection upon request at any time.

An O&M Plan must be submitted with this WQMP to the City and approved prior to construction approvals, permit close out and issuance of certificates of use and occupancy   The O&M plan must list all non-structural BMPs, source control BMPs, structural BMPs and treatment control BMPs listed as applicable to the project in the WQMP in the following format with information as indicated (insert rows as needed):

Desig-nator. Code (e.g. N1 or SC-1)	BMP Name and BMP Implementation, Maintenance, and Inspection Procedures	Implementation, Maintenance, and Inspection Frequency and Schedule	Person or Entity with Operation & Maintenance Responsibility
Non-Structural Source Control BMPs			
Structural Source Control BMPs			
Treatment Control BMPs			

Required Posting

A statement requiring the above table to be laminated and posted in the primary maintenance worker assembly area(s) related to the project shall be included in the WQMP.

Required Permits

List any permits required for the implementation, operation, and maintenance of the BMPs. Possible examples are:

- Permits for connection to sanitary sewer
- Permits from California Department of Fish and Game
- Encroachment permits

If no permits are required, a statement to that effect should be made.

Forms to Record BMP Implementation, Maintenance, and Inspection

The form that will be used to record implementation, maintenance, and inspection of BMPs is attached.

WQMP Operations and Maintenance Log

Designator Code	Date of Inspection	Date of Maintenance	Verified/ Inspected by	Comments

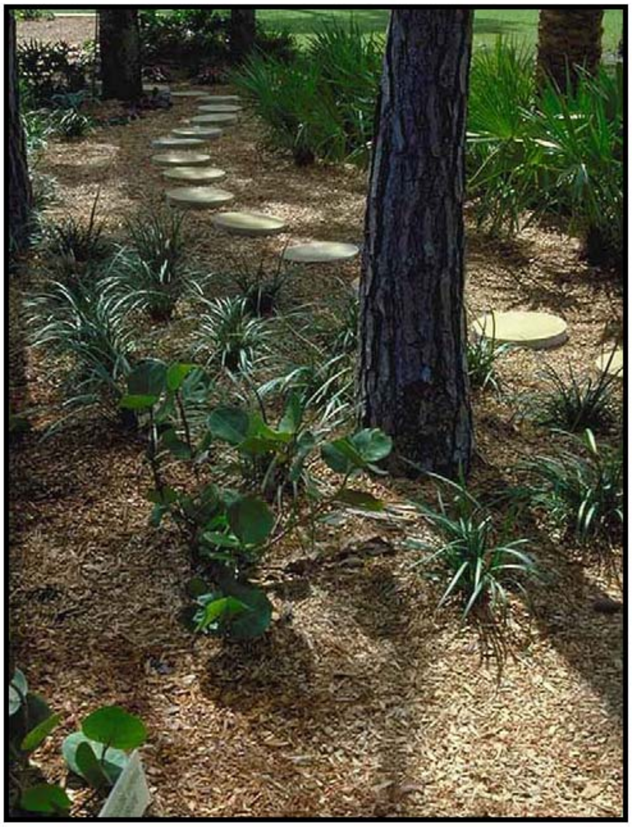
Exhibit A-7.II

BMP Fact Sheets for Source Control BMPs
and
Site Design BMPs

CITY OF LAKE FOREST

DECEMBER 20, 1991

Site Design & Landscape Planning SD-10



Design Objectives

☑ Maximize Infiltration
☑ Provide Retention
☑ Slow Runoff
☑ Minimize Impervious Land Coverage
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 stormwater.

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.

CASQA
CALIFORNIA STORMWATER QUALITY ASSOCIATION

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 unwooded 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 (e.g., 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 stormwater management manual for the jurisdiction and pay particular attention to the selection criteria for avoiding groundwater contamination, poor soils, and hydrogeological 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.
- Vegetate 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

Various jurisdictional stormwater management and mitigation plans (SUSMP, WQMP, etc.) define "redevelopment" in terms of amounts of additional impervious area, increases in gross floor area and/or exterior construction, and land disturbing activities with structural or impervious surfaces. 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.

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, disconnect directly connected impervious areas.

Other Resources

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.

Roof Runoff Controls SD-11


Rain Garden

Design Objectives

☑ Maximize Infiltration

☑ Provide Retention

☑ Slow Runoff

Minimize Impervious Land Coverage

Prohibit Dumping of Improper Materials

☑ Contain Pollutants

Collect and Convey

Description
Various roof runoff controls are available to address stormwater 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; pop-up emitters, and foundation planting. The first three 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 stormwater 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 2 rain barrels, with a minimum storage capacity of 1000 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 stormwater 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 stormwater 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 must be sized according to the amount of rooftop runoff received, but are typically 4 to 5 feet square, 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. They must be installed in solids that accommodate infiltration. In poorly drained soils, dry wells have very limited feasibility.

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 stormwater 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 stormwater 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

Various jurisdictional stormwater management and mitigation plans (SUSMP, WQMP, etc.) define "redevelopment" in terms of amounts of additional impervious area, increases in gross floor area and/or exterior construction, and land disturbing activities with structural or impervious surfaces. 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

Other Resources

Hager, Marty Catherine, Stormwater, "Low-Impact Development", January/February 2003. www.stormh2o.com

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

Efficient Irrigation SD-12

Design Objectives

- ☑ Maximize Infiltration
- ☑ Provide Retention
- ☑ Slow Runoff
- Minimize Impervious Land Coverage
- 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 stormwater 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 stormwater 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 by the Permittee:

- 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 County or City water conservation resolutions, which may include provision of water sensors, programmable irrigation times (for short cycles), etc.

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- 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

Various jurisdictional stormwater management and mitigation plans (SUSMP, WQMP, etc.) define "redevelopment" in terms of amounts of additional impervious area, increases in gross floor area and/or exterior construction, and land disturbing activities with structural or impervious surfaces. 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

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 Signage SD-13

Design Objectives

Maximize Infiltration

Provide Retention

Slow Runoff

Minimize Impervious Land Coverage

☑ 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 show 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 "NO DUMPING

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– DRAINS TO OCEAN" 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 - Some local agencies have approved specific signage and/or storm drain message placards for use. Consult local agency stormwater staff to determine specific requirements for placard types and methods of application.

Redeveloping Existing Installations

Various jurisdictional stormwater management and mitigation plans (SUSMP, WQMP, etc.) define "redevelopment" in terms of amounts of additional impervious area, increases in gross floor area and/or exterior construction, and land disturbing activities with structural or impervious surfaces. 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.

Additional 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.

Supplemental Information

Examples

- Most MS4 programs have storm drain signage programs. Some MS4 programs will provide stencils, or arrange for volunteers to stencil storm drains as part of their outreach program.

Other Resources

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.

Pervious Pavements SD-20

Design Objectives

☑ Maximize Infiltration
☑ Provide Retention
☑ Slow Runoff
☑ Minimize Impervious Land Coverage
Prohibit Dumping of Improper Materials
Contain Pollutants
Collect and Convey

Description

Pervious paving is used for light vehicle loading in parking areas. The term describes a system comprising a load-bearing, durable surface together with an underlying layered structure that temporarily stores water prior to infiltration or drainage to a controlled outlet. The surface can itself be porous such that water infiltrates across the entire surface of the material (e.g., grass and gravel surfaces, porous concrete and porous asphalt), or can be built up of impermeable blocks separated by spaces and joints, through which the water can drain. This latter system is termed 'permeable' paving. Advantages of pervious pavements is that they reduce runoff volume while providing treatment, and are unobtrusive resulting in a high level of acceptability.

Approach

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 (e.g., 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.

Suitable Applications

Residential, commercial and industrial applications are possible. 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:

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- 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.
- Their application should be limited to highways with low traffic volumes, axle loads and speeds (less than 30 mph 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.
- 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.
- Porous block paving has a higher risk of abrasion and damage than solid blocks.

Design Considerations

Designing New Installations

If the grades, subsoils, 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. Slopes should be flat or very gentle. 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.

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 4 feet below the surface.

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.

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 of 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 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 stormwater 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.

- 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.

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 Requirements

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
- Ownership
- Level of trafficking
- The local environment and any contributing catchments

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, Table 1 shows typical recommended maintenance regimes:

Table 1 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 x 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

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)

Table 1 gives US cost estimates for capital and maintenance costs of porous pavements (Landphair et al., 2000)

Redeveloping Existing Installations

Various jurisdictional stormwater management and mitigation plans (SUSMP, WQMP, etc.) define "redevelopment" in terms of amounts of additional impervious area, increases in gross floor area and/or exterior construction, and land disturbing activities with structural or impervious surfaces. 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.

Additional Information

Cost Considerations

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)

Table 2 gives US cost estimates for capital and maintenance costs of porous pavements (Landphair et al., 2000)

Table 2 **Engineer's Estimate for Porous Pavement**

Porous Pavement														
Item	Units	Price	Cycles/ Year	Quant. 1 Acre WS	Total	Quant. 2 Acre WS	Total	Quant. 3 Acre WS	Total	Quant. 4 Acre WS	Total	Quant. 5 Acre WS	Total
Grading	SY	$2.00		604	$1,208	1209	$2,418	1812	$3,624	2419	$4,838	3020	$6,040
Paving	SY	$19.00		212	$4,028	424	$8,056	636	$12,084	848	$16,112	1060	$20,140
Excavation	CY	$3.60		201	$724	403	$1,451	604	$2,174	806	$2,902	1008	$3,629
Filter Fabric	SY	$1.15		700	$805	1400	$1,610	2000	$2,300	2800	$3,220	3600	$4,140
Stone Fill	CY	$16.00		201	$3,216	403	$6,448	604	$9,664	806	$12,896	1008	$16,128
Sand	CY	$7.00		100	$700	200	$1,400	300	$2,100	400	$2,800	500	$3,500
Sight Well	EA	$300.00		2	$600	3	$900	4	$1,200	7	$2,100	7	$2,100
Seeding	LF	$0.05		644	$32	1288	$64	1932	$97	2576	$129	3220	$161
Check Dam	CY	$35.00		0	$0	0	$0	0	$0	0	$0	0	$0
Total Construction Costs					**$10,105**		**$19,929**		**$29,619**		**$40,158**		**$49,798**
Construction Costs Amortized for 20 Years					**$505**		**$996**		**$1,481**		**$2,008**		**$2,490**
Annual Maintenance Expense													
Item	Units	Price	Cycles/ Year	Quant. 1 Acre WS	Total	Quant. 2 Acre WS	Total	Quant. 3 Acre WS	Total	Quant. 4 Acre WS	Total	Quant. 5 Acre WS	Total
Sweeping	AC	$250.00	6	1	$1,500	2	$3,000	3	$4,500	4	$6,000	5	$7,500
Washing	AC	$250.00	6	1	$1,500	2	$3,000	3	$4,500	4	$6,000	5	$7,500
Inspection	MH	$20.00	5	5	$100	5	$100	5	$100	5	$100	5	$100
Deep Clean	AC	$450.00	0.5	1	$225	2	$450	3	$675	3.9	$878	5	$1,125
Total Annual Maintenance Expense					**$3,960**		**$7,792**		**$11,651**		**$15,483**		**$19,370**

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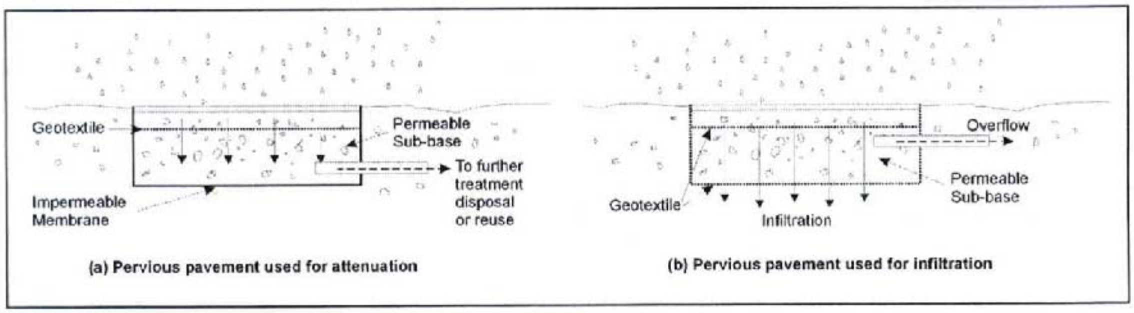

Schematics of a Pervious Pavement System

Infiltration Trench TC-10

Design Considerations

- Accumulation of Metals
- Clogged Soil Outlet Structures
- Vegetation/Landscape Maintenance

Description

An infiltration trench is a long, narrow, rock-filled trench with no outlet that receives stormwater 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.

California Experience

Caltrans constructed two infiltration trenches at highway maintenance stations in Southern California. Of these, one failed to operate to the design standard because of average soil infiltration rates lower than that measured in the single infiltration test. This highlights the critical need for appropriate evaluation of the site. Once in operation, little maintenance was required at either site.

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 creeks.
- If the water quality volume 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.

Targeted Constituents

☑	Sediment	■
☑	Nutrients	■
☑	Trash	■
☑	Metals	■
☑	Bacteria	■
☑	Oil and Grease	■
☑	Organics	■

Legend *(Removal Effectiveness)*

● Low ■ High

▲ Medium

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- As an underground BMP, trenches are unobtrusive and have little impact of site aesthetics.

Limitations

- 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 5 acres.
- Infiltration basins require a minimum soil infiltration rate of 0.5 inches/hour, not appropriate at sites with Hydrologic Soil Types C and D.
- If infiltration rates exceed 2.4 inches/hour, then the runoff should be fully 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

- 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 stormwater 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 2.5 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 72 hr by dividing the WQV by the infiltration rate.

$$d = \frac{WQV + RFV}{SA}$$

- Calculate trench depth using the following equation:

where:

D = Trench depth

WQV = Water quality volume

RFV = Rock fill volume

SA = Surface area of the trench bottom

- The use of vertical piping, either for distribution or infiltration enhancement shall not be allowed to avoid device classification as a Class V injection well per 40 CFR146.5(e)(4).
- 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.

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 percent of sediments, metals, coliform bacteria and organic matter, and up to 60 percent of phosphorus and nitrogen in the infiltrated runoff (Schueler, 1992). Biochemical oxygen demand (BOD) removal is estimated to be between 70 to 80 percent. 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 (consider RCS soil type '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 percent clay or more than 40 percent of clay and silt combined. Eliminate sites that are clearly unsuitable for infiltration.

- Groundwater separation should be at least 3 m from the basin invert to the measured ground water elevation. There is concern at the state and regional levels 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 m) and wells and bridge structures (greater than 30 m). Sites constructed of fill, having a base flow or with a slope greater than 15 percent 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

- At least three in-hole conductivity tests shall be performed using USBR 7300-89 or Bouwer-Rice procedures (the latter if groundwater is encountered within the boring), two tests at different locations within the proposed basin and the third down gradient by no more than approximately 10 m. The tests shall measure permeability in the side slopes and the bed within a depth of 3 m of the invert.

- The minimum acceptable hydraulic conductivity as measured in any of the three required test holes is 13 mm/hr. 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 stormwater 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 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 hr/yr.

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 2 inches to provide a fresh surface for infiltration.

Cost

Construction Cost

Infiltration trenches are somewhat expensive, when compared to other stormwater practices, in terms of cost per area treated. Typical construction costs, including contingency and design costs, are about $5 per ft^3 of stormwater treated (SWRPC, 1991; Brown and Schueler, 1997). Actual construction costs may be much higher. The average construction cost of two infiltration trenches installed by Caltrans in southern California was about $50/ft^3; however, these were constructed as retrofit installations.

Infiltration trenches typically consume about 2 to 3 percent of the site draining to them, which is relatively small. In addition, infiltration trenches can fit into thin, linear areas. Thus, they can generally fit into relatively unusable portions of a site.

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 percent and 20 percent of the construction cost. More realistic values are probably closer to the 20-percent range, to ensure long-term functionality of the practice.

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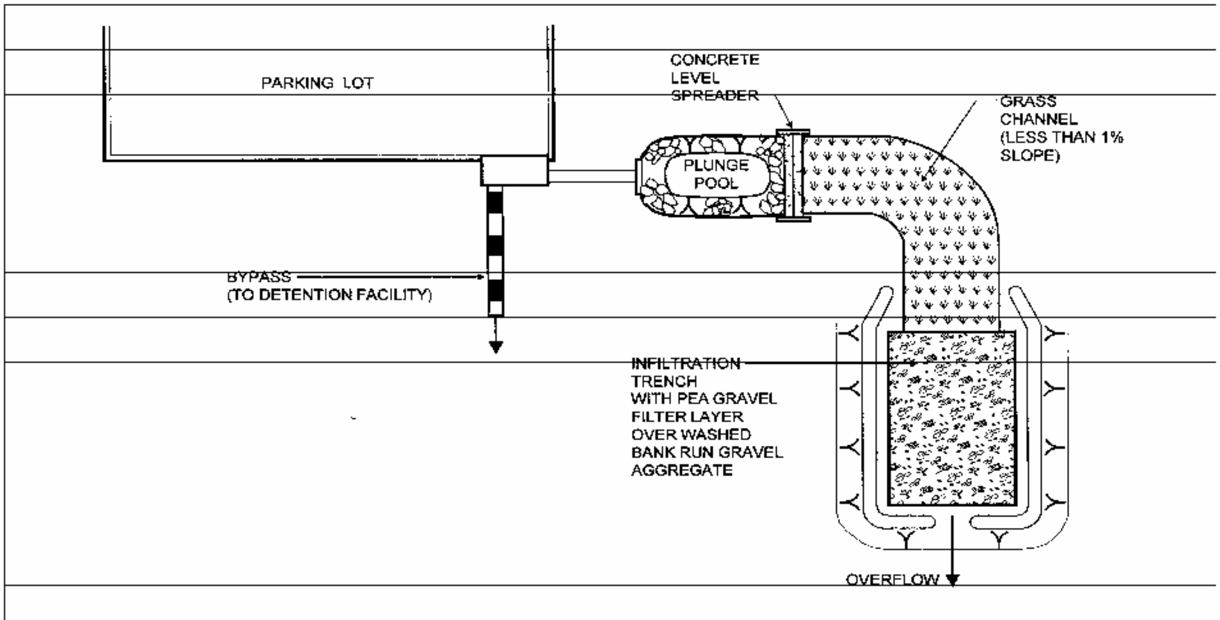
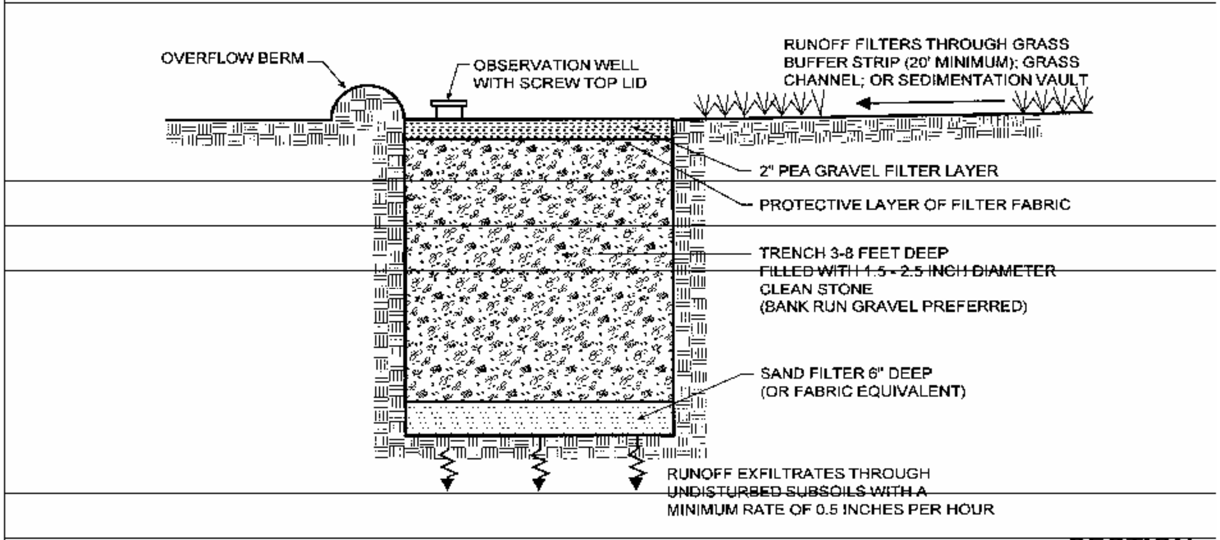


PLAN VIEW



SECTION

Infiltration Basin TC-11

Design Considerations

- ■ Soil for Infiltration
- ■ Slope
- ■ Aesthetics

Targeted Constituents

☑	Sediment	■
☑	Nutrients	■
☑	Trash	■
☑	Metals	■
☑	Bacteria	■
☑	Oil and Grease	■
☑	Organics	■

Legend *(Removal Effectiveness)*

● Low ■ High

▲ Medium

Description

An infiltration basin is a shallow impoundment that is designed to infiltrate stormwater. Infiltration basins use the natural filtering ability of the soil to remove pollutants in stormwater 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, however, because of soils requirements. In addition, some studies have shown relatively high failure rates compared with other management practices.

California Experience

Infiltration basins have a long history of use in California, especially in the Central Valley. Basins located in Fresno were among those initially evaluated in the National Urban Runoff Program and were found to be effective at reducing the volume of runoff, while posing little long-term threat to groundwater quality (EPA, 1983; Schroeder, 1995). Proper siting of these devices is crucial as underscored by the experience of Caltrans in siting two basins in Southern California. The basin with marginal separation from groundwater and soil permeability failed immediately and could never be rehabilitated.

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 Soil Types C and D.
- If infiltration rates exceed 2.4 inches/hour, then the runoff should be fully 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

- Water quality volume determined by local requirements or sized so that 85% of the annual runoff volume is captured.
- Basin sized so that the entire water quality volume is infiltrated within 48 hours.
- Vegetation establishment on the basin floor may help reduce the clogging rate.

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 2 inches of soil after the site is stabililized. 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 can not 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 stormwater 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 stormwater 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. Conversely, Schroeder (1995) reported that there was no evidence of groundwater impacts from an infiltration basin serving a large industrial catchment in Fresno, CA.

Siting Criteria

The key element in siting infiltration basins is identifying sites with appropriate soil and hydrogeologic 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 2 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 in/hr, 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 RCS soil type '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 m from the basin invert to the measured ground water elevation. There is concern at the state and regional levels 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 m) and wells and bridge structures (greater than 30 m). 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

- At least three in-hole conductivity tests shall be performed using USBR 7300-89 or Bouwer-Rice procedures (the latter if groundwater is encountered within the boring), two tests at different locations within the proposed basin and the third down gradient by no more than approximately 10 m. The tests shall measure permeability in the side slopes and the bed within a depth of 3 m of the invert.

- The minimum acceptable hydraulic conductivity as measured in any of the three required test holes is 13 mm/hr. 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 stormwater 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

(1) Basin Sizing - The required water quality volume is determined by local regulations or sufficient to capture 85% of the annual runoff.

(2) Provide pretreatment if sediment loading is a maintenance concern for the basin.

(3) 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.

(4) Basin invert area should be determined by the equation:

$$A = \frac{WQV}{kt}$$

where A = Basin invert area (m^2)

WQV = water quality volume (m^3)

k = 0.5 times the lowest field-measured hydraulic conductivity (m/hr)

t = drawdown time (48 hr)

(5) The use of vertical piping, either for distribution or infiltration enhancement shall not be allowed to avoid device classification as a Class V injection well per 40 CFR146.5(e)(4).

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 ft (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. For instance, Caltrans spent about $18/ft^3 for the two infiltration basins constructed in southern California, each of which had a water quality volume of about 0.34 ac.-ft. Much of the higher cost can be attributed to changes in the storm drain system necessary to route the runoff to the basin locations.

Infiltration basins typically consume about 2 to 3% of the site draining to them, which is relatively small. 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.

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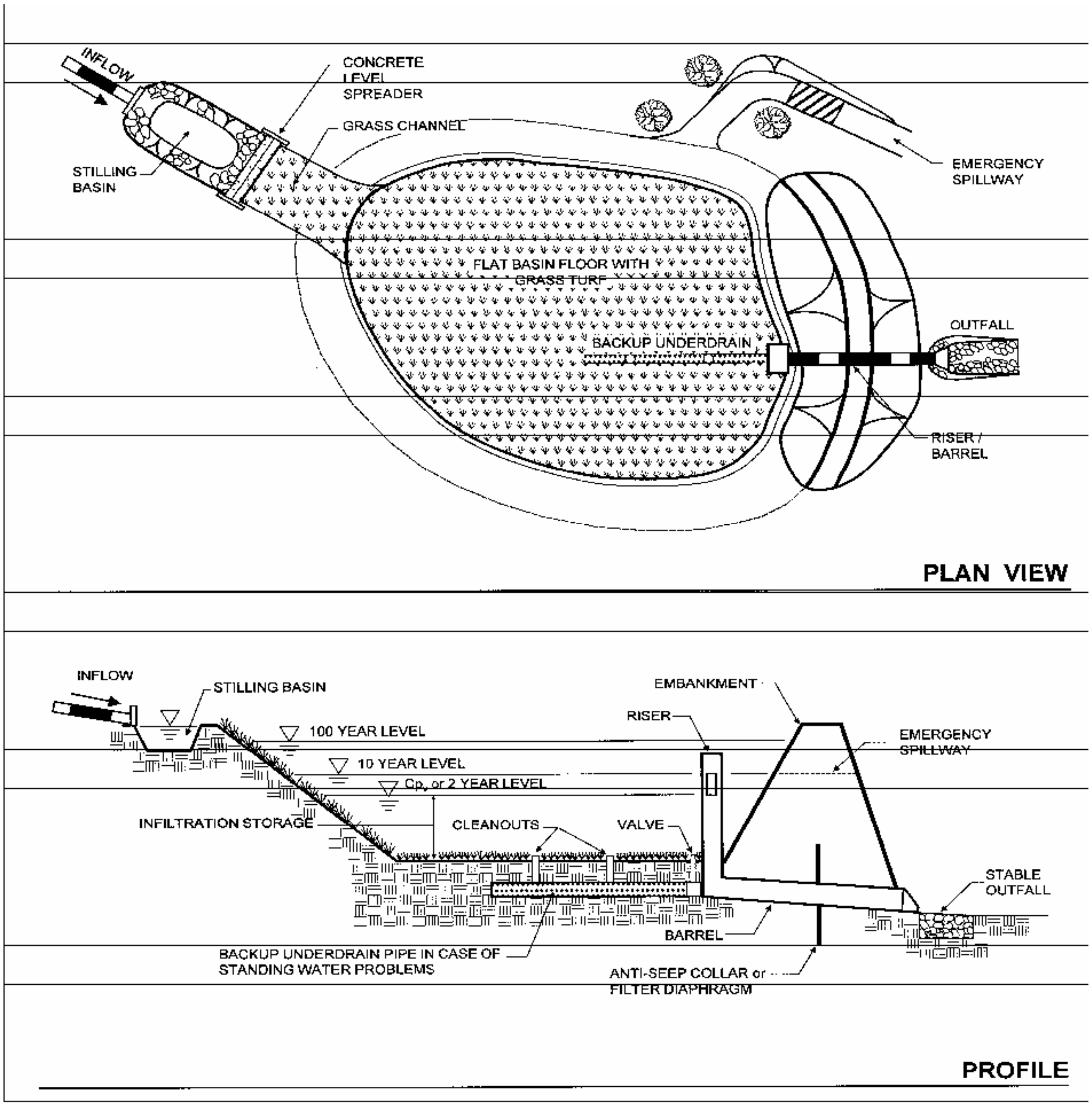
INFLOW
CONCRETE LEVEL SPREADER
GRASS CHANNEL
STILLING BASIN
EMERGENCY SPILLWAY
FLAT BASIN FLOOR WITH GRASS TURF
BACKUP UNDERDRAIN
OUTFALL
RISER / BARREL
PLAN VIEW
INFLOW
STILLING BASIN
100 YEAR LEVEL
10 YEAR LEVEL
Cp, or 2 YEAR LEVEL
EMBANKMENT
RISER
EMERGENCY SPILLWAY
INFILTRATION STORAGE
CLEANOUTS
VALVE
STABLE OUTFALL
BARREL
BACKUP UNDERDRAIN PIPE IN CASE OF STANDING WATER PROBLEMS
ANTI-SEEP COLLAR or FILTER DIAPHRAGM
PROFILE

Retention/Irrigation TC-12

Description

Retention/irrigation refers to the capture of stormwater runoff in a holding pond and subsequent use of the captured volume for irrigation of landscape of natural pervious areas. This technology is very effective as a stormwater quality practice in that, for the captured water quality volume, it provides virtually no discharge to receiving waters and high stormwater 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 stormwater 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). Collection of roof runoff for subsequent use (rainwater harvesting) also qualifies as a retention/irrigation practice.

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.

California Experience

This BMP has never been implemented in California, only in the Austin, Texas area. The use there is limited to watersheds where no increase in pollutant load is allowed because of the sensitive nature of the watersheds.

Advantages

- Pollutant removal effectiveness is high, accomplished primarily by: (1) sedimentation in the primary storage facility; (2) physical filtration of particulates through the soil profile; (3) dissolved constituents uptake in the vegetative root zone by the soil-resident microbial community.

Design Considerations

- Soil for Infiltration
- Area Required
- Slope
- Environmental Side-effects

Targeted Constituents

☑	Sediment	■
☑	Nutrients	■
☑	Trash	■
☑	Metals	■
☑	Bacteria	■
☑	Oil and Grease	■
☑	Organics	■

Legend *(Removal Effectiveness)*

● Low ■ High

▲ Medium

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The hydrologic characteristics of this technique are effective for simulating pre-developed watershed conditions through: (1) containment of higher frequency flood volumes (less than about a 2-year event); and (2) 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 stormwater 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 stormwater 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 72 hours. 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 stormwater 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:

$$A = \frac{12 \times V}{T \times r}$$

where:

A = area required for irrigation (ft2)

V = water quality volume (ft3)

T = period of active irrigation (30 hr)

r = Permeability (in/hr)

- 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 permeabilities 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.

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 stormwater 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

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

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 (e.g., 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 stormwater quality control practices because of the need for: (1) frequent inspections; (2) the reliance on mechanical equipment; and (3) power costs.

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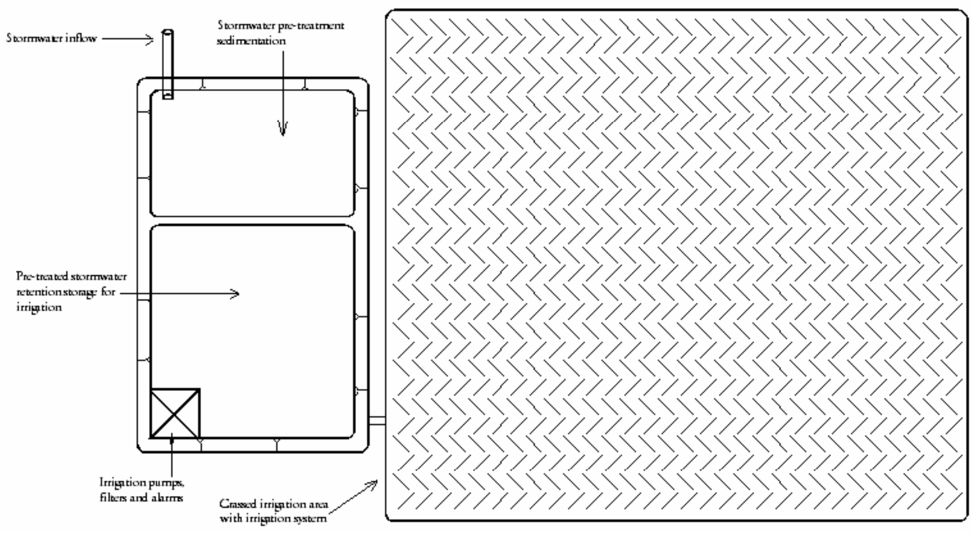

Stormwater inflow
Stormwater pre-treatment sedimentation
Pre-treated stormwater retention storage for irrigation
Irrigation pumps, filters and alarms
Grassed irrigation area with irrigation system

Design Considerations

- Area Required
- Slope
- Water Availability
- Aesthetics
- Environmental Side-effects

Targeted Constituents

☑	Sediment	■
☑	Nutrients	▲
☑	Trash	■
☑	Metals	■
☑	Bacteria	■
☑	Oil and Grease	■
☑	Organics	■

Legend *(Removal Effectiveness)*

● Low ■ High

▲ Medium

Description

Wet ponds (a.k.a. stormwater 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 stormwater runoff by settling and biological uptake. The primary removal mechanism is settling as stormwater 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 stormwater 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 stormwater 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.

California Experience

Caltrans constructed a wet pond in northern San Diego County (I-5 and La Costa Blvd.). Largest issues at this site were related to vector control, vegetation management, and concern that endangered species would become resident and hinder maintenance activities.

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 Division of Safety of Dams

Design and Sizing Guidelines

- Capture volume determined by local requirements or sized to treat 85% of the annual runoff volume.

- Use a draw down time of 48 hours in most areas of California. 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 fisheries.

- 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 resuspension 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 seven meters or less in width. Those BMPs that have shoreline-to-shoreline distances in excess of seven meters should have perimeter road access on both sides or be designed such that no parcel of water is greater than seven meters 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 stormwater 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.

Siting Criteria

Wet ponds are a widely applicable stormwater 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 (e.g., golf courses).

Ponds do not consume a large area (typically 2–3 percent 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 stormwater 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 ha (25 ac.); (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.

Wet ponds may pose a risk to cold water systems because of their potential for stream warming. When water remains in the permanent pool, it is heated by the sun. A study in Prince George's County, Maryland, found that stormwater wet ponds heat stormwater by about 9°F from the inlet to the outlet (Galli, 1990).

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 m (8 feet) and should average 1.2 – 2 m (4-6 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 percent 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 stormwater 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 stormwater. Wet ponds with greater amounts of vegetation often have channels through the vegetated areas and contain dead areas where stormwater 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 5–7 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.

Cold climates present many challenges to designers of wet ponds. The spring snowmelt may have a high pollutant load and a large volume to be treated. In addition, cold winters may cause freezing of the permanent pool or freezing at inlets and outlets. Finally, high salt concentrations in runoff resulting from road salting, and sediment loads from road sanding, may impact pond vegetation as well as reduce the storage and treatment capacity of the pond.

One option to deal with high pollutant loads and runoff volumes during the spring snowmelt is the use of a seasonally operated pond to capture snowmelt during the winter and retain the permanent pool during warmer seasons. In this option, proposed by Oberts (1994), the pond has two water quality outlets, both equipped with gate valves. In the summer, the lower outlet is closed. During the fall and throughout the winter, the lower outlet is opened to draw down the permanent pool. As the spring melt begins, the lower outlet is closed to provide detention for the melt event. The manipulation of this system requires some labor and vigilance; a careful maintenance agreement should be confirmed.

Several other modifications may help to improve the performance of ponds in cold climates. Designers should consider planting the pond with salt-tolerant vegetation if the facility receives road runoff. In order to counteract the effects of freezing on inlet and outlet structures, the use of inlet and outlet structures that are resistant to frost, including weirs and larger diameter pipes, may be useful. Designing structures on-line, with a continuous flow of water through the pond, will also help prevent freezing of these structures. Finally, since freezing of the permanent pool can reduce the effectiveness of pond systems, it is important to incorporate extended detention into the design to retain usable treatment area above the permanent pool when it is frozen.

Summary of Design Recommendations

(1) 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.

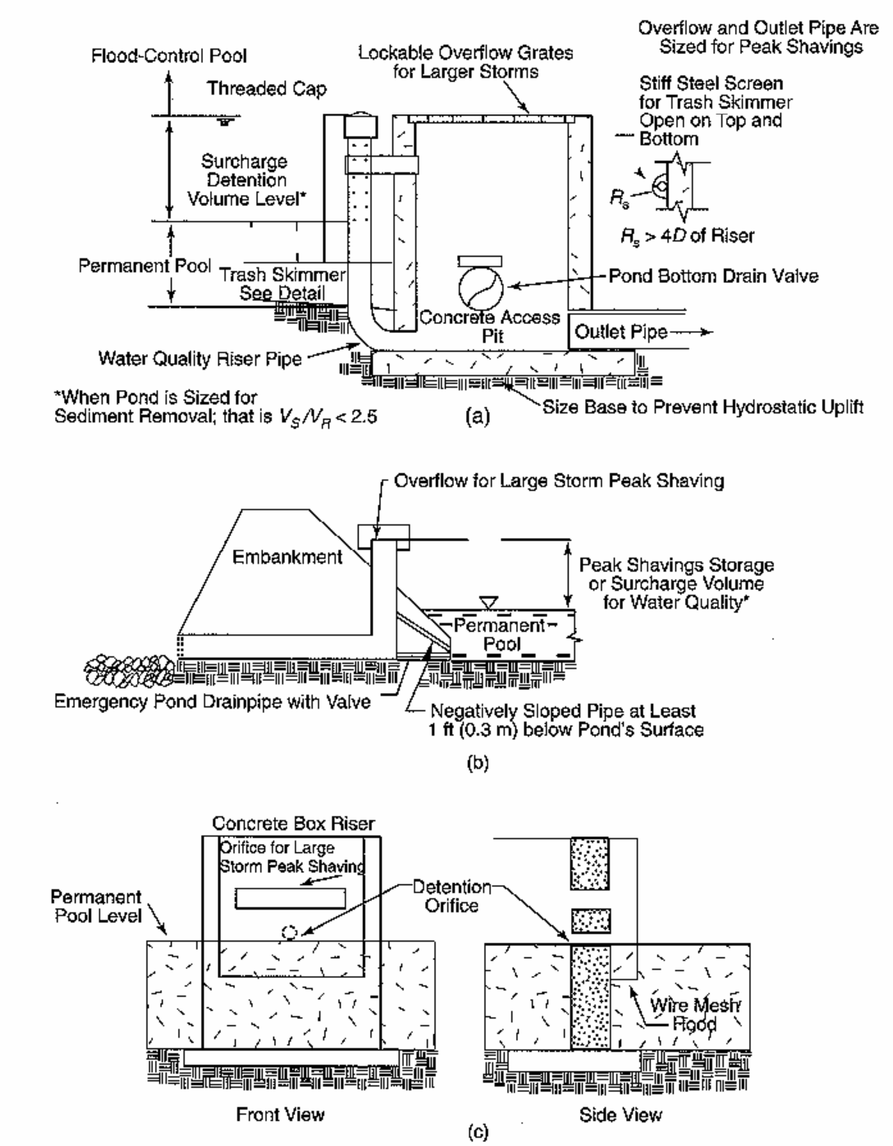
(2) Pond Configuration - The wet basin should be configured as a two stage facility with a sediment forebay and a main pool. The basins should be wedge-shaped, narrowest at the inlet and widest at the outlet. The minimum length to width ratio should be 1.5 where feasible. The perimeter of all permanent pool areas with depths of 4.0 feet or greater should be surrounded by an aquatic bench. This bench should extend inward 5-10 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 – 8 feet deep to prevent vegetation from encroaching on the pond open water surface.

(3) 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.

(4) 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.

(5) Outflow Structure - Figure 2 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 Extended Detention Basin fact sheet. 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.



(6) 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.

(7) Vegetation - A plan should be prepared that indicates how aquatic and terrestrial areas will be vegetatively 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 California is presented in Table 1.

Table 1 California Wetland Vegetation

Botanical Name	Common Name
BACCHARIS SALICIFOLIA	MULE FAT
FRANKENIA GRANDIFOLIA	HEATH
SALIX GOODINGII	BLACK WILLOW
SALIX LASIOLEPIS	ARROYO WILLOW
SAMUCUS MEXICANUS	MEXICAN ELDERBERRY
HAPLOPAPPUS VENETUS	COAST GOLDENBRUSH
DISTICHIS SPICATA	SALT GRASS
LIMONIUM CALIFORNICUM	COASTAL STATICE
ATRIPLEX LENTIFORMIS	COASTAL QUAIL BUSH
BACCHARIS PILULARIS	CHAPARRAL BROOM
MIMULUS LONGIFLORUS	MONKEY FLOWER
SCIRPUS CALIFORNICUS	BULRUSH
SCIRPUS ROBUSTUS	BULRUSH
TYPHA LATIFOLIA	BROADLEAF CATTAIL
JUNCUS ACUTUS	RUSH

Maintenance

The amount of maintenance required for a wet pond is highly dependent on local regulatory agencies, 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. 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/m2 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 is 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 stormwater 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 Fish and Game or other agency regulations, stock wet ponds/constructed wetlands regularly with mosquito fish (*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 5-7 years or when the accumulated sediment volume exceeds 10 percent of the basin volume. Sediment removal may not be required in the main pool area for as long as 20 years.

Cost

Construction Cost

Wet ponds can be relatively inexpensive stormwater 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.

A recent study (Brown and Schueler, 1997) estimated the cost of a variety of stormwater management practices. The study resulted in the following cost equation, adjusting for inflation:

$$C = 24.5^{V0.705}$$

where:

C = Construction, design and permitting cost;

V = Volume in the pond to include the 10-year storm (ft^3).

Using this equation, typical construction costs are:

$45,700 for a 1 acre-foot facility

$232,000 for a 10 acre-foot facility

$1,170,000 for a 100 acre-foot facility

In contrast, Caltrans (2002) reported spending over $448,000 for a pond with a total permanent pool plus water quality volume of only 1036 m^3 (0.8 ac.-ft.), while the City of Austin spent $584,000 (including design) for a pond with a permanent pool volume of 3,100 m^3 (2.5 ac.-ft.). The large discrepancies between the costs of these actual facilities and the model developed by Brown and Schueler indicate that construction costs are highly site specific, depending on topography, soils, subsurface conditions, the local labor, rate and other considerations.

Maintenance Cost

For ponds, the annual cost of routine maintenance has typically been estimated at about 3 to 5 percent 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 years of monitoring of a pond treating runoff from 1.7 ha. Almost all the activities are associated with the annual vegetation harvest for vector control. Total cost at this site falls within the 3-5% 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/yr 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 at sites in California depending on the aggressiveness of the vegetation management in that area and the frequency of litter removal.

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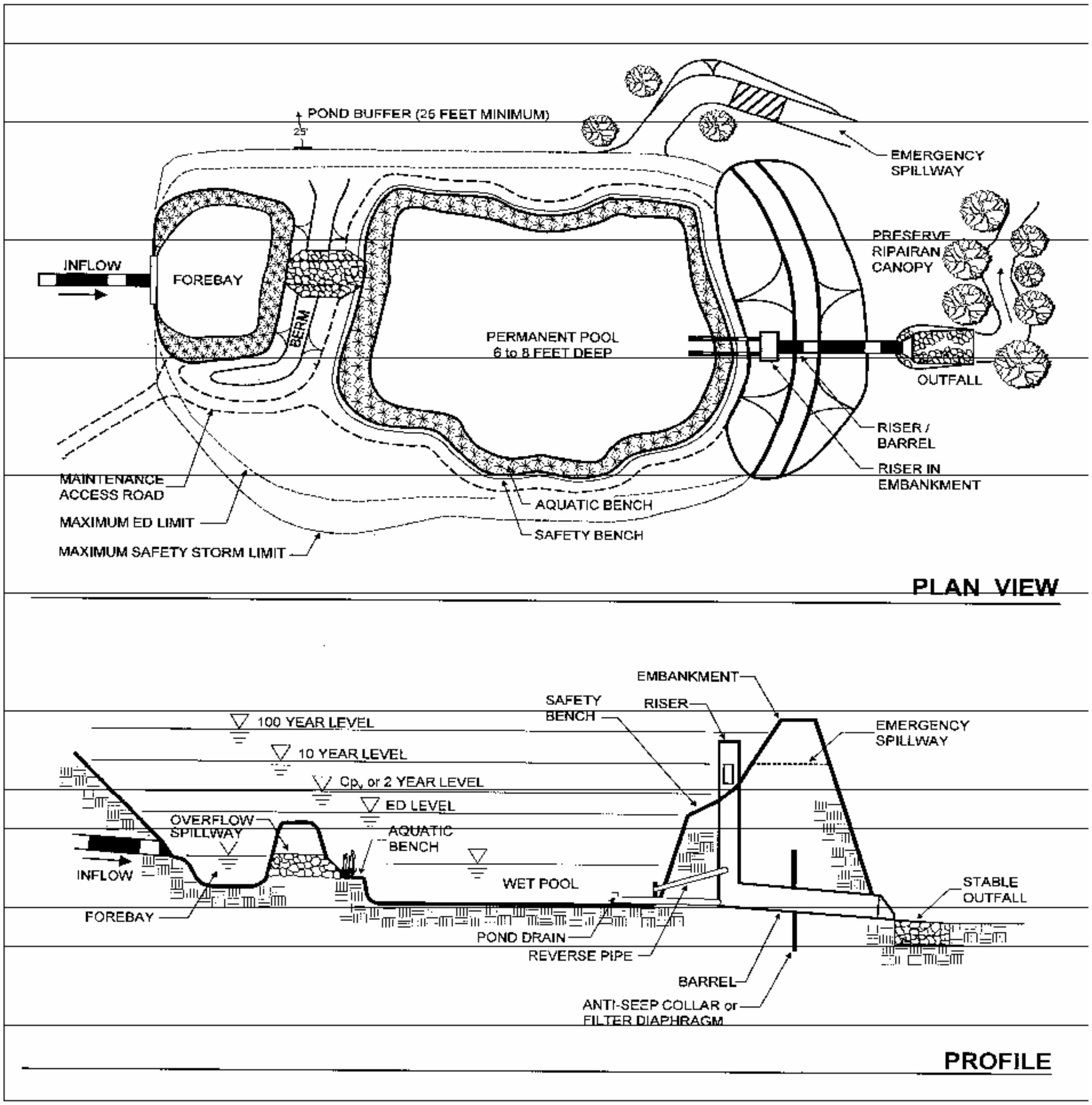
POND BUFFER (25 FEET MINIMUM)
25'
EMERGENCY SPILLWAY
PRESERVE RIPAIRAN CANOPY
INFLOW
FOREBAY
BERM
PERMANENT POOL 6 to 8 FEET DEEP
OUTFALL
RISER / BARREL
RISER IN EMBANKMENT
MAINTENANCE ACCESS ROAD
MAXIMUM ED LIMIT
MAXIMUM SAFETY STORM LIMIT
AQUATIC BENCH
SAFETY BENCH
PLAN VIEW
EMBANKMENT
SAFETY BENCH
RISER
EMERGENCY SPILLWAY
100 YEAR LEVEL
10 YEAR LEVEL
Cp_v or 2 YEAR LEVEL
ED LEVEL
OVERFLOW SPILLWAY
AQUATIC BENCH
INFLOW
WET POOL
FOREBAY
STABLE OUTFALL
POND DRAIN
REVERSE PIPE
BARREL
ANTI-SEEP COLLAR or FILTER DIAPHRAGM
PROFILE

Constructed Wetlands TC-21

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 stormwater practices in terms of pollutant removal and they also offer aesthetic value. As stormwater 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 stormwater.

California Experience

The City of Laguna Niguel in Orange County has constructed several wetlands, primarily to reduce bacteria concentrations in dry weather flows. The wetlands have been very successful in this regard. Even though there is not enough perennial flow to maintain the permanent pool at a constant elevation, the wetland vegetation has thrived.

Design Considerations

- Area Required
- Slope
- Water Availability
- Aesthetics
- Environmental Side-effects

Targeted Constituents

☑	Sediment	■
☑	Nutrients	▲
☑	Trash	■
☑	Metals	■
☑	Bacteria	■
☑	Oil and Grease	■
☑	Organics	■

Legend *(Removal Effectiveness)*

● Low ■ High

▲ Medium

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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 State Division of Safety of Dams

Design and Sizing Guidelines

- Capture volume determined by local requirements or sized to treat 85% of the annual runoff volume.
- 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 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 resuspension 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 seven meters or less in width. Those BMPs that have shoreline-to-shoreline distances in excess of seven meters should have perimeter road access on both sides or be designed such that no parcel of water is greater than seven meters 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 stormwater 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 stormwater 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 (e.g., golf courses).

Wetlands generally consume a fairly large area (typically 4-6 percent 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: (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 ha (25 ac.); (3) where base flow rates or other channel flow sources are relatively consistent year-round; (4) 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 (25-50% of the total area) no more than about 1.2 m (4 feet) 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 percent 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 microtopography." 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 5–7 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

(1) 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.

(2) 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 depth in the center of the basin should be about 4 feet deep to prevent vegetation from encroaching on the pond open water surface.

(3) 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.

(4) 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.

(5) 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.

(6) Vegetation - A plan should be prepared that indicates how aquatic and terrestrial areas will be vegetatively 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 California is presented in the wet pond fact sheet.

Maintenance

The amount of maintenance required for a constructed wetland is highly dependent on local regulatory agencies, 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 the Department of Fish and Game or other agency regulations, stock wet ponds/constructed wetlands regularly with mosquito fish (*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 5-7 years or when the accumulated sediment volume exceeds 10 percent 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 percent 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 using the equation:

$$C = 30.6^{V0.705}$$

where:

C = Construction, design, and permitting cost;

V = Wetland volume needed to control the 10-year storm (ft3).

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 percent 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.

Maintenance Cost

For ponds, the annual cost of routine maintenance has typically been estimated at about 3 to 5 percent 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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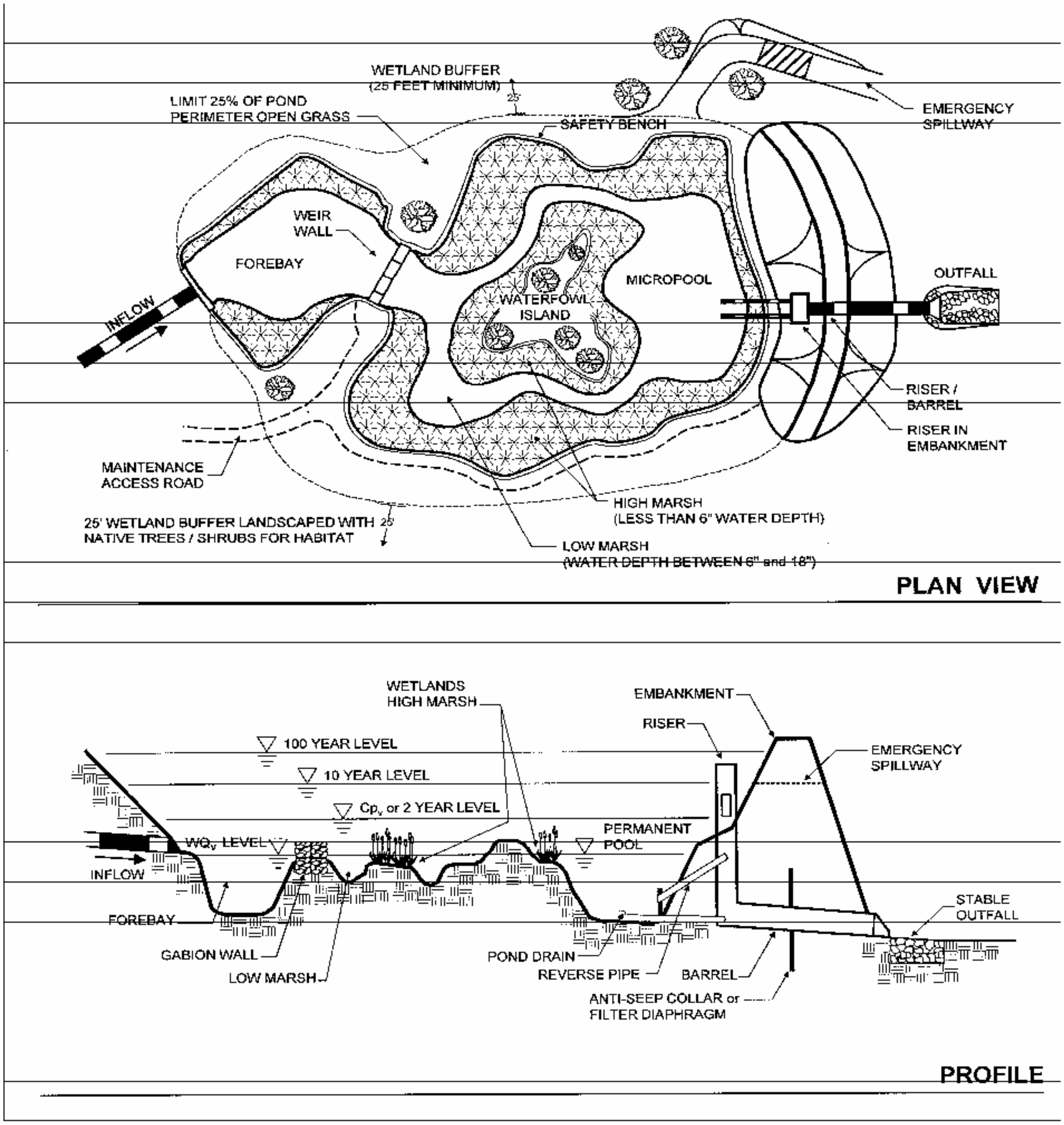
WETLAND BUFFER
(25 FEET MINIMUM)
25'
LIMIT 25% OF POND
PERIMETER OPEN GRASS
SAFETY BENCH
EMERGENCY
SPILLWAY
WEIR
WALL
FOREBAY
INFLOW
WATERFOWL
ISLAND
MICROPOOL
OUTFALL
RISER /
BARREL
RISER IN
EMBANKMENT
MAINTENANCE
ACCESS ROAD
HIGH MARSH
(LESS THAN 6" WATER DEPTH)
25' WETLAND BUFFER LANDSCAPED WITH
NATIVE TREES / SHRUBS FOR HABITAT
25'
LOW MARSH
(WATER DEPTH BETWEEN 6" and 18")
PLAN VIEW
WETLANDS
HIGH MARSH
EMBANKMENT
RISER
100 YEAR LEVEL
10 YEAR LEVEL
Cpv or 2 YEAR LEVEL
EMERGENCY
SPILLWAY
PERMANENT
POOL
WQv LEVEL
INFLOW
FOREBAY
GABION WALL
LOW MARSH
POND DRAIN
REVERSE PIPE
BARREL
STABLE
OUTFALL
ANTI-SEEP COLLAR or
FILTER DIAPHRAGM
PROFILE

Design Considerations

- Tributary Area
- Area Required
- Hydraulic Head

Description

Dry extended detention ponds (a.k.a. dry ponds, extended detention basins, detention ponds, extended detention ponds) are basins whose outlets have been designed to detain the stormwater runoff from a water quality design storm for some minimum time (e.g., 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.

California Experience

Caltrans constructed and monitored 5 extended detention basins in southern California with design drain times of 72 hours. Four 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 stormwater treatment.

Advantages

- Due to the simplicity of design, extended detention basins are relatively easy and inexpensive to construct and operate.
- Extended detention basins can provide substantial capture of sediment and the toxics 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

Targeted Constituents

☑	Sediment	▲
☑	Nutrients	●
☑	Trash	■
☑	Metals	▲
☑	Bacteria	▲
☑	Oil and Grease	▲
☑	Organics	▲

Legend *(Removal Effectiveness)*

● Low ■ High

▲ Medium

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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 5 acres (would require an orifice with a diameter of less than 0.5 inches that would be prone to clogging).
- Dry extended detention ponds have only moderate pollutant removal when compared to some other structural stormwater practices, and they are relatively ineffective at removing soluble pollutants.
- Although wet ponds can increase property values, dry ponds 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 local requirements or sized to treat 85% of the annual runoff volume.
- Outlet designed to discharge the capture volume over a period of hours.
- Length to width ratio of at least 1.5:1 where feasible.
- Basin depths optimally range from 2 to 5 feet.
- Include energy dissipation in the inlet design to reduce resuspension of accumulated sediment.
- 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 48 hours in most areas of California. 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 determined to downstream fisheries.

Construction/Inspection Considerations

- Inspect facility after first large to 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 objective of stormwater management practices can be to reduce the flood hazard associated with large storm events by reducing the peak flow associated with these storms. Dry extended detention basins can easily be designed for flood control, and this is actually the primary purpose of most detention ponds.

Dry extended 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 dry extended detention ponds including one recently concluded by Caltrans (2002).

The load reduction is greater than the concentration reduction because of the substantial infiltration that occurs. Although the infiltration of stormwater 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 percent of the runoff entering the unlined basins infiltrated and was not discharged. The percentage ranged from a high of about 60 percent to a low of only about 8 percent 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. Conversely, the most infiltration occurred at a facility located well inland in Los Angeles County where the climate is much warmer and the humidity is less, resulting in lower soil moisture content in the basin floor at the beginning of storms.

Vegetated detention basins appear to have greater pollutant removal than concrete basins. In the 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

Dry extended detention ponds are among the most widely applicable stormwater 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 dry extended detention ponds 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 dry extended detention ponds.

In general, dry extended detention ponds should be used on sites with a minimum area of 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.

Extended 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, extended detention ponds may need an impermeable liner to prevent ground water contamination.

The base of the extended 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 dry extended detention ponds, produce more mosquitoes than other pond systems, particularly when the facilities remained wet for more than 3 days following heavy rainfall.

A study in Prince George's County, Maryland, found that stormwater management practices can increase stream temperatures (Galli, 1990). Overall, dry extended detention ponds increased temperature by about 5°F. In cold water streams, dry ponds should be designed to detain stormwater for a relatively short time (i.e., 24 hours) to minimize the amount of warming that occurs in the basin.

Additional Design Guidelines

In order to enhance the effectiveness of extended 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 pond configuration, and aesthetics (Young et al., 1996).

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

Extended detention facilities should be sized to completely capture the water quality volume. A micropool is often recommended for inclusion 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 for use in California.

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 1.5:1 (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. The outlet design implemented by Caltrans in the facilities constructed in San Diego County used an outlet riser with orifices

Figure 1
Example of Extended Detention Outlet Structure

sized to discharge the water quality volume, and 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 Figure 1.

The outflow structure should be sized to allow for complete drawdown of the water quality volume in 72 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.

Summary of Design Recommendations

(1) Facility Sizing - The required water quality volume is determined by local regulations or the basin should be sized to capture and treat 85% of the annual runoff volume. See Section 5.5.1 of the handbook for a discussion of volume-based design.

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 1.5:1 (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.

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 25-year event and to safely pass the flow from 100-year storm.

(2) Pond Side Slopes - Side slopes of the pond should be 3:1 (H:V) or flatter for grass stabilized slopes. Slopes steeper than 3:1 (H:V) must be stabilized with an appropriate slope stabilization practice.

(3) Basin Lining – Basins must be constructed to prevent possible contamination of groundwater below the facility.

(4) Basin Inlet – Energy dissipation is required at the basin inlet to reduce resuspension of accumulated sediment and to reduce the tendency for short-circuiting.

(5) 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 outflow structure should be sized to allow for complete drawdown of the water quality volume in 72 hours. No more than 50% of the water quality volume should drain from the facility within the first 24 hours. The outflow structure should be fitted with a valve so that discharge from the basin can be halted in case of an accidental spill in the watershed. This same valve also can be used to regulate the rate of discharge from the basin.

The discharge through a control orifice is calculated from:

$$Q = CA(2gH-H_o)^{0.5}$$

where: Q = discharge (ft^3/s)
C = orifice coefficient
A = area of the orifice (ft^2)
g = gravitational constant (32.2)
H = water surface elevation (ft)
H_o= orifice elevation (ft)

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 pond 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_o. When using multiple orifices the discharge from each is summed.

(6) Splitter Box - When the pond 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 25-year storm event while providing at least 1.0 foot of freeboard along pond side slopes.

(7) 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 pond 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.

(8) Safety Considerations - Safety is provided either by fencing of the facility or by managing the contours of the pond 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. During a recent study by Caltrans, 72 hours of maintenance was performed annually, but only a little over 7 hours was spent on sediment and trash removal. The largest recurring activity was vegetation management, routine mowing. The largest absolute number of hours was associated with vector control because of mosquito breeding that occurred in the stilling basins (example of standing water to be avoided) installed as energy dissipaters. In most cases, basic housekeeping practices such as removal of debris accumulations and vegetation management to ensure that the basin dewaters completely in 48-72 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 regrade about every 10 years or when the accumulated sediment volume exceeds 10 percent of the basin volume. Inspect the basin each year for accumulated sediment volume.

Cost

Construction Cost

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

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

where: C = Construction, design, and permitting cost, and
V = Volume (ft^3).

Using this equation, typical construction costs are:

$ 41,600 for a 1 acre-foot pond

$ 239,000 for a 10 acre-foot pond

$ 1,380,000 for a 100 acre-foot pond

Interestingly, these costs are generally slightly higher than the predicted cost of wet ponds (according to Brown and Schueler, 1997) on a cost per total volume basis, which highlights the difficulty of developing reasonably accurate construction estimates. In addition, a typical facility constructed by Caltrans cost about $160,000 with a capture volume of only 0.3 ac-ft.

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

Maintenance Cost

For ponds, the annual cost of routine maintenance is typically estimated at about 3 to 5 percent of the construction cost (EPA website). Alternatively, a community can estimate the cost of the maintenance activities outlined in the maintenance section. Table 1 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).

Table 1 Estimated Average Annual Maintenance Effort

Activity	Labor Hours	Equipment & Material ($)	Cost
Inspections	4	7	183
Maintenance	49	126	2282
Vector Control	0	0	0
Administration	3	0	132
Materials	-	535	535
Total	**56**	**$668**	**$3,132**

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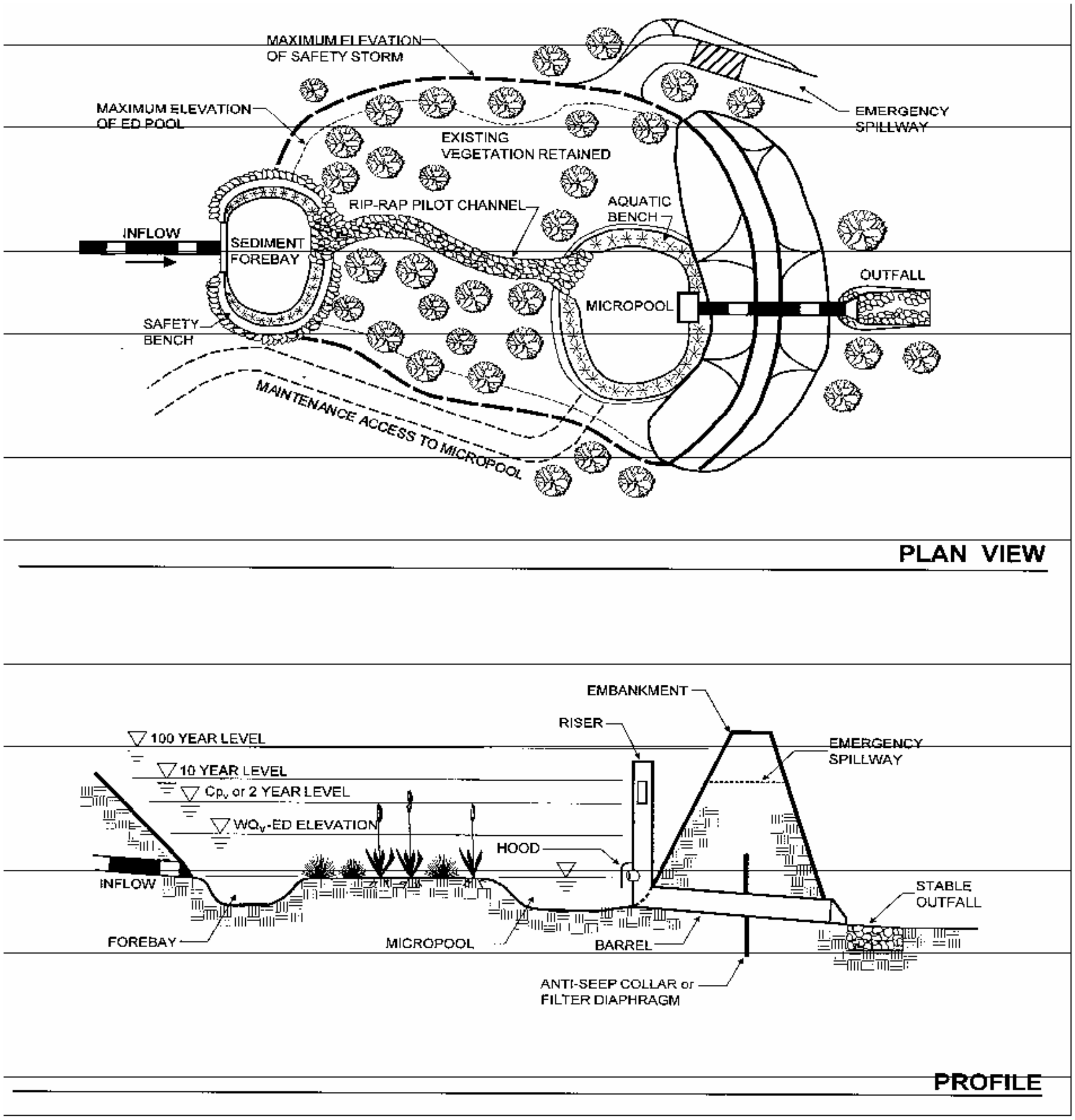

Schematic of an Extended Detention Basin (MDE, 2000)

Vegetated Swale TC-30

Design Considerations

- Tributary Area
- Area Required
- Slope
- Water Availability

Targeted Constituents

☑	Sediment	▲
☑	Nutrients	●
☑	Trash	●
☑	Metals	▲
☑	Bacteria	●
☑	Oil and Grease	▲
☑	Organics	▲

Legend *(Removal Effectiveness)*

● Low ■ High

▲ Medium

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 stormwater runoff. Vegetated swales can serve as part of a stormwater drainage system and can replace curbs, gutters and storm sewer systems.

California Experience

Caltrans constructed and monitored six vegetated swales in southern California. These swales were generally effective in reducing the volume and mass of pollutants in runoff. Even in the areas where the annual rainfall was only about 10 inches/yr, the vegetation did not require additional irrigation. One factor that strongly affected performance was the presence of large numbers of gophers at most of the sites. The gophers created earthen mounds, destroyed vegetation, and generally reduced the effectiveness of the controls for TSS reduction.

Advantages

- 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.

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- Roadside ditches should be regarded as significant potential swale/buffer strip sites and should be utilized for this purpose whenever possible.

Limitations

- Can be difficult to avoid channelization.
- May not be appropriate for industrial sites or locations where spills may occur
- 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.
- They are not effective and may even erode when flow velocities are high, if the grass cover is not properly maintained.
- In some places, their use is restricted by law: many local municipalities require curb and gutter systems in residential areas.
- Swales are mores susceptible to failure if not properly maintained than other treatment BMPs.

Design and Sizing Guidelines

- Flow rate based design determined by local requirements or sized so that 85% of the annual runoff volume is discharged at less than the design rainfall intensity.
- Swale should be designed so that the water level does not exceed 2/3rds the height of the grass or 4 inches, which ever is less, at the design treatment rate.
- Longitudinal slopes should not exceed 2.5%
- Trapezoidal channels are normally recommended but other configurations, such as parabolic, can also provide substantial water quality improvement and may be easier to mow than designs with sharp breaks in slope.
- Swales constructed in cut are preferred, or in fill areas that are far enough from an adjacent slope to minimize the potential for gopher damage. Do not use side slopes constructed of fill, which are prone to structural damage by gophers and other burrowing 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 are 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 0.25 for Manning's n.

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

The literature suggests that 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, frozen ground, 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 percent. However, the swale proved largely ineffective for removing soluble nutrients.

The effectiveness of vegetated swales can be enhanced by adding check dams at approximately 17 meter (50 foot) increments along their length (See Figure 1). 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.

Only 9 studies have been conducted on all grassed channels designed for water quality (Table 1). The data suggest relatively high removal rates for some pollutants, but negative removals for some bacteria, and fair performance for phosphorus.

Table 1 Grassed swale pollutant removal efficiency data

	Removal Efficiencies (% Removal)						
Study	**TSS**	**TP**	**TN**	**NO_3**	**Metals**	**Bacteria**	**Type**
Caltrans 2002	77	8	67	66	83-90	-33	dry swales
Goldberg 1993	67.8	4.5	-	31.4	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	67	39	-	9	-35 to 6	-	wet swale

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 2 and 6 percent. 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 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 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.

Summary of Design Recommendations

1) The swale should have a length that provides a minimum hydraulic residence time of at least 10 minutes. The maximum bottom width should not exceed 10 feet unless a dividing berm is provided. The depth of flow should not exceed 2/3rds the height of the grass at the peak of the water quality design storm intensity. The channel slope should not exceed 2.5%.

2) A design grass height of 6 inches is recommended.

3) Regardless of the recommended detention time, the swale should be not less than 100 feet in length.

4) 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 0.25.

5) 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." The side slopes should be no steeper than 3:1 (H:V).

6) 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.

7) 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

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 (e.g., silt, grass cuttings) must be disposed in accordance with local or State 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 to schedule summer maintenance and before major fall runoff to be sure the swale is ready for winter. However, additional inspection after periods of heavy runoff is desirable. The swale should be checked for debris and litter, and areas of sediment accumulation.

- 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 in.) 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 (e.g. debris accumulation, invasive vegetation) and/or if proper drainage slopes are not implemented and maintained.

Cost

Construction Cost

Little data is available to estimate the difference in cost between various swale designs. One study (SWRPC, 1991) estimated the construction cost of grassed channels at approximately \$0.25 per ft^2. This price does not include design costs or contingencies. Brown and Schueler (1997) estimate these costs at approximately 32 percent of construction costs for most stormwater 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 ft^2, which compares favorably with other stormwater management practices.

Table 2 Swale Cost Estimate (SEWRPC, 1991)

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}	Yd^{3}	372	$2.10	$3.70	$5.30	$761	$1,376	$1,972
Level and Till^{e}	Yd^{2}	1,210	$0.20	$0.35	$0.50	$242	$424	$605
Sites Development								
Salvaged Topsoil Seed, and Mulch^{f}	Yd^{2}	1,210	$0.40	$1.00	$1.60	$464	$1,210	$1,936
Sod^{g}	Yd^{2}	1,210	$1.20	$2.40	$3.60	$1,452	$2,904	$4,356
Subtotal	--	–	--	–	--	$5,116	$9,386	$13,660
Contingencies	Swale	1	25%	25%	25%	$1,279	$2,347	$3,415
Total	--	–	--	–	--	$6,395	$11,735	$17,075

Source: (SEWRPC, 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 = $\left(\text{top width} + \frac{8(\text{swale depth}^2)}{3(\text{top width})}\right)$ x swale length (parabolic cross-section).

[f] Area seeded = area cleared x 0.5.

[g] Area sodded = area cleared x 0.5.

Table 3 Estimated Maintenance Costs (SEWRPC, 1991)

Component	Unit Cost	Swale Size (Depth and Top Width)		Comment
		1.5 Foot Depth, One-Foot Bottom Width, 10-Foot Top Width	3-Foot Depth, 3-Foot Bottom Width, 21-Foot Top Width	
Lawn Mowing	$0.85 / 1,000 ft^2/ mowing	$0.14 / linear foot	$0.21 / linear foot	Lawn maintenance area=(top width + 10 feet) x length. Mow eight times per year
General Lawn Care	$9.00 / 1,000 ft^2/ year	$0.18 / linear foot	$0.28 / linear foot	Lawn maintenance area = (top width + 10 feet) x length
Swale Debris and Litter Removal	$0.10 / linear foot / year	$0.10 / linear foot	$0.10 / linear foot	–
Grass Reseeding with Mulch and Fertilizer	$0.30 / yd^2	$0.01 / linear foot	$0.01 / linear foot	Area revegetated equals 1% of lawn maintenance area per year
Program Administration and Swale Inspection	$0.15 / linear foot / year, plus $25 / inspection	$0.15 / linear foot	$0.15 / linear foot	Inspect four times per year
Total	--	**$0.58 / linear foot**	**$ 0.75 / linear foot**	--

Maintenance Cost

Caltrans (2002) estimated the expected annual maintenance cost for a swale with a tributary area of approximately 2 ha 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 Table 3. 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.

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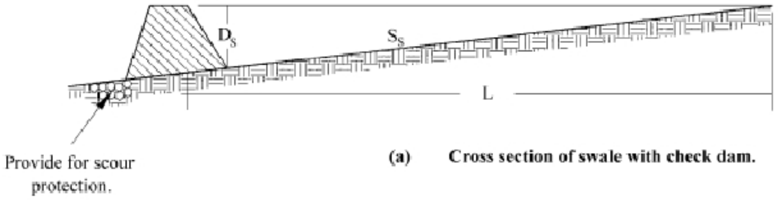
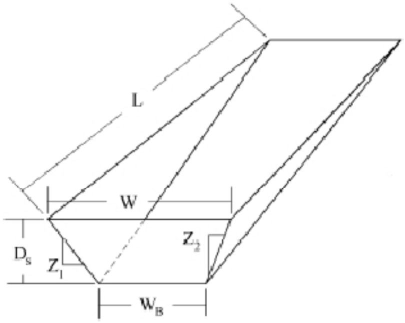


(a) **Cross section of swale with check dam.**



(b) **Dimensional view of swale impoundment area.**

Notation:

L = Length of swale impoundment area per check dam (ft)
D_S = Depth of check dam (ft)
S_S = Bottom slpe of swale (ft/ft)
W = Top width of check dam (ft)
W_B = Bottom width of check dam (ft)
$Z_{1\&2}$ = Ratio of horizontal to vertical change in swale side slope (ft/ft)

Design Considerations

- Tributary Area
- Slope
- Water Availability
- Aesthetics

Targeted Constituents

☑	Sediment	■
☑	Nutrients	●
☑	Trash	▲
☑	Metals	■
☑	Bacteria	●
☑	Oil and Grease	■
☑	Organics	▲

Legend *(Removal Effectiveness)*

● Low ■ High

▲ Medium

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 stormwater infrastructure. Consequently, there is little resistance to their use.

California Experience

Caltrans constructed and monitored three vegetated buffer strips in southern California and is currently evaluating their performance at eight additional sites statewide. These strips were generally effective in reducing the volume and mass of pollutants in runoff. Even in the areas where the annual rainfall was only about 10 inches/yr, the vegetation did not require additional irrigation. One factor that strongly affected performance was the presence of large numbers of gophers at most of the southern California sites. The gophers created earthen mounds, destroyed vegetation, and generally reduced the effectiveness of the controls for TSS reduction.

Advantages

- 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.

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- 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 below.

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.
- 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 60 feet.
- Slopes should not exceed 15%.
- Minimum length (in direction of flow) is 15 feet.
- Width should be the same as the tributary area.
- 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.

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 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.

Performance

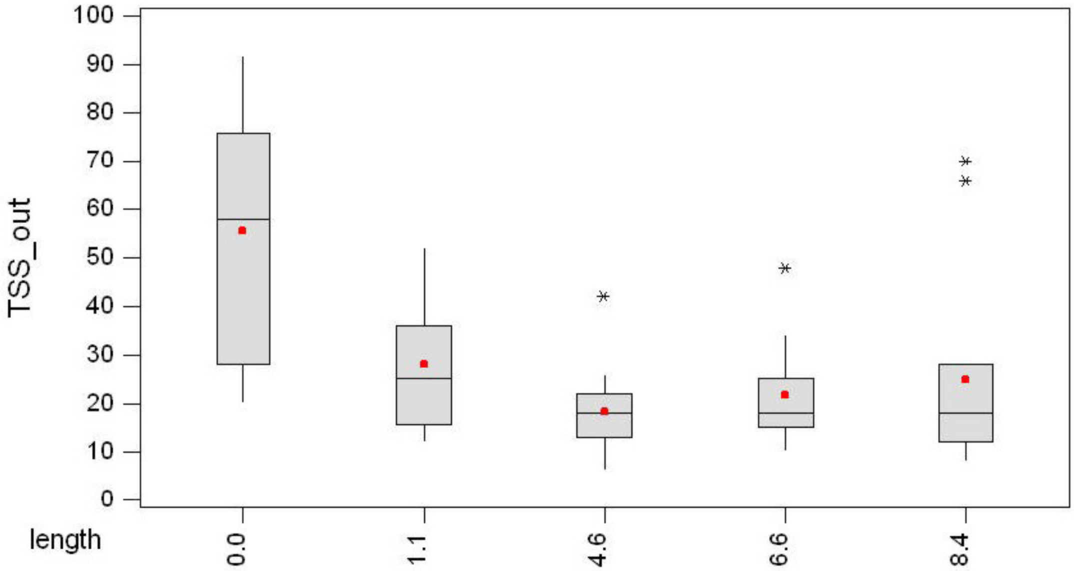
Vegetated buffer strips tend to provide somewhat better treatment of stormwater runoff than swales and have fewer tendencies for channelization or erosion. Table 1 documents the pollutant removal observed in a recent study by Caltrans (2002) based on three sites in southern California. The column labeled "Significance" is the probability that the mean influent and effluent EMCs are not significantly different based on an analysis of variance.

The removal of sediment and dissolved metals was comparable to that observed in much more complex controls. Reduction in nitrogen was not significant and all of the sites exported phosphorus for the entire study period. This may have been the result of using salt grass, a warm weather species that is dormant during the wet season, and which leaches phosphorus when dormant.

Another Caltrans study (unpublished) of vegetated highway shoulders as buffer strips also found substantial reductions often within a very short distance of the edge of pavement. Figure 1 presents a box and whisker plot of the concentrations of TSS in highway runoff after traveling various distances (shown in meters) through a vegetated filter strip with a slope of about 10%. One can see that the TSS median concentration reaches an irreducible minimum concentration of about 20 mg/L within 5 meters of the pavement edge.

Table 1 Pollutant Reduction in a Vegetated Buffer Strip

Constituent	Mean EMC		Removal %	Significance
	Influent (mg/L)	Effluent (mg/L)		P
TSS	119	31	74	<0.000
NO_3-N	0.67	0.58	13	0.367
TKN-N	2.50	2.10	16	0.542
Total N[a]	3.17	2.68	15	-
Dissolved P	0.15	0.46	-206	0.047
Total P	0.42	0.62	-52	0.035
Total Cu	0.058	0.009	84	<0.000
Total Pb	0.046	0.006	88	<0.000
Total Zn	0.245	0.055	78	<0.000
Dissolved Cu	0.029	0.007	77	0.004
Dissolved Pb	0.004	0.002	66	0.006
Dissolved Zn	0.099	0.035	65	<0.000



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 percent or be less than 1 percent. 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 a 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.

Some cold water species, such as trout, are sensitive to changes in temperature. While some treatment practices, such as wet ponds, can warm stormwater substantially, filter strips do not are not expected to increase stormwater temperatures. Thus, these practices are good for protection of cold-water streams.

Filter strips should be separated from the ground water by between 2 and 4 ft 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. In general the slope of the strip should not exceed 15fc% and the strip should be at least 15 feet long to provide water quality treatment. 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 2-5 inches below the adjacent pavement, so that vegetation and sediment accumulation at the edge of the strip does not prevent runoff from entering.

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 about 1 fps 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.

In cold climates, filter strips provide a convenient area for snow storage and treatment. If used for this purpose, vegetation in the filter strip should be salt-tolerant (e.g., creeping bentgrass), and a maintenance schedule should include the removal of sand built up at the bottom of the slope. In arid or semi-arid climates, designers should specify drought-tolerant grasses to minimize irrigation requirements.

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, preferably at the end of the wet season to schedule summer maintenance and before major fall run-off to be sure the strip is ready for winter. However, additional inspection after periods of heavy run-off is most desirable. 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 48-72 hours), in pools of standing water if obstructions develop (e.g. debris accumulation, invasive vegetation), and/or if proper drainage slopes are not implemented and maintained.

Cost

Construction Cost

Little data is available on the actual construction costs of filter strips. One rough estimate can be the cost of seed or sod, which is approximately 30¢ per ft^2 for seed or 70¢ per ft^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 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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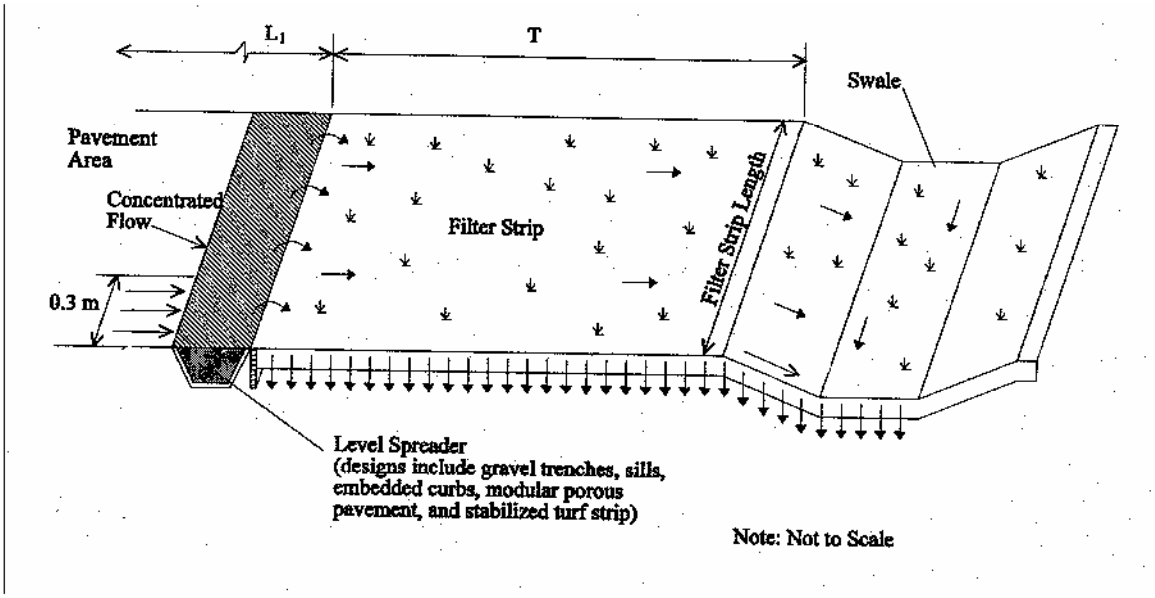
L1
T
Swale
Pavement Area
Concentrated Flow
Filter Strip
Filter Strip Length
0.3 m
Level Spreader
(designs include gravel trenches, sills, embedded curbs, modular porous pavement, and stabilized turf strip)
Note: Not to Scale

Bioretention TC-32

Design Considerations

- Soil for Infiltration
- Tributary Area
- Slope
- Aesthetics
- Environmental Side-effects

Targeted Constituents

☑	Sediment	■
☑	Nutrients	▲
☑	Trash	■
☑	Metals	■
☑	Bacteria	■
☑	Oil and Grease	■
☑	Organics	■

Legend *(Removal Effectiveness)*

● Low ■ High

▲ Medium

Description

The bioretention best management practice (BMP) functions as a soil and plant-based filtration device that removes pollutants through a variety of physical, biological, and chemical treatment processes. 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. Exfiltration of the stored water in the bioretention area planting soil into the underlying soils occurs over a period of days.

California Experience

None documented. Bioretention has been used as a stormwater BMP since 1992. In addition to Prince George's County, MD and Alexandria, VA, bioretention has 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

- Bioretention provides stormwater 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.

Limitations

- The bioretention 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).

- Bioretention is 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, bioretention 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.
- In cold climates the soil may freeze, preventing runoff from infiltrating into the planting soil.

Design and Sizing Guidelines

- The bioretention area should be sized to capture the design storm runoff.
- In areas where the native soil permeability is less than 0.5 in/hr 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 72 hours.
- Approximately 1 tree or shrub per 50 ft^2 of bioretention area should be included.
- Cover area with about 3 inches of mulch.

Construction/Inspection Considerations

Bioretention area should not be established until contributing watershed is stabilized.

Performance

Bioretention removes stormwater 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 (e.g., 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 bioretention area media, such as the sand bed, ground cover, and planting soil.

Common particulates removed from stormwater 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 bioretention area is not adequately aerated. Sedimentation occurs in the swale or ponding area as the velocity slows and solids fall out of suspension.

The removal effectiveness of bioretention has been studied during field and laboratory studies conducted by the University of Maryland (Davis et al, 1998). During these experiments, synthetic stormwater runoff was pumped through several laboratory and field bioretention areas to simulate typical storm events in Prince George's County, MD. Removal rates for heavy metals and nutrients are shown in Table 1.

Table 1 Laboratory and Estimated Bioretention Davis et al. (1998); PGDER (1993)

Pollutant	Removal Rate
Total Phosphorus	70-83%
Metals (Cu, Zn, Pb)	93-98%
TKN	68-80%
Total Suspended Solids	90%
Organics	90%
Bacteria	90%

Results for both the laboratory and field experiments were similar for each of the pollutants analyzed. Doubling or halving the influent pollutant levels had little effect on the effluent pollutants concentrations (Davis et al, 1998).

The microbial activity and plant uptake occurring in the bioretention area will likely result in higher removal rates than those determined for infiltration BMPs.

Siting Criteria

Bioretention BMPs are generally used to treat stormwater from impervious surfaces at commercial, residential, and industrial areas (EPA, 1999). Implementation of bioretention for stormwater 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 bioretention area or convey into the bioretention area by a curb and gutter collection system.

The best location for bioretention areas 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 bioretention area can be readily incorporated into the site plan without further environmental damage are preferred. Furthermore, to effectively minimize sediment loading in the treatment area, bioretention only should be used in stabilized drainage areas.

Additional Design Guidelines

The layout of the bioretention area 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 bioretention because the excavated soil can be backfilled and used as the planting soil, thus eliminating the cost of importing planting soil.

The use of bioretention may not be feasible given an unstable surrounding soil stratum, soils with clay content greater than 25 percent, a site with slopes greater than 20 percent, and/or a site with mature trees that would be removed during construction of the BMP.

Bioretention can be designed to be off-line or on-line of the existing drainage system (EPA, 1999). The drainage area for a bioretention area should be between 0.1 and 0.4 hectares (0.25 and 1.0 acres). Larger drainage areas may require multiple bioretention areas. Furthermore, the maximum drainage area for a bioretention area is determined by the expected rainfall intensity and runoff rate. Stabilized areas may erode when velocities are greater than 5 feet per second (1.5 meter per second). The designer should determine the potential for erosive conditions at the site.

The size of the bioretention area, 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 bioretention area 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 bioretention area 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. The preferred width is 25 feet (7.6 meters), with a length of twice the width. Essentially, any facilities wider than 20 feet (6.1 meters) should be twice as long as they are wide, which promotes the distribution of flow and decreases the chances of concentrated flow.

In order to provide adequate storage and prevent water from standing for excessive periods of time the ponding depth of the bioretention area should not exceed 6 inches (15 centimeters). Water should not be left to stand for more than 72 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 bioretention area. Planting soils should be sandy loam, loamy sand, or loam texture with a clay content ranging from 10 to 25 percent.

Generally the soil should have infiltration rates greater than 0.5 inches (1.25 centimeters) per hour, which is typical of sandy loams, loamy sands, or loams. The pH of the soil should range between 5.5 and 6.5, where pollutants such as organic nitrogen and phosphorus can be adsorbed by the soil and microbial activity can flourish. Additional requirements for the planting soil include a 1.5 to 3 percent 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 bioretention area (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 bioretention area 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 2500 trees and shrubs per hectare (1000 per acre). For instance, a 15 foot (4.6 meter) by 40 foot (12.2 meter) bioretention area (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 fourteen days following its planting. Plant species tolerant of pollutant loads and varying wet and dry conditions should be used in the bioretention area.

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 bioretention area. Regional landscaping manuals should be consulted to ensure that the planting of the bioretention area meets the landscaping requirements established by the local authorities. The designers should evaluate the best placement of vegetation within the bioretention area. 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. Two to 3 inches (5 to 7.6 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 bioretention areas 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 bioretention cell. Appropriately selected plants will aide in reducing fertilizer, pesticide, water, and overall maintenance requirements. Bioretention 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 biannual 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, bioretention BMPs 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 to three 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 bioretention 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 5-10 years of construction (LID, 2000).

Cost

Construction Cost

Construction cost estimates for a bioretention area 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 bioretention areas average about $3 to $4 per square foot, 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 foot, based on the need for control structures, curbing, storm drains and underdrains.

Retrofitting a site typically costs more, averaging $6,500 per bioretention area. 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 bioretention areas were estimated at $111,600.

In any bioretention area 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 bioretention installation should be subtracted when determining the net cost.

Perhaps of most importance, however, the cost savings compared to the use of traditional structural stormwater conveyance systems makes bioretention areas quite attractive financially. For example, the use of bioretention can decrease the cost required for constructing stormwater 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 bioretention cells on each lot instead of nearly $400,000 for the traditional stormwater ponds that were originally planned (Rappahanock,). Also, in residential areas, stormwater 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 bioretention facility 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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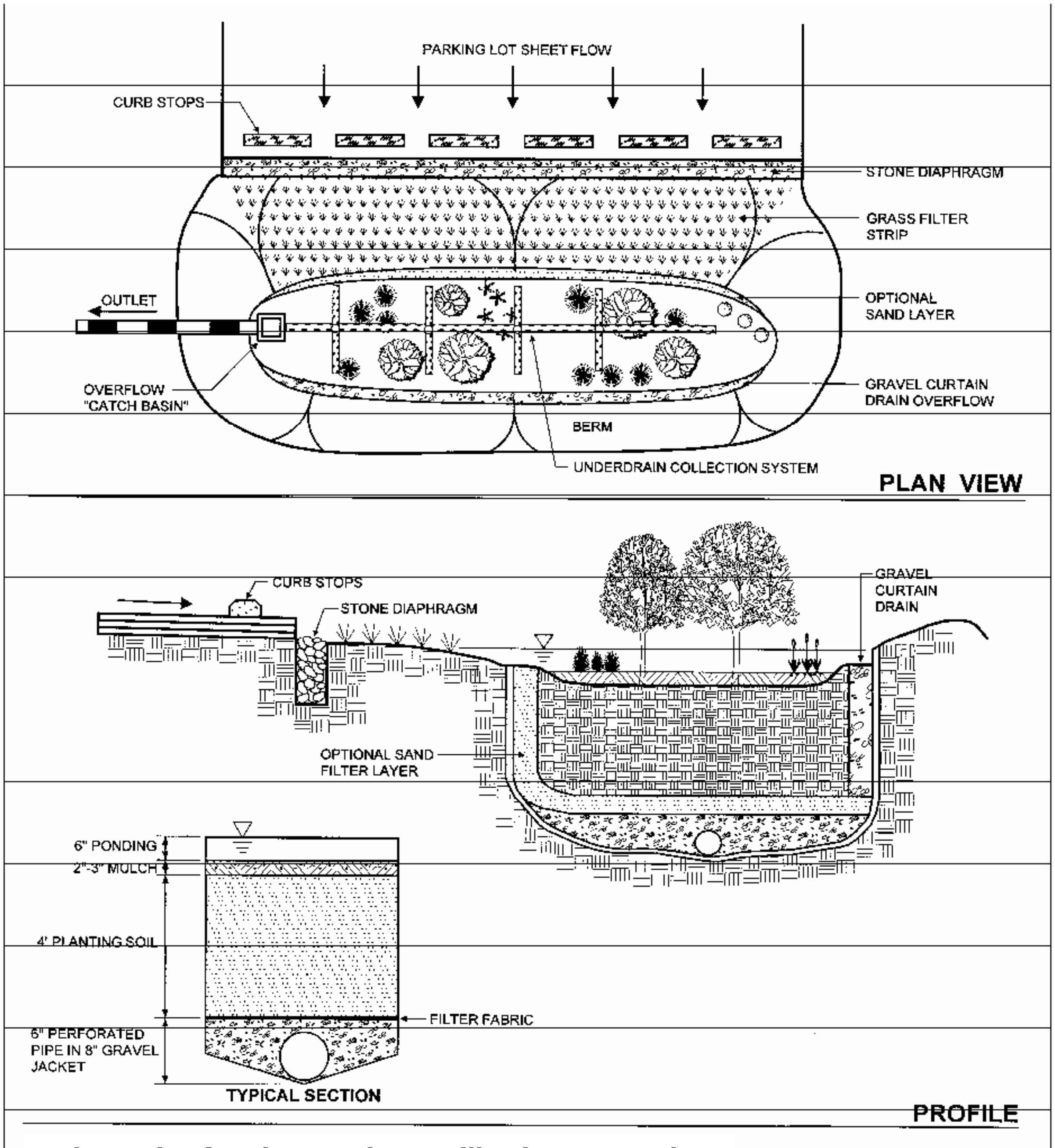


Schematic of a Bioretention Facility (MDE, 2000)

Media Filter TC-40

Design Considerations

- ■ Aesthetics
- ■ Hydraulic Head

Targeted Constituents

☑	Sediment	■
☑	Nutrients	●
☑	Trash	■
☑	Metals	■
☑	Bacteria	▲
☑	Oil and Grease	■
☑	Organics	■

Legend ***(Removal Effectiveness)***

● Low	■ High
▲ Medium	

Description

Stormwater media filters are usually two-chambered including a pretreatment settling basin and a filter bed filled with sand or other absorptive filtering media. As stormwater flows into the first chamber, large particles settle out, and then finer particles and other pollutants are removed as stormwater 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).

California Experience

Caltrans constructed and monitored five Austin sand filters, two MCTTs, and one 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 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 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 (e.g., MCTT and Delaware filter) maintain permanent sources of standing water where mosquito and midge breeding is likely to occur.

Design and Sizing Guidelines

- Capture volume determined by local requirements or sized to treat 85% of the annual runoff volume.
- 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 resuspension 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 stormwater 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. Figure 4 presents a graph relating influent and effluent TSS concentrations for the Austin full sedimentation design.

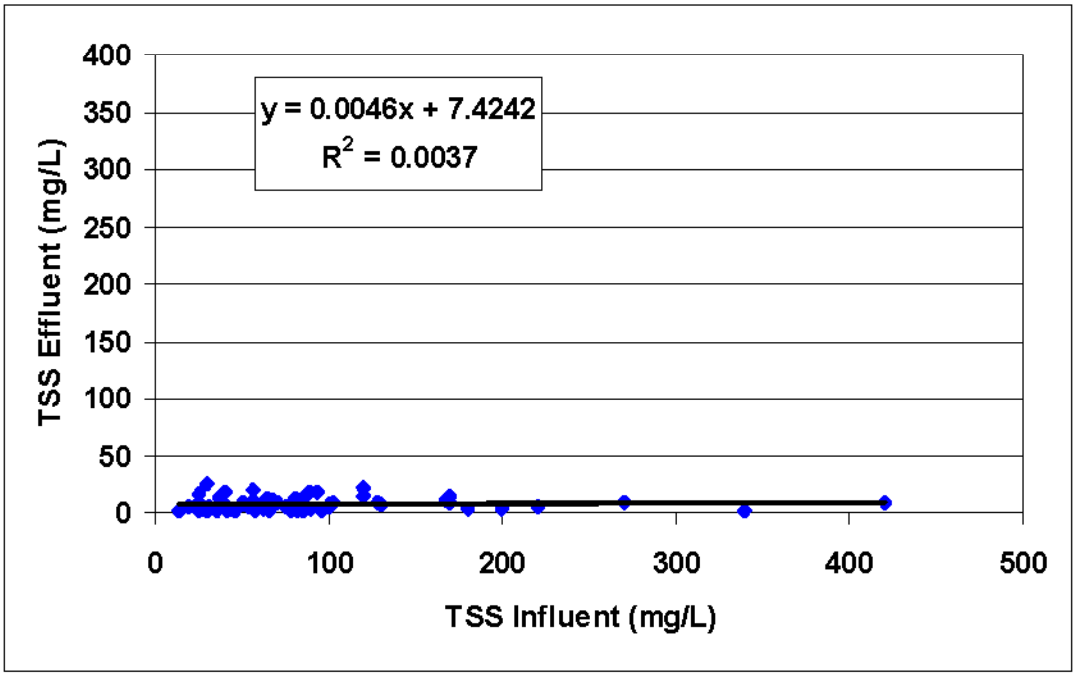


Figure 4
Comparison of Influent and Effluent Concentrations for TSS

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 stormwater.

Sand filters are effective stormwater management practices for pollutant removal. Conventional removal rates for all sand filters and organic filters are presented in Table 1. 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.

Table 1 Sand filter removal efficiencies (percent)

	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	17	-	-	-	-	-
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.

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 stormwater 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 stormwater 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 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

$$Af = WQV\ d/[k\ t\ (h+d)]$$

Where:

Af = area of the filter bed (ft^2);

d = depth of the filter bed (ft; usually about 1.5 feet, depending on the design);

k = coefficient of permeability of the filtering medium (ft/day);

t = time for the water quality volume to filter through the system (days; usually assumed to be 1.67 days); and

h = average water height above the sand bed (ft; assumed to be one-half of the maximum head).

Typical values for k, as assembled by CWP (1996), are shown in Table 2.

Table 2 Coefficient of permeability values for stormwater filtering practices (CWP, 1996)

Filter Medium	Coefficient of Permeability (ft/day)
Sand	3.5
Peat/Sand	2.75
Compost	8.7

The permeability of sand shown in Table 2 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 ft/d) 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

$$Af = WQV/18$$

If no pretreatment is provided then the filter area is calculated more conservatively as:

$$Af = WQV/10$$

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

(1) Capture Volume - The facility should be sized to capture the required water quality volume, preferably in a separate pretreatment sedimentation basin.

(2) 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 (Af) is calculated from the following equation:

$$Af = WQV/18$$

If no pretreatment is provided then the filter area is calculated as:

$$Af = WQV/10$$

(3) 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. Figure 5 presents a schematic representation of a standard sand bed profile.

(4) 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.

(5) 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.

(6) Flow Splitter - The inflow structure to the sedimentation chamber should incorporate a flow-splitting device capable of isolating the capture volume and bypassing the 25-year peak flow around the facility with the sedimentation/filtration pond full.

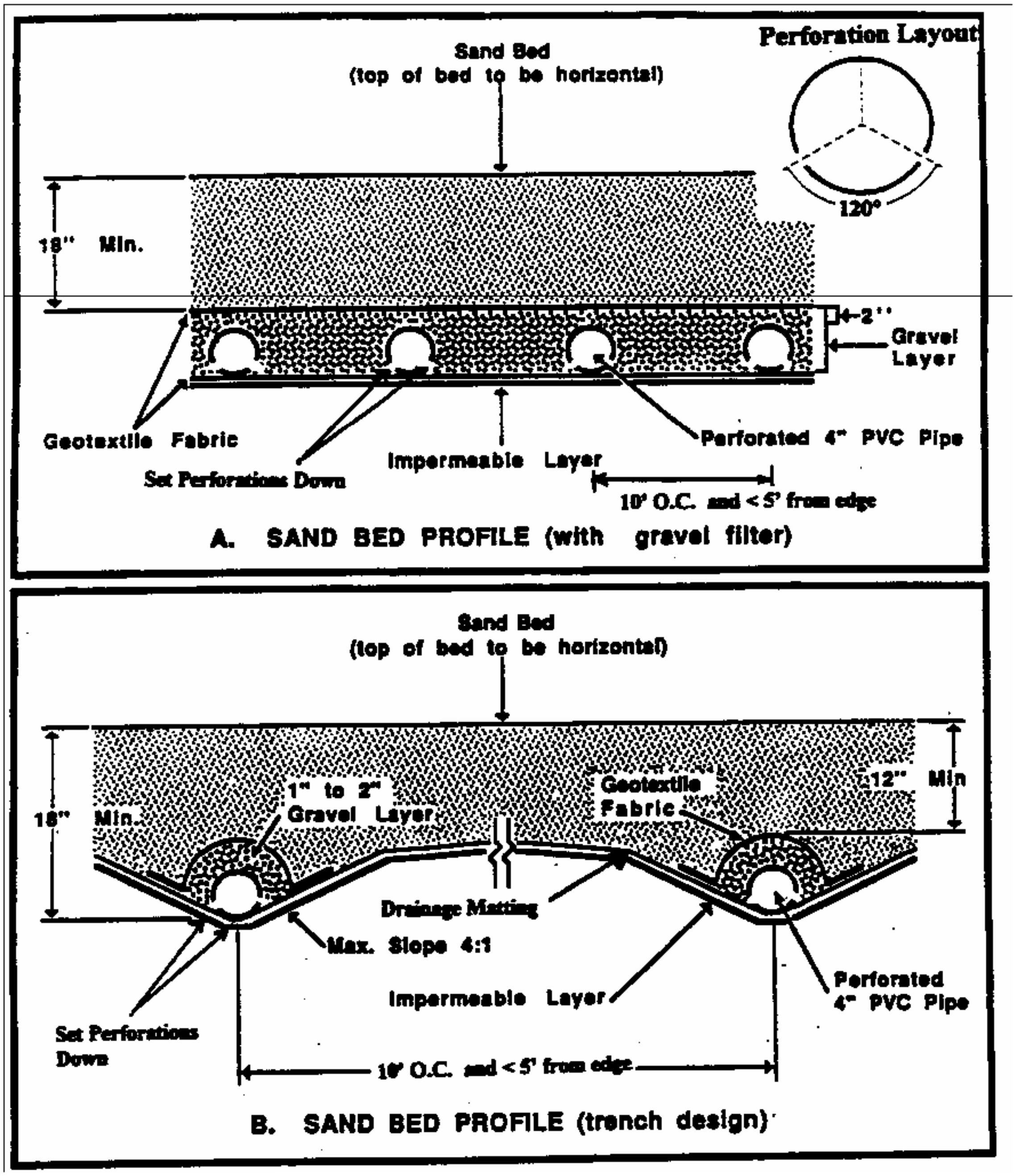


Figure 5
Schematic of Sand Bed Profile

(7) 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 resuspension and encourage quiescent conditions necessary for deposition of solids.

(8) 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 (example in Figure 6), 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).

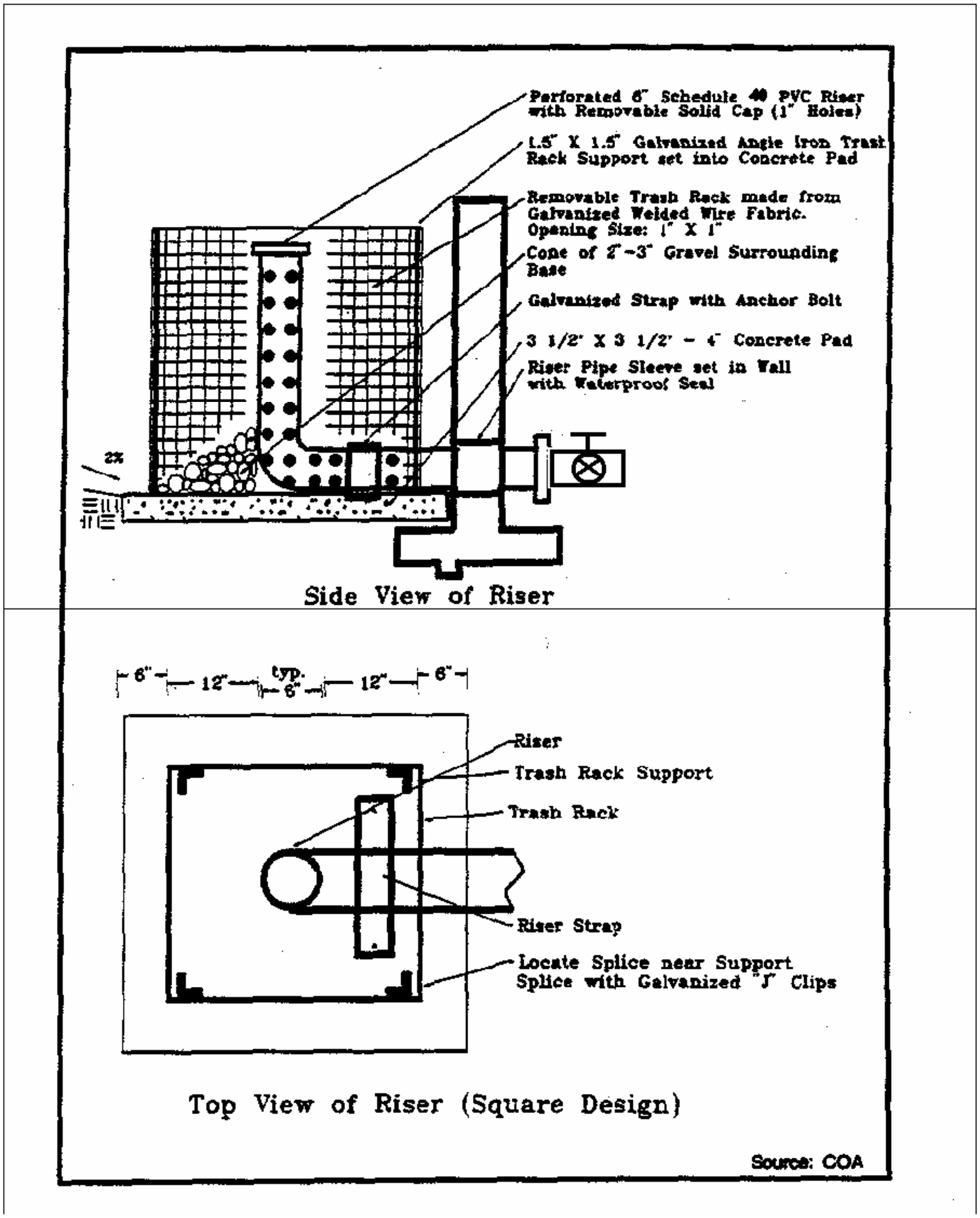
(9) Sand Filter Discharge – If a gabion structure is used to separate the sedimentation and filtration basins, a valve must installed so that discharge from the BMP can be stopped in case runoff from a spill of hazardous material enters the sand filter. The control for the valve must be accessible at all times, including when the basin is full.

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 Figure 7. 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 – 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 – 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 prohibitive, generally ranging between $2,000 (EPA Fact Sheet) and $4,000 (Caltrans, 2002) depending on the size of the filter.

Media filters can become a nuisance due to mosquito and midge breeding in certain designs or if not regularly maintained. "Wet" designs (e.g., MCTT and Delaware filter) are more conducive to vectors than others (e.g., 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.



Side View of Riser

Top View of Riser (Square Design)

Source: COA

Figure 6
Detail of Sedimentation Riser Pipe

Figure 7
Formation of Clogging Crust on Filter Bed

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 hr.
- Remove top 50 mm (2 in.) of sand and dispose of sediment if facility drain time exceeds 72 hr. Restore media depth to 450 mm (18 in.) when overall media depth drops to 300 mm (12 in.).
- Remove accumulated sediment in the sedimentation basin every 10 yr or when the sediment occupies 10 percent of the basin volume, whichever is less.

Cost

Construction Cost

There are few consistent published data on the cost of sand filters, largely because, with the exception of Austin, Texas, Alexandria, Virginia, and Washington, D.C., they have not been widely used. Furthermore, filters 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. The EPA filter fact sheet indicates a cost for an Austin sand filter at $18,500 (1997 dollars) for a 0.4 hectare- (1 acre-)

drainage area. However, the same design implemented at a 1.1 ha site by the California Department of Transportation, cost $240,000. Consequently, there is a tremendous uncertainty about what the average construction cost might be.

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.

Given the number of facilities installed in the areas that promote their use it should be possible to develop fairly accurate construction cost numbers through a more comprehensive survey of municipalities and developers that have implemented these filters.

Maintenance Cost

Annual costs for maintaining sand filter systems average about 5 percent 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 3-10 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 Table 3 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.

Table 3 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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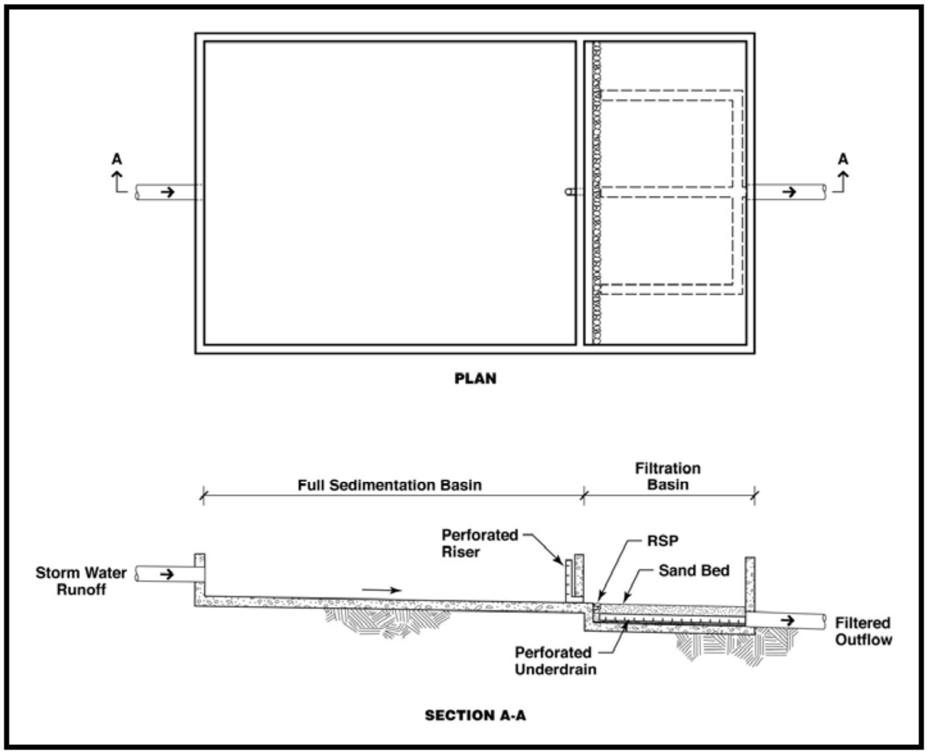
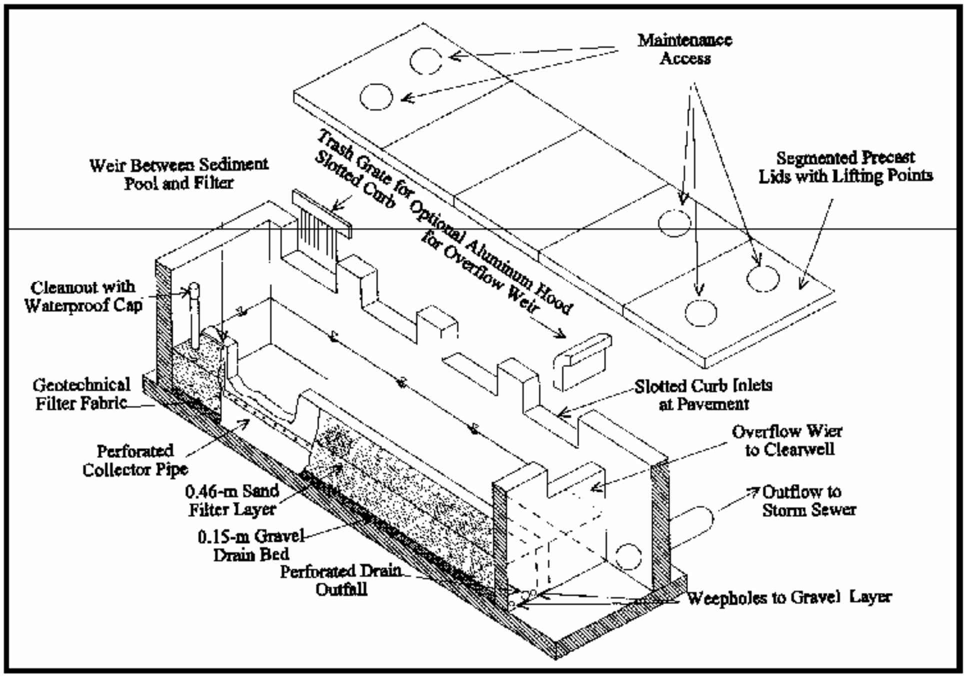
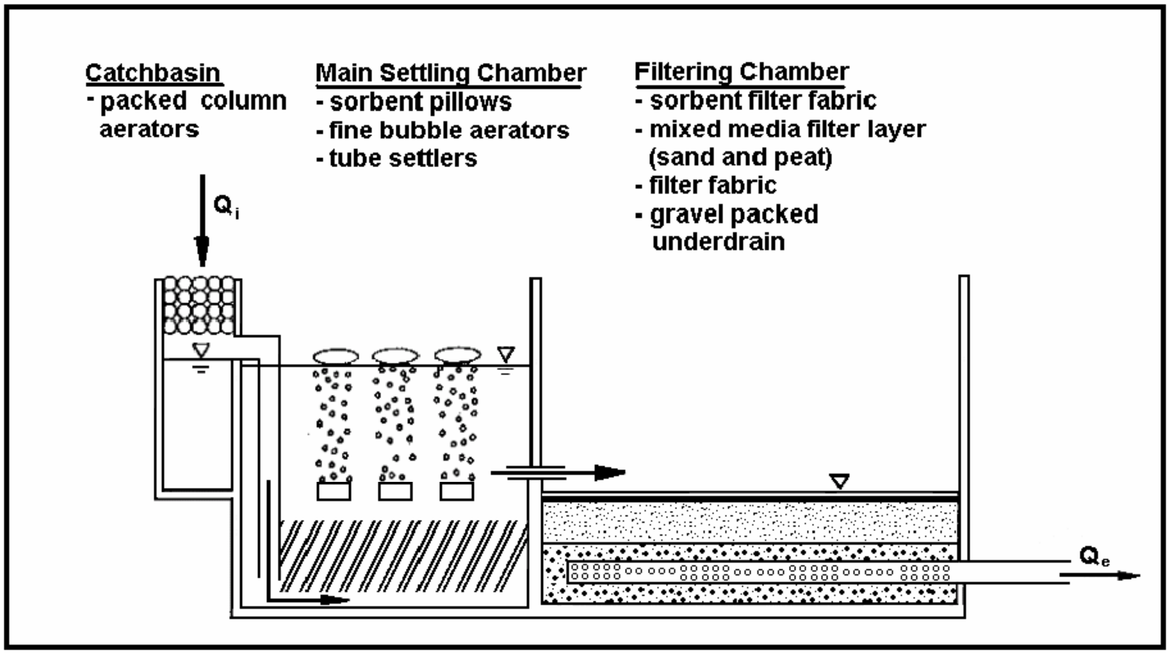


Schematic of the “Full Sedimentation” Austin Sand Filter



Schematic of a Delaware Sand Filter (Young et al., 1996)



Schematic of a MCTT (Robertson et al., 1995)

Water Quality Inlet

TC-50

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 stormwater. 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 stormwater runoff. WQIs typically capture only the first portion of runoff for treatment and are generally used for pretreatment before discharging to other best management practices (BMPs).

California Experience

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 stormwater 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 stormwater improvement.

- Standing water in the devices can provide a breeding ground for mosquitoes.

- Certain designs maintain permanent sources of standing water where mosquito and other vector breeding may to occur.

Design and Sizing Guidelines

- Water quality inlets are most effective for spill control and should be sized accordingly.

Design Considerations

- Area Required

Targeted Constituents

☑	Sediment	●
☑	Nutrients	●
☑	Trash	▲
☑	Metals	●
☑	Bacteria	●
☑	Oil and Grease	▲
☑	Organics	●

Legend *(Removal Effectiveness)*

● Low ■ High

▲ Medium

- 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 stormwater runoff. Grit and sediment are partially removed by gravity settling within the first two chambers. A WQI with a detention time of 1 hour may expect to have 20 to 40 percent 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).

A 1993 MWCOG study found that an average of less than 5 centimeters (2 inches) of sediments (mostly coarse-grained grit and organic matter) were trapped in the WQIs. Hydrocarbon and total organic carbon (TOC) concentrations of the sediments averaged 8,150 and 53,900 milligrams per kilogram, respectively. The mean hydrocarbon concentration in the WQI water column was 10 milligrams per liter. 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 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 stormwater 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 washdown areas, or vehicle storage areas. In these instances, runoff from the area of concern will usually be diverted directly into the unit, while all other runoff is sent to the storm drain downstream from the oil/water separator. Oil/water separation tanks are often fitted with diffusion baffles at the inlets to prevent turbulent flow from entering the unit and resuspending settled pollutants.

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 resuspension 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 resuspending 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.

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 GIS systems 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 percent of the sump volume. When sediment fills greater than 60 percent of their volume, catch basins reach steady state. Storm flows can then resuspend 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 stormwater 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. Depending on the regulations within a community, disposal costs of the sediment captured in catch basins may be significant.

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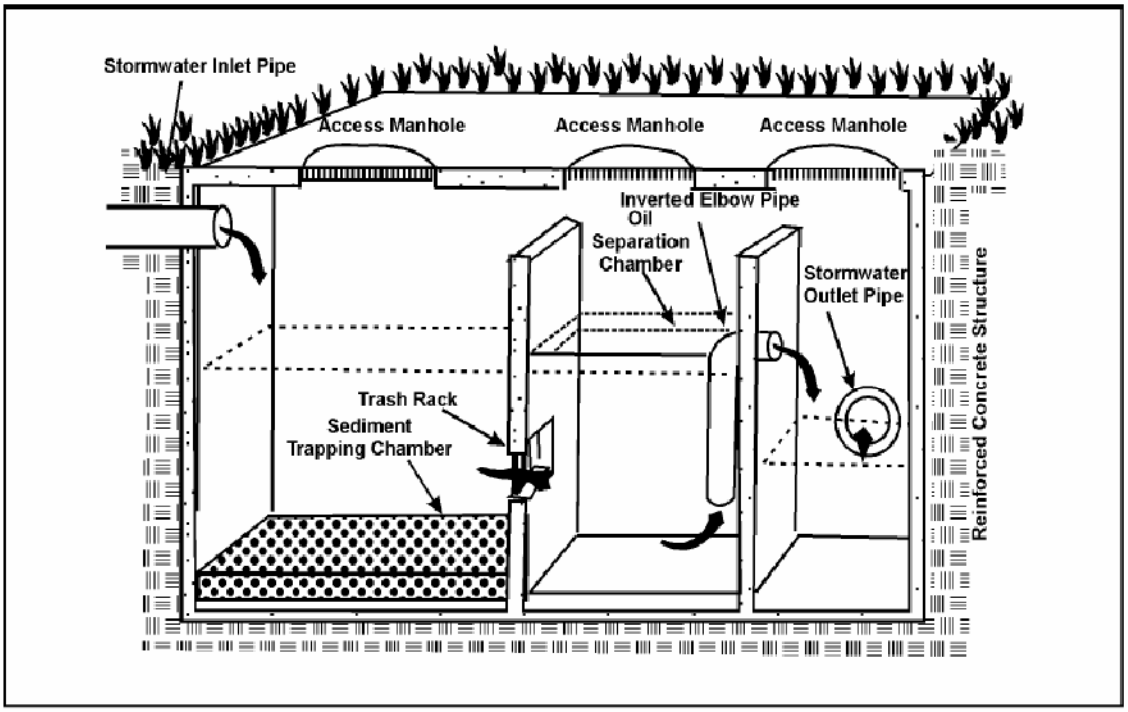
Stormwater Inlet Pipe
Access Manhole
Access Manhole
Access Manhole
Inverted Elbow Pipe
Oil
Separation
Chamber
Stormwater
Outlet Pipe
Reinforced Concrete Structure
Trash Rack
Sediment
Trapping Chamber

Multiple System Fact Sheet TC-60

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.

California Experience

The research wetlands at Fremont, California are a combination of wet ponds, wetlands, and vegetated controls.

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.

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.

Design Considerations

- Area Required
- Slope
- Water Availability
- Hydraulic Head
- Environmental Side-effects

Targeted Constituents

☑	Sediment	■
☑	Nutrients	●
☑	Trash	■
☑	Metals	■
☑	Bacteria	▲
☑	Oil and Grease	■
☑	Organics	■

Legend *(Removal Effectiveness)*

● Low ■ High

▲ Medium

- 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 BMP fact sheets.

Additional Design Guidelines

- When using two 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 BMP combinations.

Maintenance

Refer to individual treatment control BMP fact sheets.

Cost

Refer to individual treatment control BMP fact sheets.

Resources and Sources of Additional Information

Refer to individual treatment control BMP fact sheets.

Wetland MP-20

Description

A manufactured wetland is similar to public domain stormwater wetlands. In a manufactured wetland, gravel substrate and subsurface flow of the stormwater through the root systems force the vegetation to remove nutrients and dissolved pollutants from the stormwater.

Only one company currently manufactures a pre-engineered wetland: It consists of a standard module, about 9.5 feet in diameter and 4 feet in height. The module is constructed of recycled polyethylene. The number of units is varied to meet the design volume of the site.

California Experience

There are currently only a few installations in California.

Advantages

- Constructed wetlands remove dissolved pollutants unlike many of the other treatment technologies, whether manufactured or in the public domain.
- Gravel substrate and subsurface flow of the stormwater through the root systems forces the vegetation to remove nutrients and dissolved pollutants from the stormwater.
- 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.
- Can be incorporated into the landscaping of the development.
- The gravel substrate likely 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 be augmented with media that is specifically effective at removing dissolved pollutants, increasing further the performance of the system.
- Vegetation is more easily harvested in comparison to a wet pond or standard constructed wetland (TC-21).
- Provides modest habitat for insects and other small invertebrates which in turn provide food for birds and other small animals.

Design Considerations

- Drainage Area Size
- Potential Pretreatment Requirements

Targeted Constituents

☑ Sediment
☑ Nutrients
☑ Trash
☑ Metals
☑ Bacteria
☑ Oil and Grease
☑ Organics

Removal Effectiveness

See New Development and Redevelopment Handbook-Section 5.

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Limitations

- Not likely suitable for drainage areas greater than an acre due to the number of units that is required for larger sites.
- May attract invasive wetland species
- May require irrigation during the dry season
- With an emptying time as much as 5 days, a breeding ground for mosquitoes may occur during and immediately following each storm
- If site development requirements of local government also includes 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.

Design and Sizing Guidelines

The unit consists of two concentric chambers, analogous to a doughnut. The inner chamber is open whereas the outer chamber is filled with gravel in which the wetland plants reside. The water enters a center well, moving in a circular motion around nearly the entire circumference of the well. Via floating surface skimmers the water then enters the outer chamber. The flow rate is controlled at the outlet with a valve. The substrate for the vegetation is small gravel. Gravel substrate encourages the wetland vegetation to use nutrients and metals in the stormwater. The concept of subsurface flow through gravel has its parentage with subsurface flow constructed wetlands used to treat wastewater.

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.

Table 1 Supplemental Media

Targeted Pollutant	Alternative Media	References
Complex organics (e.g., 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 phosphorus	Blast furnace slag, iron-ore, iron wool, limestone, aluminum oxide, dolomite, iron-infused resin	James, et al. (1992), Minton (2002), Shapiro (1999), Ayoub, et al. (2001), Storm-water Management Inc memos

The design water quality volume is determined by local governments or sized so that 85% of the annual runoff volume is treated.

Construction/Inspection Considerations
Refer to manufacturer guidelines.

Performance

There is little operating data for the manufactured wetland, although these data indicate very high removal efficiencies, similar to created stormwater 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 stormwater 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 stormwater flowing directly through the root system forces uptake by the vegetation. To maintain performance therefore requires annual or harvesting of the vegetation (See Maintenance). 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 no 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. Table 1 lists media that have been evaluated in either stormwater 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

Siting Criteria

While not stated by the manufacturer, the system is likely most appropriate for small drainage areas of an 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 stormwater 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). To illustrate sizing, assume a development site of one acre and the design event is 0.75 inches. The total volume of the design event is 2,722 cubic feet. Thus, a minimum of 15 units is required, ignoring throughput during the storm. At this rate, a unit drains in approximately 3.8 days.

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 stormwater volume over time.

Fewer units are possible if the upstream drainage system is able to store water, although this extends the emptying time. If a detection 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.

Maintenance

To maximize the benefits of wetland vegetation in its removal of pollutants, the vegetation must be harvested each growth season. Harvesting is particularly important with respect to the removal of phosphorus and metals, less so nitrogen. Harvesting should occur by mid-summer before the plants begin to transfer phosphorus from the aboveground foliage to subsurface roots, or begin to lose metals that desorb during plant die-off. While not stated by the manufacturer, it is also desirable that every few years the entire plant mass including roots is harvested. This is because the belowground biomass constitutes a significant reservoir (possibly half) of the nutrients and metals that are removed from the stormwater by plants (Minton, 2002). Annual maintenance is typical.

If debris and floatable material is not effectively removed in the pretreatment unit, premature clogging of the debris bag may occur.

- Crop vegetation near end of each growth season to capture the nutrients and pollutants removed by the wetland vegetation.
- Inspect periodically to ensure that invasive species of wetland plants is not occurring
- Conduct inspection during the dry season to determine if irrigation of plants is necessary
- Clean center well periodically.

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

- 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.

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Media Filter MP-40

Description

Stormwater media filters are usually two-chambered including a pretreatment settling basin and a filter bed filled with sand or other absorptive filtering media. As stormwater flows into the first chamber, large particles settle out, and then finer particles and other pollutants are removed as stormwater flows through the filtering media in the second chamber.

There are currently three manufacturers of stormwater filter systems. Two are similar in that they use cartridges of a standard size. The cartridges are placed in vaults; the number of cartridges 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.

California Experience

There are currently about 75 facilities in California that use manufactured 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 does not entirely eliminate the opportunity for mosquito breeding.
- Media capable of removing dissolved pollutants can be selected.
- 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

- As some of the manufactured filter systems function at higher flow rates and/or have larger media than found in flatbed filters, the former may not provide the same level of performance as standard sand filters. However, the level of treatment may still be satisfactory.
- As with all filtration systems, use in catchments that have significant areas of non-stabilized soils can lead to premature clogging.

Design Considerations

- Design Storm
- Media Type
- Maintenance Requirement

Targeted Constituents

☑ Sediment
☑ Nutrients
☑ Trash
☑ Metals
Bacteria
☑ Oil and Grease
☑ Organics

Removal Effectiveness

See New Development and Redevelopment Handbook-Section 5.

Design and Sizing Guidelines

There are currently three manufacturers of stormwater 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 cm). It operates at a very high rate, 20 gpm/ft2 at peak flows. Normal operating rates are much lower assuming that the stormwater 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.

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 stormwater 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. Stormwater 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 gpm/ft2 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 stormwater 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 is 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 include compost, zeolite, and iron-infused polymer. Pretreatment occurs in an upstream unit and/or the vault within which the cartridges are located.

Water quality volume or flow rate (depending on the particular product) is determined by local governments or sized so that 85% of the annual runoff volume is treated.

Construction/Inspection Considerations

- Inspect one or more times as necessary during the first wet season of operation to be certain that it is draining properly.

Performance

The mechanisms of pollutant removal are essentially the same as with public domain filters (TC -40) if of a similar design. Whether removal of dissolved pollutants occurs depends on the media. Perlite and fabric do not remove dissolved pollutants, whereas for examples, 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

There are no unique siting criteria.

Additional Design Guidelines

Follow guidelines provided by the manufacturer.

Maintenance

- Maintenance activities and frequencies are specific to each product. Annual maintenance is typical.
- 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.
- 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.

References and Sources of Additional Information

Minton, G.R., 2002, Stormwater Treatment: Biological, Chemical, and Engineering Principles, RPA Press, 416 pages.

Vortex Separator MP-51

Description

Vortex separators: (alternatively, 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. Vortex separators were originally developed for combined sewer overflows (CSOs), where it is used primarily to remove coarse inorganic solids. Vortex separation has been adapted to stormwater treatment by several manufacturers.

California Experience

There are currently about 100 installations in California.

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 vortex separators are not as effective as wet vaults at removing fine sediments, on the order 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 stormwater decreases the efficiency of vortex separators from what may be estimated or determined from testing under constant flow.
- Do not remove dissolved pollutants.

Design Considerations

- Service Area
- Settling Velocity
- Appropriate Sizing
- Inlet Pipe Diameter

Targeted Constituents

☑	Sediment	▲
☑	Nutrients	●
☑	Trash	
☑	Metals	●
	Bacteria	
☑	Oil and Grease	
☑	Organics	

Legend *(Removal Effectiveness)*

● Low ■ High

▲ Medium

- A loss of dissolved pollutants may occur as accumulated organic matter (e.g., leaves) decomposes in the units.

Design and Sizing Guidelines

The stormwater 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 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 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.

The commercial separators applied to stormwater 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.

- Sized is based on the peak flow of the design treatment event as specified by local government.

- 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.

- Headloss 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 (cfs) 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 (glacial sand) down to 150 microns, and to capture the floatables, and oil and grease. Laboratory tests of two 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

Experience with the use of vortex separators for treating combined sewer overflows (CSOs), the original application of this technology, suggests that the lower practical limit for particle removal are particles with a settling velocity of 12 feet per hour (Sullivan, 1982), which represents a particle diameter of 100 to 200 microns, depending on the specific gravity of the particle. The CSO experience therefore seems consistent with the limited experience with treating stormwater, summarized above

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 stormwater. 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. Only two of manufactured products currently available have been field tested. Two 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 stormwater contained significant quantities of deicing sand. Consequently, the influent TSS concentrations and particle size are both likely considerably higher than is found in California stormwater. These data suggest that if the stormwater 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 handbook.

There are no equations that provide a straightforward determination of efficiency as a function of unit configuration and size. Design specifications of commercial separators are derived from empirical equations that are unique and proprietary to each manufacturer. However, some general relationships between performance and the geometry of a separator have been developed. CSO studies have found that the primary determinants of performance of vortex separators are the diameters of the inlet pipe and chamber with all other geometry proportional to these two.

Sullivan et al. (1982) found that performance is related to the ratios of chamber to inlet diameters, D2/D1, and height between the inlet and outlet and the inlet diameter, H1/D1, shown in Figure 3. The relationships are: as D2/D1 approaches one, the efficiency decreases; and, as the H1/D1 ratio decreases, the efficiency decreases. These relationships may allow qualitative comparisons of the alternative designs of manufacturers. Engineers who wish to apply these concepts should review relevant publications presented in the References.

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 capacities if positioned as in-line facilities, a treatment capacity and a hydraulic capacity. Failure to recognize the difference between the two may lead to significant under sizing; i.e., too small a model is selected. This observation is relevant to three of the five products. These three technologies all are designed to experience a unit flow rate of about 24 gallons/square foot 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 with an eductor 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 (e.g., groundwater levels) may affect the relative cost-effectiveness.

References and Sources of Additional Information

Field, R., 1972, The swirl concentrator as a combined sewer overflow regulator facility, EPA/R2-72-008, U.S. Environmental Protection Agency, Washington, D.C.

Field, R., D. Averill, T.P. O'Connor, and P. Steel, 1997, Vortex separation technology, Water Qual. Res. J. Canada, 32, 1, 185

Manufacturers technical materials

Sullivan, R.H., et al., 1982, Design manual – swirl and helical bend pollution control devices, EPA-600/8-82/013, U.S. Environmental Protection Agency, Washington, D.C.

Sullivan, R.H., M.M. Cohn, J.E. Ure, F.F. Parkinson, and G. Caliana, 1974, Relationship between diameter and height for the design of a swirl concentrator as a combined sewer overflow regulator, EPA 670/2-74-039, U.S. Environmental Protection Agency, Washington, D.C.

Sullivan, R.H., M.M. Cohn, J.E. Ure, F.F. Parkinson, and G. Caliana, 1974, The swirl concentrator as a grit separator device, EPA670/2-74-026, U.S. Environmental Protection Agency, Washington, D.C.

Sullivan, R.H., M.M. Cohn, J.E. Ure, F.F. Parkinson, and G. Caliana, 1978, Swirl primary separator device and pilot demonstration, EPA600/2-78-126, U.S. Environmental Protection Agency, Washington, D.C.

Wet Vault MP-50

Description

A wet vault is a vault with 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 live volume generally drains within 12 to 48 hours after the end of each storm.

California Experience

There are currently several hundred stormwater treatment facilities in California that use manufactured wet vaults currently in operation in California.

Advantages

- Internal baffling and other design features such as bypasses may increase performance over traditional wet vaults and/or reduce the likelihood of resuspension 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.
- Do not remove dissolved pollutants.
- A loss of dissolved pollutants may occur as accumulated organic matter (e.g., leaves) decomposes in the units.

Design and Sizing Guidelines

Water quality volume or flow rate (depending on the particular product) is determined by local governments or sized so that 85% of the annual runoff volume is treated. There are three general configurations of wet vaults currently available, differing with the particular manufacturer.

Vault System A: This system consists of two standard precast manholes, the size varying to achieve the desired capacity. Stormwater enters the first (primary) manhole where coarse solids are removed. The stormwater flows from the first to the second (storage) manhole, carrying floatables where they are captured and retained. Further sedimentation occurs in this second manhole. The off-line serves as a storage reservoir for

Design Considerations

- Hydraulic Capacity
- Sediment Accumulation

Targeted Constituents

☑ Sediment
☑ Nutrients
☑ Trash
☑ Metals
Bacteria
☑ Oil and Grease
☑ Organics

Removal Effectiveness

See New Development and Redevelopment Handbook-Section 5.

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floatables as stormwater flows though at flow rates less than the design flow. A patented device controls the flow into the storage manhole. All flows above the stated treatment flow rate bypass through the device. The bypass prevents resuspension or loss of sediment and floatables that have accumulated in the second manhole. It is important to recognize that has storage of accumulated sediment occurs directly in the operating area of the manholes; treatment efficiency will decline over time given the reduction in treatment volume

The manufacturer currently provides 4 models, with treatment capacities (flow rate above which bypass occurs) from 2.4 to 21.8 cfs. The hydraulic capacities range from 10 to 100 cfs. As such, all stormwater achieves at least partial treatment through essentially all but the most extreme storm flows since some settling occurs in the first manhole. The manufacturer provides information on the total system (water) volume, sediment capacity, and floatable capacities. The size of the storage manhole can be varied with each of the four models to increase storage capacity as desired, following recommendations of the manufacturer. The footprint of this system ranges from about 200 to 350 ft2, with heights of about 11.5 to 13.5 feet (excluding minimum soil cover and access port extenders), depending on the model. Head loss ranges from 5 to 12 inches, depending on the model. Sediment and floatable capacities range up to 201 cf and 150 gallons, respectively. The recommended point of maintenance is when about 25% of the wet pool volume is supplanted by sediment. The affect of the accumulation of sediment on performance is not given

Vault System B: This wet vault has outward appearance of a standard, rectangular wet vault, but with its own unique design for internal baffles. Included is an entrance baffle, presumably to reduce the energy of the flow entering the unit. Baffles are also affixed to the floor, purportedly to reduce resuspension of settled sediments improve performance. A floating sorbent pad may be placed near the outlet to remove free oil floating on the surface. The vault includes both a permanent wet pool, 3 feet in depth, and live storage volume that is filled during each storm. The live storage volume is accomplished by restricting the outlet. The system is modular: that is, it consists of standard units that are added to increase the length, thereby providing the desired volume. Presumably for very large sites there is a practical total length. Further capacity could be accomplished by having two or more vaults in parallel. The capacity of the system is therefore essentially unlimited, Being modular may allow the design engineer to more closely match facility size to the design event.

Vault System C: This system is like System A, but differs in two primary respects. The Stormceptor module consists of only one circular structure. Hence, standard precast manholes can be used for the smaller models but larger models are non-standard sizes. Like System A, System C has an internal bypass, involving a unique design. The purpose of the bypass is to prevent resuspension of previously suspended material. All stormwater up to the bypass rate is diverted downward into the center well where removal occurs. Flows in excess of the treatment capacity are diverted directly across the top of the device to the outlet. According to the manufacturer there is also some storage capacity for floatables immediately beneath the bypass structure.

Twelve models are available. The treatment capacity of each is not indicated for the Stormceptor as it is a function of the removal efficiency specified by the designer. The manufacturer provides a methodology for the calculation of efficiency as a function of flow rate (see Design Guidelines). Hydraulic capacities range up to approximately 63 cfs. The head requirement is a function of the model and desired hydraulic flow rate, ranging up to 21 inches.

Diameters range from 4 to 12 feet, and minimum heights up to about 13 feet plus the diameter of the incoming pipe. Sediment and floatable capacities range up to 1,470 cf and 3,055 gallons, respectively. The recommended point of maintenance is when about 15% of the wet pool volume is supplanted by sediment. The affect of the accumulation of sediment on performance is not given but can be estimated using the manufacturer's sizing methodology.

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 s/he 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 resuspension. Given this benefit, it could be argued that manufactured wet vaults can be smaller than traditional catch basins, to achieve similar performance. However, there are no 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 an eductor truck. It may be necessary to remove and dispose the floatables separately due to the presence of petroleum product. 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 to two 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 (e.g., 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.

References and Sources of Additional Information

Manufacturers literature.

Drain Inserts MP-52

Description

Drain inserts are manufactured filters or fabric placed in a drop inlet to remove sediment and debris. There are a multitude of inserts of various shapes and configurations, typically falling into one of three different 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 occur in the same box. Some products consist of one or more trays or mesh grates. The trays may hold different types of media. Filtration media vary by manufacturer. Types include polypropylene, porous polymer, treated cellulose, and activated carbon.

California Experience

The number of installations is unknown but likely exceeds a thousand. Some users have reported that these systems require considerable maintenance to prevent plugging and bypass.

Advantages

- Does not require additional space as 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 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.

Design and Sizing Guidelines

Refer to manufacturer's guidelines. Drain inserts come any 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

Design Considerations

- Use with other BMPs
- Fit and Seal Capacity within Inlet

Targeted Constituents

☑ Sediment
☑ Nutrients
☑ Trash
☑ Metals
Bacteria
☑ Oil and Grease
☑ Organics

Removal Effectiveness

See New Development and Redevelopment Handbook-Section 5.

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one box; that is, the setting area and filtration through media occurs in the same box. One manufacturer has a double-box. Stormwater enters the first box where setting occurs. The stormwater 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.

Construction/Inspection Considerations

Be certain that installation is done in a manner that makes certain that the stormwater 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.

Performance

Few products have performance data collected under field conditions.

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).

References and Sources of Additional Information

Hrachovec, R., and G. Minton, 2001, Field testing of a sock-type catch basin insert, Planet CPR, Seattle, Washington

Interagency Catch Basin Insert Committee, Evaluation of Commercially-Available Catch Basin Inserts for the Treatment of Stormwater Runoff from Developed Sites, 1995

Larry Walker Associates, June 1998, NDMP Inlet/In-Line Control Measure Study Report

Manufacturers literature

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Exhibit A-7.II

Interim Hydromodification BMP Sizing Tool Technical Guidance Document

CITY OF LAKE FOREST

DECEMBER 20, 1991

TECHNICAL GUIDANCE DOCUMENT FOR THE SOUTH ORANGE COUNTY HYDROMODIFICATION CONTROL BMP SIZING TOOL

December 13, 2010

Table of Contents

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Section 1. Introduction

This South Orange County Hydromodification Control BMP Sizing Tool Guidance Document has been developed by the County of Orange in cooperation with the incorporated Cities of South Orange County (Aliso Viejo, Dana Point, Laguna Beach, Laguna Hills, Laguna Niguel, Laguna Woods, Lake Forest, Mission Viejo, Rancho Santa Margarita, San Clemente, and San Juan Capistrano) to aid agency staff and project proponents with addressing the Interim Hydromodification Criteria in the Fourth Term South Orange County MS4 Permit (Order R9-2009-0002). This document serves as the technical resource companion to the Hydromodification Control BMP Sizing Tool (Sizing Tool - South OC Interim Hydromod Criteria v1.xlsx).

1.1. Applicability

Priority Development Projects subject to the Interim Hydromodification Criteria are described below (see also R9-2009-0002 Section F.1.d.)

1.1.1. Priority Development Project Categories

Projects in the following categories are considered Priority Development Projects. Where a new development project feature, such as a parking lot, falls into a Priority Development Project category, the entire project footprint is subject to the Interim Hydromodification Criteria.

1. **New development projects that create 10,000 square feet or more of impervious surfaces** (collectively over the entire project site) including commercial, industrial, residential, mixed-use, and public projects. This category includes development projects on public or private land which fall under the planning and building authority of the Copermittees.

2. **Automotive repair shops**. This category is defined as a facility that is categorized in any one of the following Standard Industrial Classification (SIC) codes: 5013, 5014, 5541, 7532-7534, or 7536-7539.

3. **Restaurants**. This category is defined as a facility that sells prepared foods and drinks for consumption, including stationary lunch counters and refreshment stands selling prepared foods and drinks for immediate consumption (SIC code 5812), where the land area for development is greater than 5,000 square feet. Restaurants where land development is less than 5,000 square feet are not subject to the Interim Hydromodification Criteria.

4. **All hillside development greater than 5,000 square feet**. This category is defined as any development which creates 5,000 square feet of impervious surface which is located in an area with known erosive soil conditions, where the development will grade on any natural slope that is twenty-five percent or greater.

5. **Environmentally Sensitive Areas (ESAs)**[1]. All development located within or directly adjacent to or discharging directly to an ESA (where discharges from the development or redevelopment will enter receiving waters within the ESA), which either creates 2,500 square feet of impervious surface on a proposed project site or increases the area of imperviousness of a proposed project site to 10 percent or more of its naturally occurring condition. "Directly adjacent" means situated within 200 feet of the ESA. "Discharging directly to" means outflow from a drainage conveyance system that is composed entirely of flows from the subject development or redevelopment site, and not commingled with flows from adjacent lands.

6. **Parking lots 5,000 square feet or more or with 15 or more parking spaces and potentially exposed to runoff**. Parking lot is defined as a land area or facility for the temporary parking or storage of motor vehicles used personally, for business, or for commerce.

7. **Street, roads, highways, and freeways**. This category includes any paved surface that is 5,000 square feet or greater used for the transportation of automobiles, trucks, motorcycles, and other vehicles.

8. **Retail Gasoline Outlets (RGOs)**. This category includes RGOs that meet the following criteria: (a) 5,000 square feet or more or (b) a projected Average Daily Traffic (ADT) of 100 or more vehicles per day.

9. **One acre threshold.** Effective December 16, 2012, Priority Development Projects also includes all other pollutant-generating development projects[2] that result in the disturbance of one acre or more of land. As an alternative to this one-acre threshold, the Copermittees may collectively identify a different threshold, provided the Copermittees' threshold is at least as inclusive of development projects as the one-acre threshold.

1.1.2. Redevelopment Projects

Those redevelopment projects that create, add, or replace at least 5,000 square feet of impervious surfaces on an already developed site and the existing development and/or the redevelopment project falls under the project categories or locations listed in Section 1.1.1.

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[1] Environmentally Sensitive Areas (ESAs) are areas that include but are not limited to all Clean Water Act Section 303(d) impaired water bodies; areas designated as Areas of Special Biological Significance by the State Water Resources Control Board (Water Quality Control Plan for the San Diego Basin (1994) and amendments); State Water Quality Protected Areas; water bodies designated with the RARE beneficial use by the State Water Resources Control Board (Water Quality Control Plan for the San Diego Basin (1994) and amendments); areas designated as preserves or their equivalent under the Natural Communities Conservation Program within the Cities and County of Orange; and any other equivalent environmentally sensitive areas which have been identified by the Copermittees.

[2] Pollutant generating development projects are those projects that generate pollutants at levels greater than natural background levels.

Where redevelopment results in an increase of less than 50 percent of the impervious surfaces of a previously existing development, and the existing development was not subject to SSMP requirements, the Interim Hydromodification Criteria applies only to the addition or replacement, and not to the entire development. Where redevelopment results in an increase of more than 50 percent of the impervious surfaces of a previously existing development, the Interim Hydromodification Criteria applies to the entire development.

1.1.3. Effective Date

The Interim Hydromodification Criteria apply to all projects or phases of projects, unless, on December 16, 2010, the projects or project phases meet any one of the following conditions:

1. The project or phase has begun grading or construction activities; or
2. The local permitting authority determines that lawful prior approval rights for the project or project phase exist, whereby application of the Interim Hydromodification Criteria to the project is legally infeasible.

1.2. Interim Hydromodification Criteria

Order No. R9-2009-0002 contains the following interim hydromodification control (IHC) requirement:

> *Within one year of adoption of this Order, each Copermittee must ensure that all Priority Development Projects are implementing the following criteria by comparing the pre-development (naturally occurring) and post-project flow rates and durations using a continuous simulation hydrologic model such as US EPA's Hydrograph Simulation Program-Fortran (HSPF):*
>
> *(a) For flow rates from 10 percent of the 2-year storm event to the 5 year storm event, the post-project peak flows shall not exceed predevelopment (naturally occurring) peak flows.*
>
> *(b) For flow rates from the 5 year storm event to the 10 year storm event, the post-project peak flows may exceed pre-development (naturally occurring) flows by up to 10 percent for a 1-year frequency interval.*
>
> *The interim hydromodification criteria do not apply to Priority Development Projects where the project discharges (1) storm water runoff into underground storm drains discharging directly to bays or the ocean, or (2) storm water runoff into conveyance channels whose bed and bank are concrete lined all the way from the point of discharge to ocean waters, enclosed bays, estuaries, or water storage reservoirs and lakes.*
>
> *Within one year of adoption of this Order, each Copermittee must submit a signed, certification statement to the Regional Board verifying implementation of the interim hydromodification criteria.*

The following sections discuss some of the key concepts contained in the criteria and their relevance to preventing excessive stream erosion and sedimentation.

1.2.1. Flow Duration Matching

A basic concept in hydromodification management control is to design hydromodification control BMPs such that runoff from a project does not exceed the baseline condition. The introduction of new or increasing impervious surfaces can increase both the magnitude and duration of runoff and it is these characteristics that the interim hydromodification criteria is intended to address. Moreover, the effect of increased runoff on stream channel erosion is not restricted to a specific flow rate (or design storm), but rather a range of flows are important. The concept of flow duration matching is to incorporate hydrologic controls such that the flows and their durations do not differ from the baseline case over some specified range of flows. Plots showing flow versus duration are referred to as "flow duration curves[3]." The goal of the IHC is to integrate hydrologic controls into a proposed project such that the flow duration curve corresponding to the post-project condition agrees with the baseline condition curve over the range of flows of interest. When this is accomplished, runoff from the proposed development would not contribute additional erosive forces in the receiving stream channel.

1.2.2. Flow Range of Interest

Geomorphic research has found that the most important range of flows, from the perspective of affecting channel form, are the relatively more frequent flows that are contained primarily within the active channel and not the rare, high magnitude flows. Flows which create shear stresses (forces) high enough to initiate sediment transport within the channel and which occur frequently enough to have influence over long-term stream morphology are considered "geomorphically-significant" flows. Sand bedded streams have lower critical shear stresses and are readily moved by increased flows, whereas channel materials that are larger, such as gravels and cobbles, and more cohesive, such as clays, are more resistant to being moved. The IHC calls for considering a range of flows extending from 10% of the 2-year peak flow (0.1Q2) to the 10-year peak flow (Q10)[4].

1.2.3. Baseline Condition

The baseline condition assumption depends on the requirements of the MS4 Permit. The baseline condition in the South Orange County MS4 Permit is the pre-development (naturally occurring) condition. This is equivalent to the most prominent naturally vegetated condition that existed prior to urbanization and agriculture in those portions of southern Orange County that are likely to be developed. For example, the oak grasslands habitat is one possible pre-development condition that might be adopted as part of the interim criteria.

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[3] A flow duration curve is a plot of flow rate (y-axis) vs. the cumulative duration, or percentage of time, that a flow rate is exceeded in the simulation record (x-axis).

[4] Specifically, the South Orange County Interim Hydromodification Criteria requires that post-project peak flows not exceed pre-development flows up to Q_5. For flow rates from Q_5 to Q_{10}, post-project peak flows may exceed pre-development peak flows by up to 10 percent for a 1-year frequency interval.

1.2.4. Length of Rainfall Record

The IHC calls for the use of continuous hydrologic modeling to account for the response of channels to a range of flows, as described above. These types of models use a continuous rainfall record to predict project runoff. As a practical matter, the longer the rainfall record the better, but at a minimum, a rainfall record of at least 20 years with an hourly time interval of rainfall readings should be used. Upwards of 50 years is preferred if the data is available.

1.3. Hydromodification Control BMPs

A variety of volume / flow management structural BMPs are available that utilize the following two basic principles:

- Detain runoff and release it in a controlled way that either mimics pre-development hydrograph or reduces flow durations to account for a reduction in sediment supply.
- Manage excess runoff volumes through one or more of the following pathways: infiltration, evapotranspiration, storage and use, discharge at a rate below the critical rate for adverse impact, or discharge downstream to a non-susceptible water body.

1.3.1. Distributed/Onsite BMPs

Distributed BMPs are small scale facilities, typically treating runoff from less than ten acres. These types of facilities include, but are not limited to, infiltration trenches, bioretention areas, permeable pavement, green roofs, cisterns, and underground vaults or pipes. These types of facilities may also help to achieve the MS4 Permit's LID performance standard.

1.3.2. Detention/Retention Basins

Detention/retention basins are stormwater management facilities that are designed to detain and infiltrate runoff from one or multiple projects or project areas. These basins are typically shallow with flat, vegetated bottoms. Detention/retention basins can be constructed by either excavating a depression or building a berm to create above ground storage, such that runoff can drain into the basin by gravity. Runoff is stored in the basin as well as in the pore spaces of the surface soils. Pretreatment BMPs such as swales, filter strips, and sedimentation forebays minimize fine sediment loading to the basins, thereby reducing maintenance frequencies.

Detention/retention basins for hydromodification management incorporate outlet structures designed for flow duration control. These basins can also be designed to support flood control and water quality treatment objectives in addition to hydromodification. If underlying soils are not suitable for infiltration, the basin may be designed for flow detention only, with alternative practices to manage increased volumes, such as storage and use, discharge at a rate below the critical rate for adverse impacts, or discharge to a non-susceptible water body.

Detention/retention basins should be designed to receive flows from developed areas only, for both design optimization as well as to avoid intercepting coarse sediments from open spaces that should ideally be passed through to the stream channel. Reduction in coarse sediment loads contributes to channel instability.

1.3.3. In-Stream Controls

Hydromodification management can also be achieved by in-stream controls, including drop structures, bed and bank reinforcement, and grade control structures.

Drop Structures

Drop structures are designed to reduce the channel slope, thereby reducing the shear stresses generated by stream flows. These controls can be incorporated as natural appearing rock structures with a step-pool design which allows drop energy to be dissipated in the pools while providing a reduced longitudinal slope between structures.

Grade Control Structures

Grade control structures are designed to maintain the existing channel slope while allowing for minor amounts of local scour. These control measures are often buried and would entail a narrow trench across the width of the stream backfilled with concrete or similar material, as well as the creation of a “plunge pool” feature on the downstream side of the sill by placing boulders and vegetation. A grade control option provides a reduced footprint and impact compared to drop structures, which are designed to alter the channel slope.

Bed and Bank Reinforcement

Channel reinforcement serves to increase bed and bank resistance to stream flows. In addition to conventional techniques such as riprap and concrete, a number of vegetated approaches are increasingly utilized, including products such as vegetated reinforcement mats. This technology provides erosion control with an open-weave material that stabilizes bed and bank surfaces and allows for re-establishment of native plants, which serves to further increase channel stability.

Section 2. BMP Sizing Tool

Hydrologic modeling was used to develop a series of simplified sizing charts and a sizing spreadsheet tool to standardize the sizing of four types of BMPs for hydromodification control. The sizing tool allows project proponents to easily determine the necessary BMP storage volume and footprint area for flow duration control as a function of the proposed level of imperviousness and the onsite Hydrologic Soil Group[5] (A/B or C/D). The sizing tool takes into account a reasonable range of design and environmental conditions. In addition, because the BMP footprint is expressed as a percentage of the project catchment area, the BMPs can range in size. This flexibility allows a project proponent to strategically situate many small scale distributed facilities or fewer larger facilities depending on site constraints.

The four BMP types incorporated in the sizing tool are: (1) a bioretention facility, (2) a rectangular underground vault with an open bottom, (3) a rectangular underground vault with a closed bottom, and (4) a planter box. The bioretention facility and open-bottomed vault allow for infiltration into the underlying soils and the closed bottom vault and planter boxes do not. Figures 1 through 4 illustrate the BMP configurations that were modeled to develop the sizing tool.

2.1. Methodology

For each BMP type, ten continuous hydrologic simulations using US EPA's Storm Water Management Model (SWMM) were conducted with a combination of two soil types (A/B and C/D) and five imperviousness values (1%, 25%, 50%, 75%, and 100%). The simulations were performed on a generic catchment area in order to generate long-term flow records. A generic 1 acre catchment area was selected to size the bioretention facility, a 10 acre catchment area was used to size the underground vaults, and a ¼ acre catchment area was used to size the planter box[6]. The 1% imperviousness simulation represents the baseline (pre-development) flow records and the 25%, 50%, 75%, and 100% imperviousness simulations represent a range of post-development conditions. The BMPs were sized by iteratively adjusting the BMP footprint until flow duration control was achieved with the minimum BMP footprint.

Appendix I provides more detail on the modeling approach.

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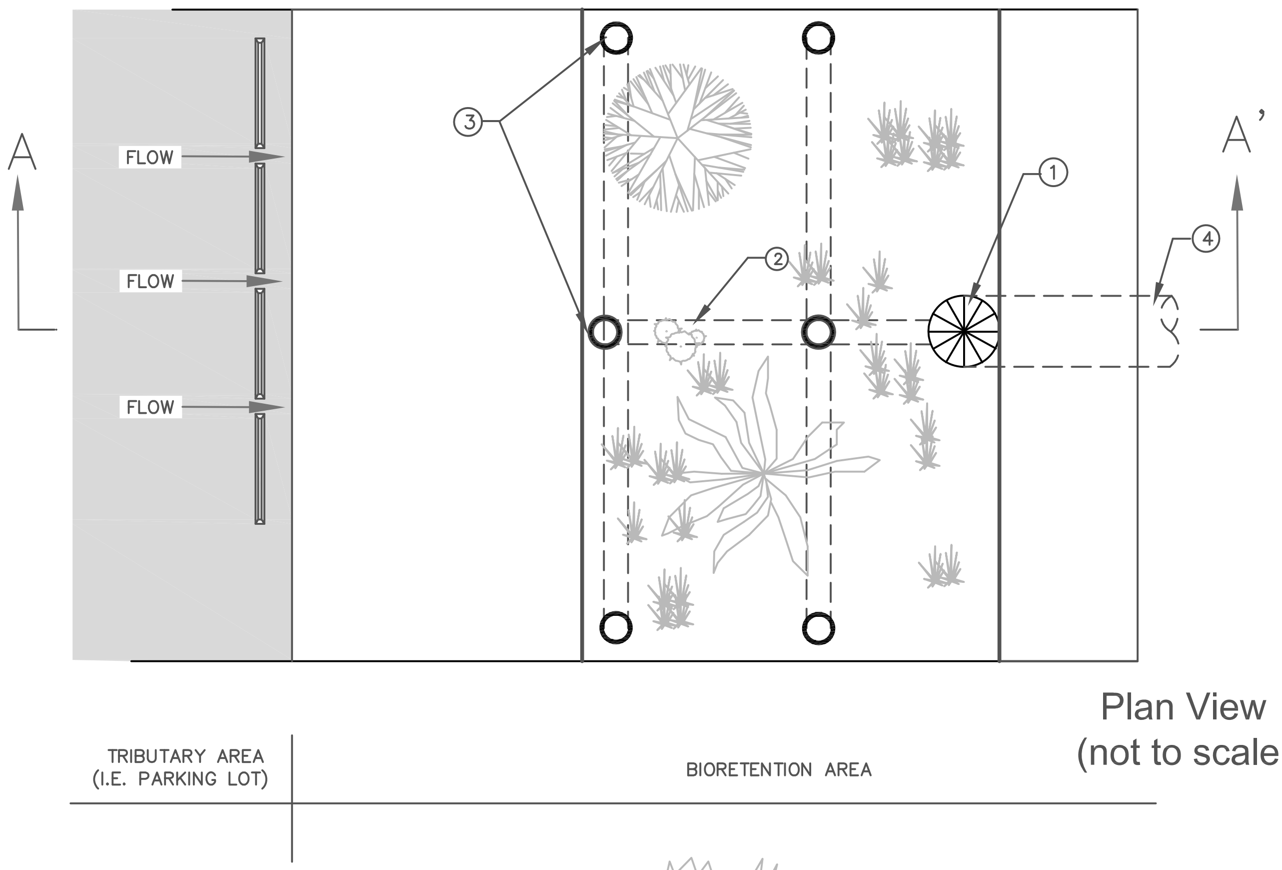
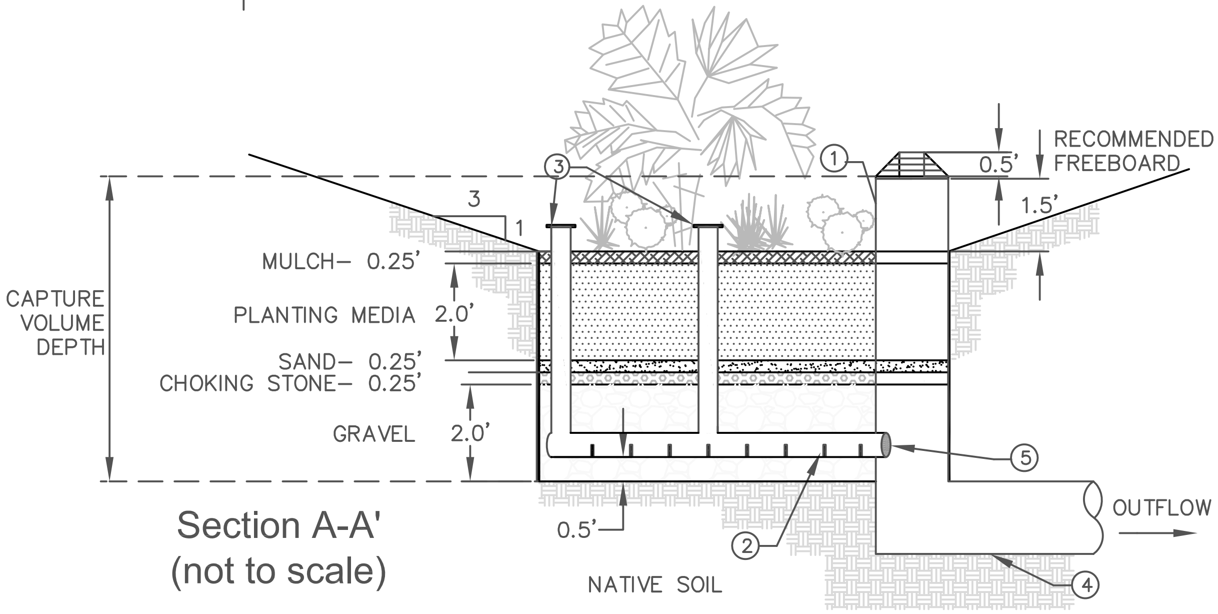
[5] Based on NRCS soil survey data, approximately 47% of South Orange County is considered Type D soil, 37% is Type C, 13% is Type B, and 3% is Type A.

[6] These areas were used because they are between the expected lower and upper limits of catchment areas likely to drain into each BMP type. Bioretention facilities were expected to be applied to catchments ranging between 5,000 square feet (0.11 acres) to 5 acres. Underground vaults were expected to be applied to catchments ranging between 1 acre and 50 acres. Planter boxes were expected to be applied to catchments less than 1 acre.



Plan View
(not to scale)



Section A-A'
(not to scale)

NOTES:

① OVERFLOW DEVICE WITH WEIR LENGTH SIZED TO CONVEY THE DESIGN DISCHARGE AS REQUIRED BY THE ORANGE COUNTY LOCAL DRAINAGE MANUAL AND HYDROLOGY MANUAL OR THE LOCAL PERMITTING AUTHORITY

② SLOTTED 6" MIN PVC PIPE UNDERDRAIN (C/D SOILS ONLY)

③ 6" MIN PVC PIPE CLEANOUT (C/D SOILS ONLY)

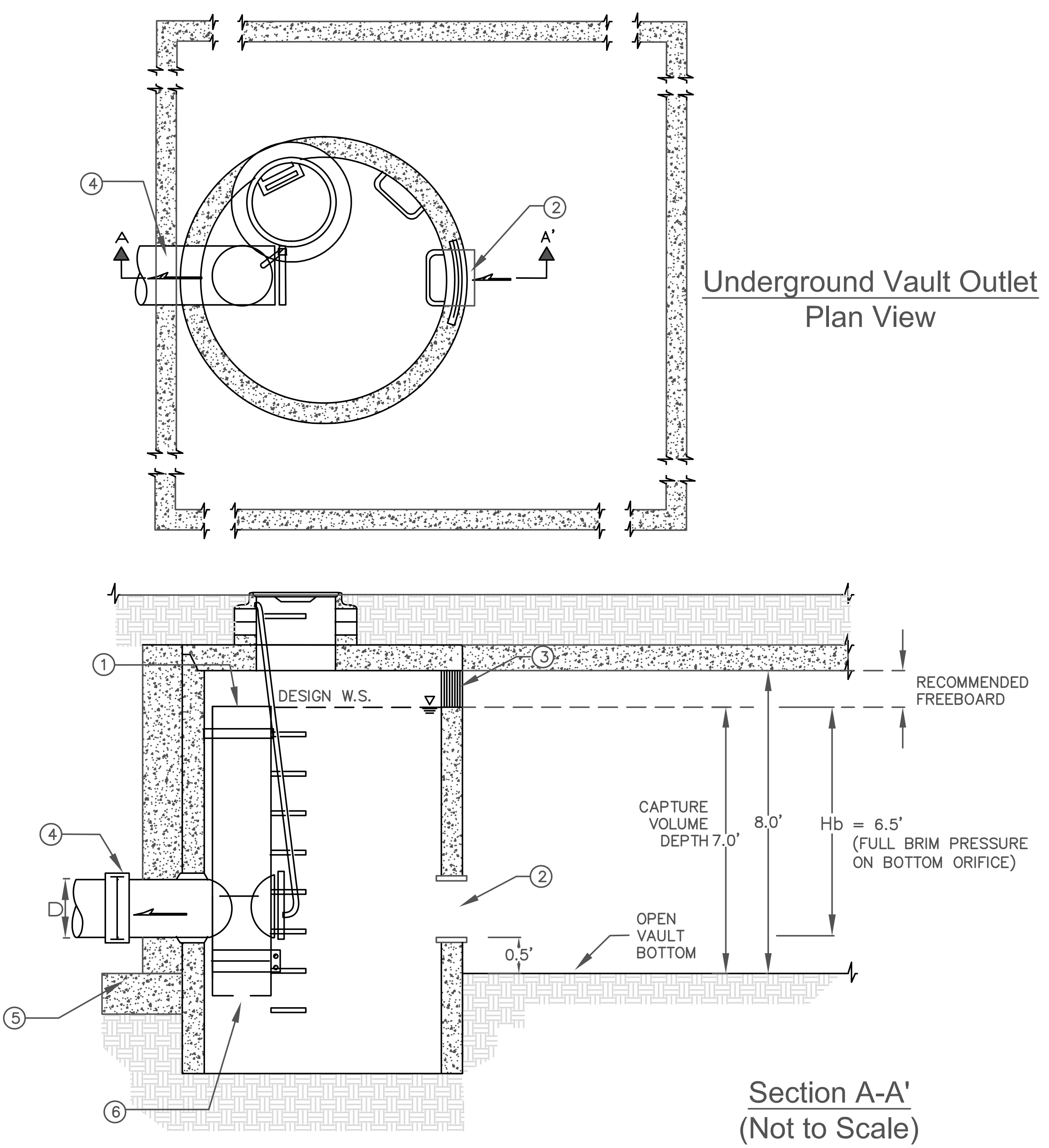
④ OUTLET PIPE SIZED TO CONVEY THE DESIGN DISCHARGE AS REQUIRED BY THE ORANGE COUNTY LOCAL DRAINAGE MANUAL AND HYDROLOGY MANUAL OR THE LOCAL PERMITTING AUTHORITY

⑤ BLIND FLANGE AT END OF SLOTTED UNDERDRAIN DRILLED TO SPECIFIC ORIFICE DIAMETER (C/D SOILS ONLY)

Geosyntec
consultants

Bioretention Facility

Figure 1. Bioretention Facility Schematic



NOTES:

① OVERFLOW DEVICE WITH WEIR LENGTH SIZED TO CONVEY THE DESIGN DISCHARGE AS REQUIRED BY THE ORANGE COUNTY LOCAL DRAINAGE MANUAL AND HYDROLOGY MANUAL OR THE LOCAL PERMITTING AUTHORITY

② PRIMARY INLET

③ SECONDARY INLET

④ OUTLET PIPE SIZED TO CONVEY THE DESIGN DISCHARGE AS REQUIRED BY THE ORANGE COUNTY LOCAL DRAINAGE MANUAL AND HYDROLOGY MANUAL OR THE LOCAL PERMITTING AUTHORITY

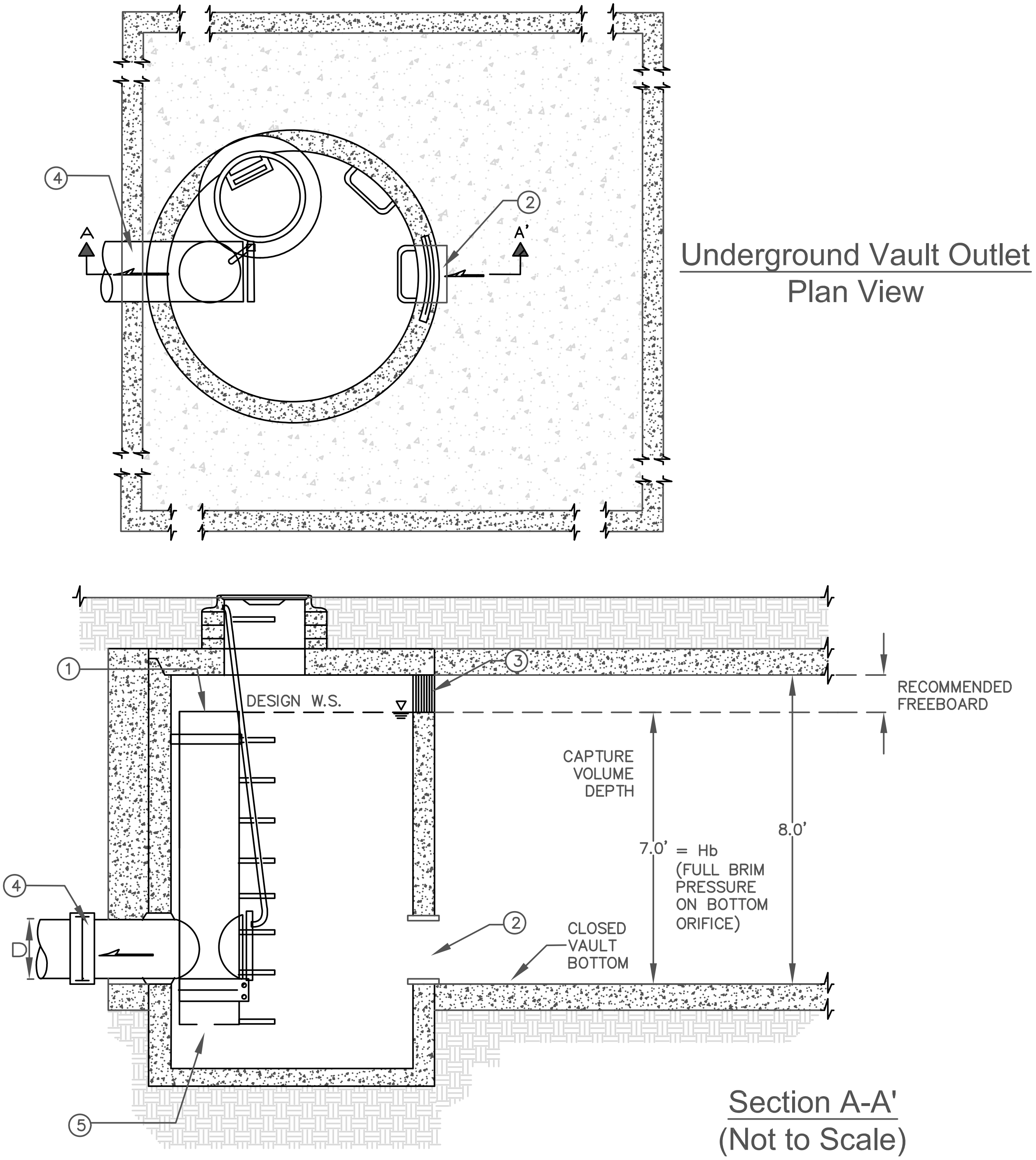
⑤ FOOTING FOUNDATION TO PROMOTE INFILTRATION WITHIN THE VAULT

⑥ RESTRICTOR PLATE WITH ORIFICE DIAMETER (C/D SOILS ONLY)

Geosyntec consultants

Vault- Open Bottom

Figure 2 Open-Bottom Underground Vault Schematic



NOTES:

① OVERFLOW DEVICE WITH WEIR LENGTH SIZED TO CONVEY THE DESIGN DISCHARGE AS REQUIRED BY THE ORANGE COUNTY LOCAL DRAINAGE MANUAL AND HYDROLOGY MANUAL OR THE LOCAL PERMITTING AUTHORITY

② PRIMARY INLET

③ SECONDARY INLET

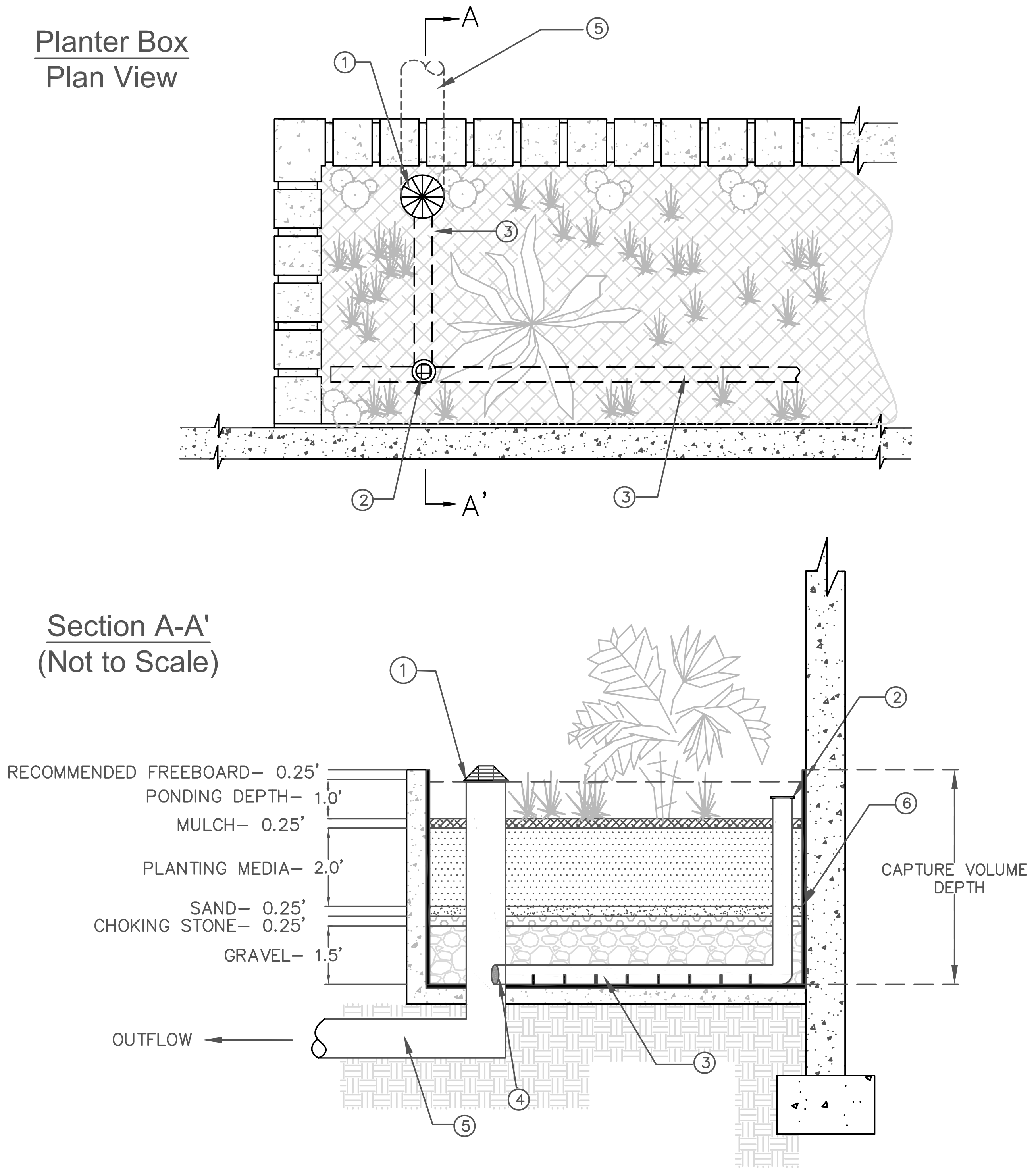
④ OUTLET PIPE SIZED TO CONVEY THE DESIGN DISCHARGE AS REQUIRED BY THE ORANGE COUNTY LOCAL DRAINAGE MANUAL AND HYDROLOGY MANUAL OR THE LOCAL PERMITTING AUTHORITY

⑤ RESTRICTOR PLATE WITH ORIFICE DIAMETER

Geosyntec consultants

Vault- Closed Bottom

Figure 3. Closed-Bottom Underground Vault Schematic



NOTES:

① OVERFLOW DEVICE WITH WEIR LENGTH SIZED TO CONVEY THE DESIGN DISCHARGE AS REQUIRED BY THE ORANGE COUNTY LOCAL DRAINAGE MANUAL AND HYDROLOGY MANUAL OR THE LOCAL PERMITTING AUTHORITY

② 6" MIN PVC PIPE CLEANOUT

③ SLOTTED 6" MIN PVC PIPE UNDERDRAIN

④ BLIND FLANGE AT END OF SLOTTED UNDERDRAIN DRILLED TO SPECIFIC ORIFICE DIAMETER

⑤ OUTLET PIPE SIZED TO CONVEY THE DESIGN DISCHARGE AS REQUIRED BY THE ORANGE COUNTY LOCAL DRAINAGE MANUAL AND HYDROLOGY MANUAL OR THE LOCAL PERMITTING AUTHORITY

⑥ WATERPROOF BARRIER

Geosyntec
consultants

Planter Box

Figure 4. Planter Box Schematic

2.2. BMP Sizing Curves

Figure 5 below shows the resulting BMP footprint area, Figure 6 shows the BMP capture volume, and Figure 7 shows the total volume (including the suggested freeboard volumes illustrated on Figures 1 to 4). The BMP footprint is defined as the plan view area at the overflow weir crest elevation and is expressed as a percentage of the tributary catchment area. The BMP capture volume is defined as the storage volume in the BMP below the overflow crest elevation and has units of watershed inches. The total BMP volume is defined as the storage volume contained beneath the suggested freeboard elevation, also expressed in watershed inches. Regression lines are provided on the charts so that the unit footprint area and storage volume can be interpolated for any value of imperviousness.

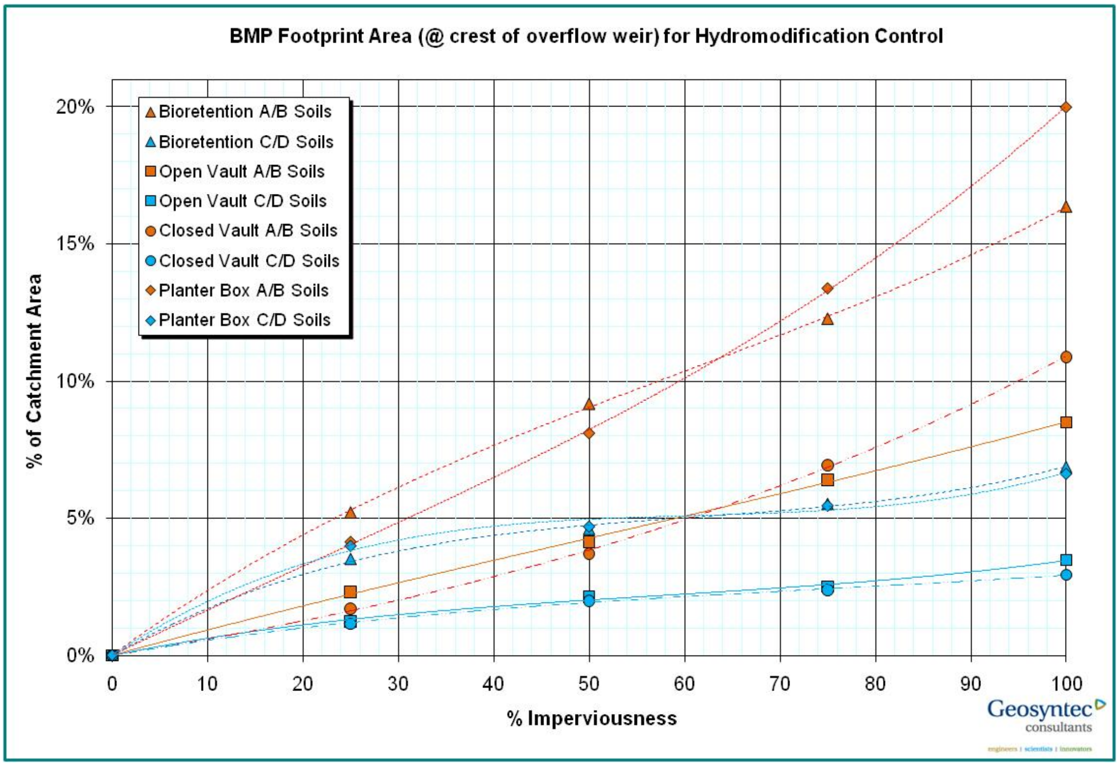


Figure 5. Sizing Chart for Unit BMP Footprint Area

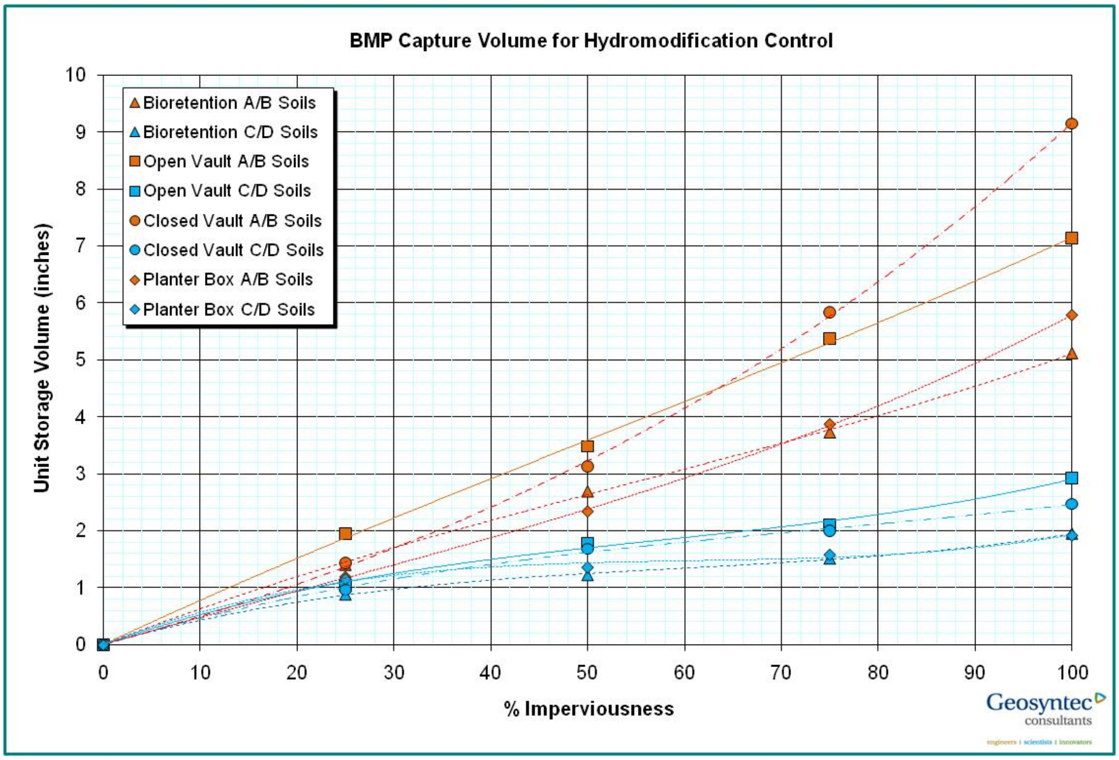


Figure 6. Sizing Chart for Unit BMP Capture Volume

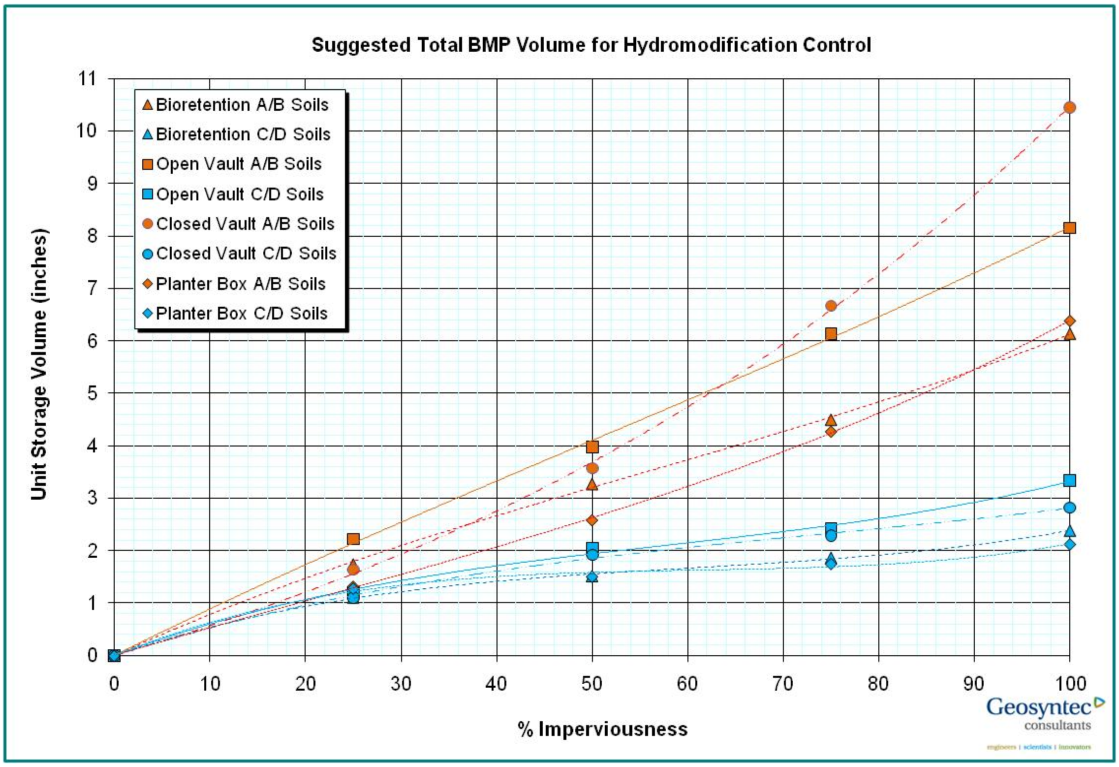


Figure 7. Sizing Chart for Unit BMP Total Volume

2.3. Instructions for Spreadsheet Sizing Tool

The South Orange County Hydromodification Control BMP Sizing Tool spreadsheet is structured so that inputs entered in the "master" worksheet generate the necessary parameters for sizing BMPs to meet the IHC. The inputs and outputs to the spreadsheet master worksheet are described below, as well as allowable modifications to the design configurations illustrated in Figures 1 through 4 that would comply with the IHC.

2.3.1. Inputs

Catchment ID is a label that helps to organize different drainage areas within a Priority Development Project. The user can choose any naming convention they wish for the Catchment ID.

BMP Type must be selected from a pull-down menu of the four BMP types included in the tool.

Soil Type must be selected from a pull-down menu as "A/B" if the catchment is a Type A or B soil or "C/D" if the catchment is a Type C or D soil[7].

Catchment Area is the acreage tributary to the BMP being sized. For a bioretention facility or planter box, the catchment area must include the area of the BMP itself. This is not the case for the underground vault BMPs because precipitation does not fall directly on the BMPs.

Imperviousness is the proportion of impervious surface area in the project catchment. Impervious areas include, but are not limited to, rooftops, asphalt pavement, and concrete surfaces. For a bioretention facility or planter box, the BMP footprint area should be assumed to be impervious.

85th Percentile Storm Depth is used to compute the Stormwater Quality Design Volume (SQDV) per the Orange County Drainage Area Management Plan Exhibit 7.II, Model Water Quality Management Plan.

2.3.2. Outputs

BMP Footprint Area is the area, in square feet, of the BMP at the overflow weir crest.

BMP Capture Volume is the storage capacity, in cubic feet, of the BMP below the overflow weir crest. This volume includes the air space above the media material, as well as the interstitial space in the media (i.e. gravel, choke stone, sand, plant media, and mulch).

Total BMP Volume is the storage capacity, in cubic feet, below the suggested freeboard elevation. Total BMP Volume is not viewed to be as crucial to flow duration control as the Capture Volume.

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[7] Hydrologic Soil Group for a site can be found at http://websoilsurvey.nrcs.usda.gov/app/websoilsurvey.aspx.

Orifice Diameter is the size of the low flow control opening, in inches. The diameter is rounded to the nearest 1/32nd inch, so that standard drill bits can be used to create the orifice.

The last output provides a yes or no answer to the question, "Is the Hydromodification Capture Volume greater than the SQDV?" If the answer is "yes", then the hydromodification BMP sizing outputs are appropriate. If the answer is "no" then the SQDV should be used in place of the Hydromodification BMP Capture Volume. For guidance on sizing treatment control BMPs, see Orange County Drainage Area Management Plan Exhibit 7.II, Model WQMP[8].

2.3.3. Modifying the BMP Design Configuration

If a project proponent wishes to modify the design configurations provided in Figures 1 through 4 while still using the spreadsheet tool to size the BMP, then the modified BMP shall meet the following criteria:

1. If the BMP allows for infiltration into the underlying soils (i.e. bioretention or vault with open bottom), then the footprint area at the bottom of the BMP shall be equal to or greater than the bottom footprint calculated using the sizing tool[9].

2. The BMP Capture Volume stored below the overflow weir crest shall be equal to or greater than the capture volume calculated using the sizing tool.

3. The available freeboard height and storage above the overflow weir crest can be modified as long as the peak design discharge, required by the Orange County Local Drainage Manual (OCEMA 1996) and Hydrology Manual (OCEMA 1986) or the local permitting authority, can be properly conveyed.

4. If the full brim pressure on the bottom orifice is modified, then the low flow orifice diameter shall be modified such that the low flow threshold ($0.1Q_2$) is conveyed at the new full brim pressure.

One example of a configuration modification is to reduce the depth of an underground vault with an open bottom. If the design depth is changed from 7 feet, as shown in Figure 2, to 4 feet, then the footprint area must increase to maintain the BMP Capture Volume. For this case the footprint must increase by at least 7/4 (1.75) times assuming the walls are vertical. Increasing the design depth beyond 7 feet in order to reduce the footprint, however, is not an allowable modification.

If the underground vault requires a low flow orifice, then the orifice diameter must increase such that the low flow threshold ($0.1Q_2$) is conveyed at the reduced brim-full depth. For

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[8] The SQDV will only be greater than the Hydromodification Capture Volume if the developed catchment has low imperviousness (2% to 4% or lower). Most Priority Development Projects are expected to have greater imperviousness than this threshold.

[9] For the bioretention facility, the bottom footprint area is the same as the top of media, which can be calculated assuming 3:1 side slopes dropping 1.5-ft from the overflow weir crest elevation to the top of mulch.

instance, assume the sizing tool computes the orifice diameter to be 3 inches for a brim-full depth of 6.5 feet. If the brim-full depth of the modified vault is 3.5 feet, then the modified low flow orifice diameter can be computed using the following formula[10]:

$$D_{mod} = D_{tool} [H_{tool}/H_{mod}]^{1/4}$$

Where:

D_{mod} = modified low flow orifice diameter (inches)
D_{tool} = calculated low flow orifice diameter from the sizing tool (inches)
H_{tool} = assumed brim-full pressure head used in the sizing tool (feet)
H_{mod} = modified brim-full pressure head (feet)

Using this formula for the example, the modified low flow orifice diameter (D_{mod}) is 3-½ inches ($3 * [6.5/3.5]^{1/4}$).

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[10] This formula is derived from the orifice discharge equation provided in Appendix I.

Appendix I. Modeling Methodology

APPROACH

BMP types were selected based on responses to a three question survey of the South Orange County cities, provided in Table A-1 below. The responses indicate that smaller, site-based BMPs were more likely to be implemented during the interim period than larger regional detention basins.

Table A-1. BMP Survey Responses

	Municipality				
QUESTIONS	**Mission Viejo**	**Laguna Niguel**	**Dana Point**	**Lake Forest**	**San Juan Capistrano**
1. What types of new development and redevelopment projects are anticipated which may need to use the interim hydromodification sizing tool?	Commercial	High Density Residential	Small Redevelop-ment	Residential, Commercial, Sports Park, & Playgrounds	Redevelopment
2. What is the range of project sizes that are anticipated in the next year or so?[1]	0.5 to 10.3 acres	2 acres	< 1 to 2.3 acres	60 to < 800 acres	1 to < 50 acres
3. What two types of structural BMPs would be most useful to have a design tool for?	Under-ground Detention Vault & Bioretention	Bioretention	Under-ground Detention Vault & Bioretention	Detention Pond, Detention Vault, Detention Pipe, & Bioretention	Detention Vault, Detention Pipe, Bioretention, Detention Domes, & Combined Bioretention and Vault

[1] Large project areas may need to be subdivided into multiple catchment areas.

ASSUMPTIONS

For each BMP type, ten continuous hydrologic simulations associated with a combination of two soil types (A/B and C/D) and five imperviousness values (1%, 25%, 50%, 75%, and 100%), were performed on a generic catchment area in order to generate long-term flow records. The generic catchment area was set to 1 acre to size the bioretention facility, 10 acres to size the underground vaults, and ¼ acre to size the planter box. These areas were used because they are between the expected lower and upper limits of catchment areas likely to drain into each BMP type. Bioretention facilities are expected to be applied to catchments ranging between 5,000 square feet (0.11 acres) to 5 acres, underground vaults are expected to be applied to catchments ranging between 1 acre and 50 acres, and planter boxes are expected to be applied to catchments less than 1 acre. While the 1% imperviousness simulation represents the baseline pre-development flow records, the 25%, 50%, 75%, and 100% simulations represent a range of post-development flow conditions. The BMPs were sized by iteratively adjusting the BMP footprint until flow duration control was achieved, as stipulated by the IHC for the minimum footprint allowable.

Geosyntec performed continuous simulations using US EPA's Storm Water Management Model (SWMM). Stage-storage-discharge relationships were included in the post-development SWMM simulations so that the post-development flow records could be routed through the BMP being sized. Table A-2 below provides the key SWMM catchment parameters.

Table A-2. Key SWMM Catchment Parameters

PARAMETER	VALUE
Precipitation Gage	Trabuco
Area	1 acre (Bioretention) 10 acres (Underground Vault)
Catchment Slope	5 %
% Imperviousness	Pre-development: 1% Post-Development: 25%, 50%, 75%, & 100%
Depression Storage – Impervious	0.02 inches
Depression Storage – Pervious	0.10 inches
Infiltration Method	GREEN AMPT
Hydraulic Conductivity	Pre-Development A/B Soils: 0.30 inches/hour Post-Development A/B Soils: 0.23 inches/hour Pre-Development C/D Soils: 0.05 inches/hour Post-Development C/D Soils: 0.04 inches/hour

Detailed SWMM parameters are listed in Table A-3 below.

Table A-3. Detailed SWMM Catchment Parameters

PARAMETER	UNIT	VALUE A/B Soils	VALUE C/D Soils
Subcatchment SWMM Parameters			
Precipitation Gage	--	Trabuco	Trabuco
Outlet	--	N/A	N/A
Area	Acres	10, 1, 0.25	10, 1, 0.25
Width	Feet	660, 209, 104	660, 209, 104
% Slope	%	5	5
% Imperv	%	1, 25, 50 75, & 100	1, 25, 50 75, & 100
N-Imperv	--	0.012	0.012
N-Perv	--	0.15	0.15
Dstore-Imperv	Inches	0.02	0.02
Dstore-Perv	Inches	0.1	0.1
%Zero-Imperv	%	25	25
Subarea Routing	--	OUTLET	OUTLET
Percent Routed	%	100	100
Infiltration	Method	GREEN_AMPT	GREEN_AMPT
Suction Head	Inches	1.5	8
Undeveloped Conductivity	in/hr	0.3	0.05
Developed Conductivity	in/hr	0.23	0.04

PARAMETER	UNIT	VALUE A/B Soils	VALUE C/D Soils
Initial Deficit	Fraction	0.33	0.30
Groundwater	yes/no	NO	NO
Climatology SWMM Parameters			
Temperature	--	N/A	N/A
Evaporation	Monthly Averages	CIMIS Zone 4	CIMIS Zone 4
Wind Speed	--	N/A	N/A
Snow Melt	--	N/A	N/A
Areal Depletion	--	N/A	N/A
Simulation Options			
Infiltration Model	--	Green Ampt	Green Ampt
Routing Method	--	None	None
Reporting Time Step	Days:Hr:Min:Sec	1 hour	1 hour
Dry Weather Time Step	Days:Hr:Min:Sec	4 hours	4 hours
Wet Weather Time Step	Days:Hr:Min:Sec	15 minutes	15 minutes
Routing Time Step	Seconds	60	60
Dynamic Wave Inertial Terms	--	Dampen	Dampen
Define Supercritical Flow By	--	Both	Both
Force Main Equation	--	Hazen-Williams	Hazen-Williams
Variable Time Step Adjustment Factor	%	75	75
Conduit Lengthening	Seconds	0	0
Minimum Surface Area	Square Feet	0	0

Additional model parameters and assumptions include:

- **Precipitation Data**: The Trabuco precipitation record was used because the rainfall intensity is greater than that measured at the Laguna gage, the other long-term precipitation record in South Orange County. By using a more intense rainfall record, this results in more conservative BMP sizes.

- **Catchment Dimensions**: The assumed generic catchment width is square.

- **Slope**: A typical South Orange County terrain is assumed to have a 5% catchment slope.

- **Infiltration Parameters**: The assumed pre-development hydraulic conductivity is based on typical values associated with Soil Types A/B and C/D, as referenced in *SWMM Hydrology: Runoff and Service Modules* (James et al, 2002)[11]. The post-development hydraulic conductivity was assumed to be 75% of the pre-development hydraulic

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[11] James W., Huber W.C., Pitt R.E., Dickinson R.E., James W.R.C. 2002. SWMM Hydrology: Runoff and Service Modules.

conductivity in order to account for disturbance and compaction. The post-development hydraulic conductivity was also used as the infiltration rate within the BMPs.

BMP CONFIGURATION ASSUMPTIONS

Bioretention Facility Assumptions (Figure 1)

- Low flow threshold = 10% of the 2-year pre-development flow rate ($0.1Q_2$)[12].
- Infiltration rate into A/B soils = 0.23 inches/hour. Infiltration rate into C/D Soils = 0.04 inches/hour.
- Media storage capacity = porosity – field capacity. This assumes that only freely drained storage is considered. The storage capacity used for gravel and choke stone is 0.4, for sand and plant media is 0.26, and for mulch is 0.5.
- An underdrain and low flow orifice is used for C/D Soils, but not for A/B Soils.
- Low flow orifice is sized to discharge the low flow threshold at the head associated with the overflow weir elevation (C/D Soils only)[13].
- Slotted underdrain pipe capacity and infiltration rate through media is significantly greater than the low flow threshold of $0.1Q_2$ (C/D Soils only).
- Overflow weir crest length is sized to convey the peak design flowrate determined from the Orange County flood control standards[14].
- Slotted underdrain pipe invert and low flow orifice @ 0.5-ft from bottom of facility (C/D Soils only).
- Top of Media @ 4.75-ft from bottom of facility.
- Vertical walls between the bottom of facility and top of media.
- 3:1 side slopes above top of media.
- Overflow weir @ 6.25-ft from bottom of facility.
- 0.5-ft of freeboard above overflow weir.

Underground Vault with Open Bottom Assumptions (Figure 2)

- Low flow threshold = 10% of the 2-year pre-development flow rate ($0.1Q_2$).

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[12] 0.1Q2 was determined by constructing a partial-duration series as follows. For the entire runoff time series generated by the model, the runoff time series was divided into a set of discrete events. Flow events were considered separate when the flow rate dropped below a threshold value of 0.002 cfs/acre for a period of at least 24 hours. The peak flow was determined for each event and ranked to establish the 2 year return frequency.

[13] Discharge from an orifice is calculated using the equation $Q = 3.78\ D^2\ H^{1/2}$ where:
Q = discharge (cfs); D = diameter (ft); H = head above the orifice center (ft).

[14] Discharge from a rectangular weir is calculated using the equation $Q = 3.33\ L\ H^{1.5}$ if the weir is suppressed and $Q = 3.33\,(L - 0.2H)\ H^{1.5}$ if the weir is contracted where:
Q = discharge (cfs), L = crest length (ft); H = head above weir crest (ft).

- Infiltration rate into A/B soils = 0.23 inches/hour. Infiltration rate into C/D Soils = 0.04 inches/hour.
- Low flow orifice is included for C/D Soils, not for A/B Soils.
- Low flow orifice is sized to discharge the low flow threshold at the head associated with the overflow weir elevation (C/D Soils only).
- Overflow weir crest length is sized to convey the peak design flow rate determined from Orange County flood control standards.
- Low flow orifice discharge @ 0.5-ft from bottom of facility (C/D Soils only).
- Vertical walls throughout.
- Overflow weir @ 7.0-ft from bottom of facility.
- 1.0-ft of freeboard above overflow weir.

Underground Vault with Closed Bottom Assumptions (Figure 3)

- Low flow threshold = 10% of the 2-year pre-development flow rate ($0.1Q_2$).
- No infiltration into soils.
- Low flow orifice is included for C/D and A/B Soils.
- Low flow orifice is sized to discharge the low flow threshold at the head associated with the overflow weir elevation.
- Overflow weir crest length is sized to convey the peak design flow rate determined from Orange County flood control standards.
- Low flow orifice discharge is located at same elevation as the bottom of vault. (Note: sediment storage capacity should be provided below the low flow orifice plate as shown on Figure 3; this can be accomplished by placing the outlet structure in a separate manhole or lowering the vault floor below the outlet. Any added storage below the outlet does not count towards the BMP Capture Volume.)
- Vertical walls throughout.
- Overflow weir @ 7.0-ft from bottom of facility.
- 1.0-ft of freeboard above overflow weir.

Planter Box Assumptions (Figure 4)

- Low flow threshold = 10% of the 2-year pre-development flow rate ($0.1Q_2$).
- No infiltration into soils.

- Media storage capacity = porosity – field capacity. This assumes that only freely drained storage is considered. The storage capacity used for gravel and choke stone is 0.4, for sand and planting media is 0.26, and for mulch is 0.5.
- An underdrain and low flow orifice is used for C/D and A/B Soils.
- Low flow orifice is sized to discharge the low flow threshold at the head associated with the overflow weir elevation.
- Slotted underdrain pipe capacity and infiltration rate through media is significantly greater than the low flow threshold of $0.1Q_2$.
- Overflow weir crest length is sized to convey the peak design flowrate determined from the Orange County flood control standards.
- Slotted underdrain pipe invert and low flow orifice @ bottom of facility.
- Top of Media @ 4.25-ft from bottom of facility.
- Vertical walls throughout.
- Overflow weir @ 5.25-ft from bottom of facility.
- 0.25-ft of freeboard above overflow weir.

RESULTS

Figures A-1 through A-8 below provide the flow duration curves for all forty SWMM simulations (2 soil types x 4 BMP types x 5 imperviousness values), which demonstrate that the IHC is met. The IHC is met because the flow duration curve for the post-development condition with BMPs is below the pre-development (naturally-occurring) condition within the flow limits specified ($0.1Q_2$ to Q_{10}).

In evaluating the proportions of runoff exiting the modeled BMPs, it was confirmed that the modeled hydromodification BMPs meet the 80% runoff capture goal for treatment[15], as shown in Table A-4 below.

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[15] It was assumed that BMPs, which allow infiltration (bioretention and underground vault w/ open bottom) and are placed in C/D soils, do require biotreatment, via a low flow orifice, in order to feasibly achieve 80% runoff capture. BMPs, which allow infiltration and are in areas with A/B soils, do not need biotreatment to achieve 80% runoff capture. BMPs, which do not allow infiltration (underground vault with closed bottom and planter box), do require biotreatment, via a low flow orifice, in order to feasibly achieve 80% runoff capture.

Table A-4. Proportions of Runoff Exiting the BMPs

BMP Type	Soil Type	Imperviousness (%)	Infiltrated Runoff (%)	Runoff Routed Through Orifice (%)	Bypassed Runoff (%)	Captured Runoff (%)	Goal Met for 80% Capture (yes/no)
Bioretention	C/D	100	18.0	75.0	7.1	92.9	Yes
Bioretention	C/D	75	13.8	77.6	8.6	91.4	Yes
Bioretention	C/D	50	14.6	75.4	9.9	90.1	Yes
Bioretention	C/D	25	15.1	71.0	14.0	86.0	Yes
Bioretention	A/B	100	98.0	N/A	2.0	98.0	Yes
Bioretention	A/B	75	97.2	N/A	2.8	97.2	Yes
Bioretention	A/B	50	96.7	N/A	3.3	96.7	Yes
Bioretention	A/B	25	93.1	N/A	6.9	93.1	Yes
Vault-Open	C/D	100	20.3	74.7	5.0	95.0	Yes
Vault-Open	C/D	75	17.5	75.6	6.8	93.2	Yes
Vault-Open	C/D	50	18.7	73.7	7.6	92.4	Yes
Vault-Open	C/D	25	14.6	72.0	13.4	86.6	Yes
Vault-Open	A/B	100	98.2	N/A	1.8	98.2	Yes
Vault-Open	A/B	75	97.8	N/A	2.2	97.8	Yes
Vault-Open	A/B	50	96.4	N/A	3.6	96.4	Yes
Vault-Open	A/B	25	94.6	N/A	5.4	94.6	Yes
Vault-Closed	C/D	100	N/A	93.8	6.2	93.8	Yes
Vault-Closed	C/D	75	N/A	93.0	7.0	93.0	Yes
Vault-Closed	C/D	50	N/A	92.2	7.8	92.2	Yes
Vault-Closed	C/D	25	N/A	86.3	13.7	86.3	Yes
Vault-Closed	A/B	100	N/A	98.4	1.6	98.4	Yes
Vault-Closed	A/B	75	N/A	98.0	2.0	98.0	Yes
Vault-Closed	A/B	50	N/A	97.4	2.6	97.4	Yes
Vault-Closed	A/B	25	N/A	96.2	3.8	96.2	Yes
Planter Box	C/D	100	N/A	92.6	7.4	92.6	Yes
Planter Box	C/D	75	N/A	91.8	8.2	91.8	Yes
Planter Box	C/D	50	N/A	91.0	9.0	91.0	Yes
Planter Box	C/D	25	N/A	89.1	10.9	89.1	Yes
Planter Box	A/B	100	N/A	97.7	2.3	97.7	Yes
Planter Box	A/B	75	N/A	97.7	2.4	97.7	Yes
Planter Box	A/B	50	N/A	97.3	2.7	97.3	Yes
Planter Box	A/B	25	N/A	96.2	3.8	96.2	Yes

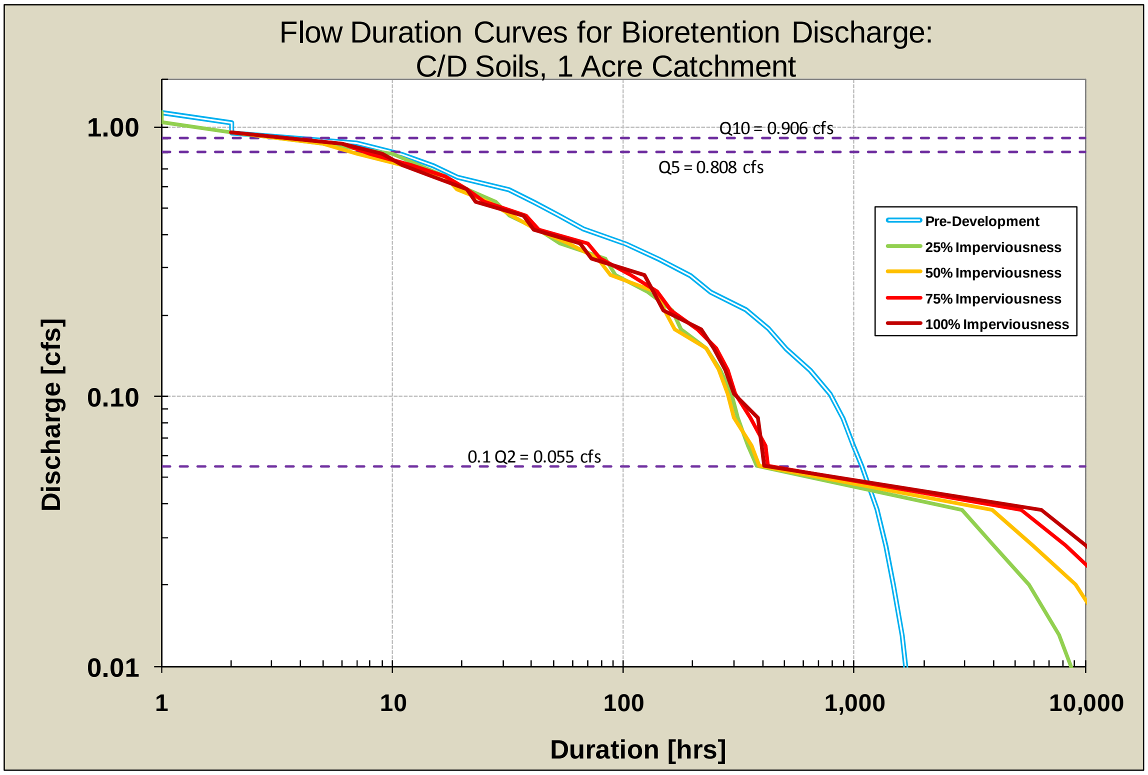

Figure A-1. Flow Duration Results for Bioretention BMP with C/D Soils

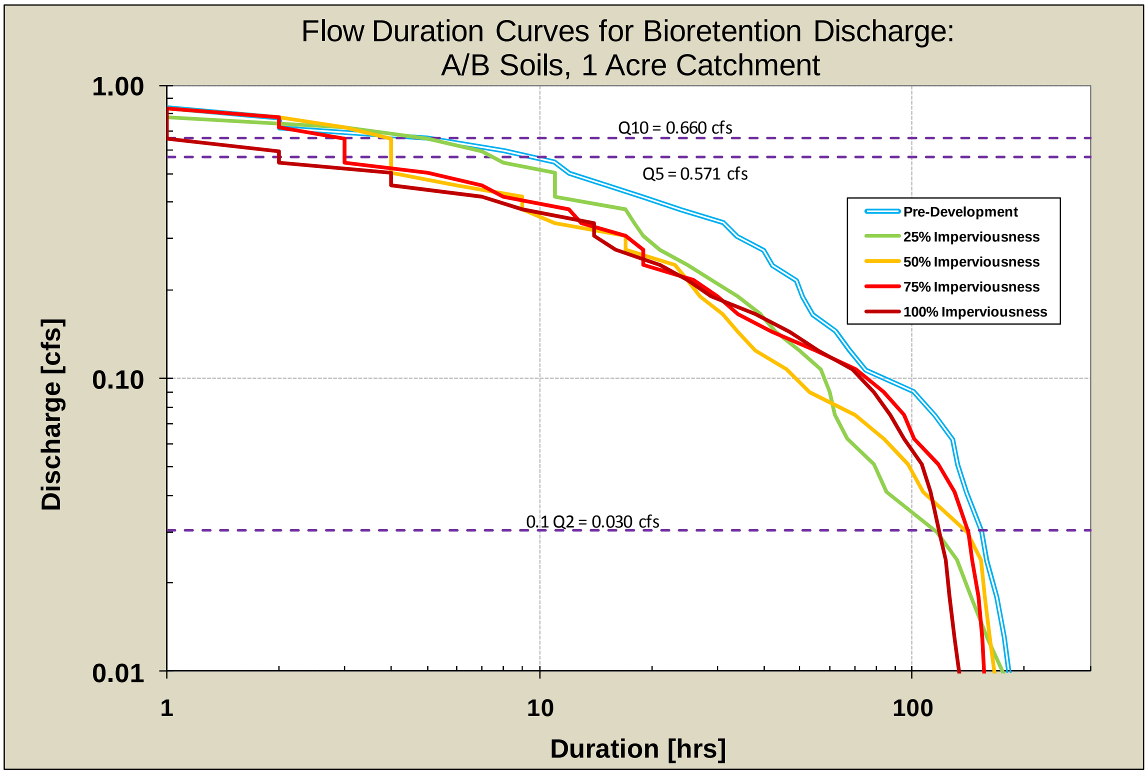

Figure A-2. Flow Duration Results for Bioretention BMP with A/B Soils

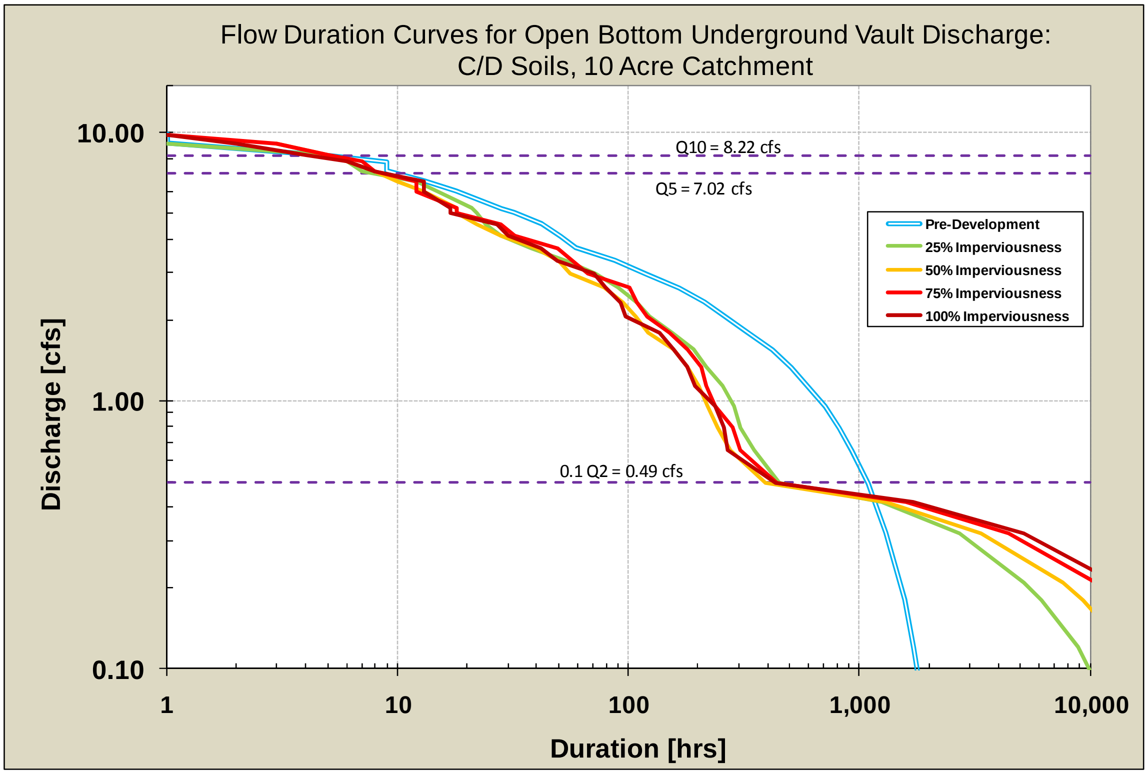

Figure A-3. Flow Duration Results for Open Bottom Underground Vault BMP with C/D Soils

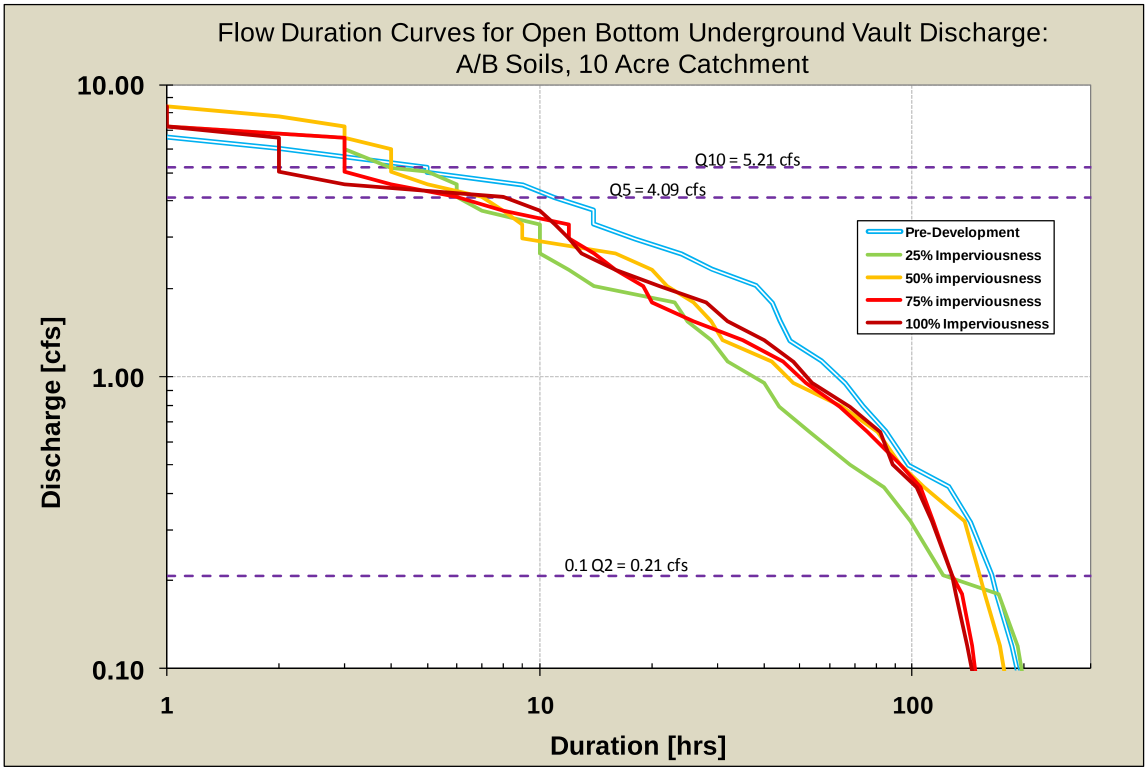

Figure A-4. Flow Duration Results for Open Bottom Underground Vault BMP with A/B Soils

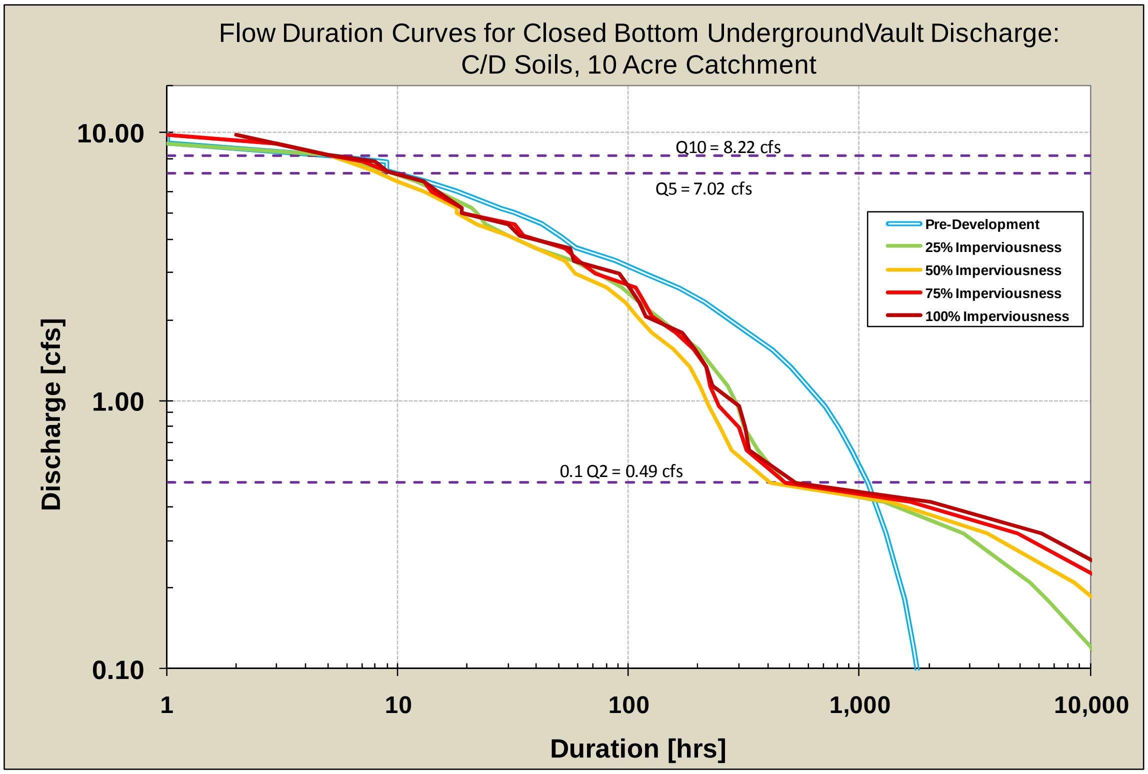

Figure A-5. Flow Duration Results for Closed Bottom Underground Vault with C/D Soils

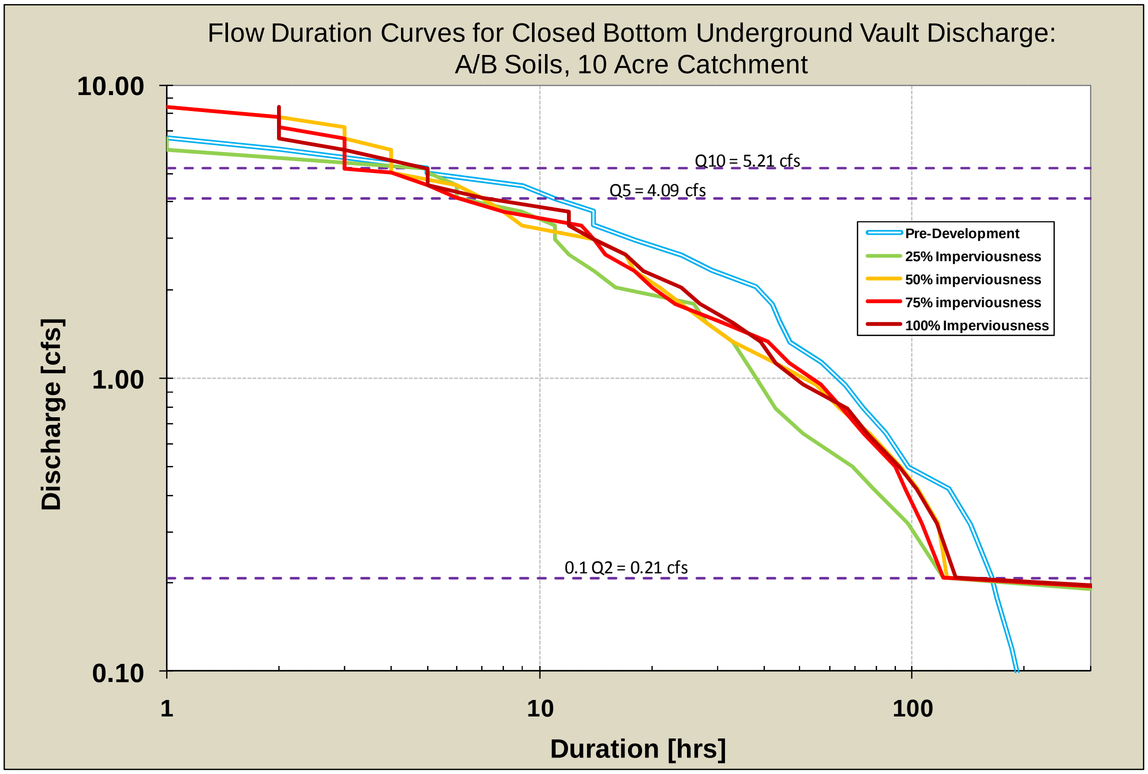

Figure A-6. Flow Duration Results for Closed Bottom Underground Vault with A/B Soils

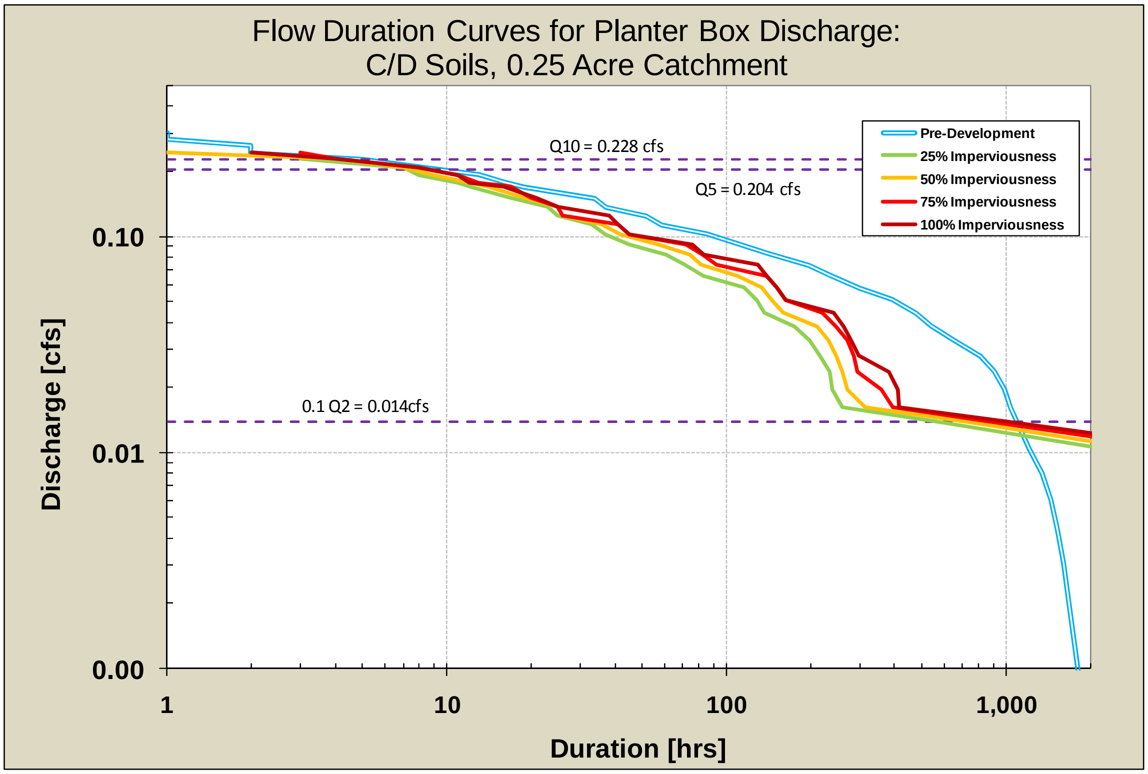

Figure A-7. Flow Duration Results for Planter Box BMP with C/D Soils

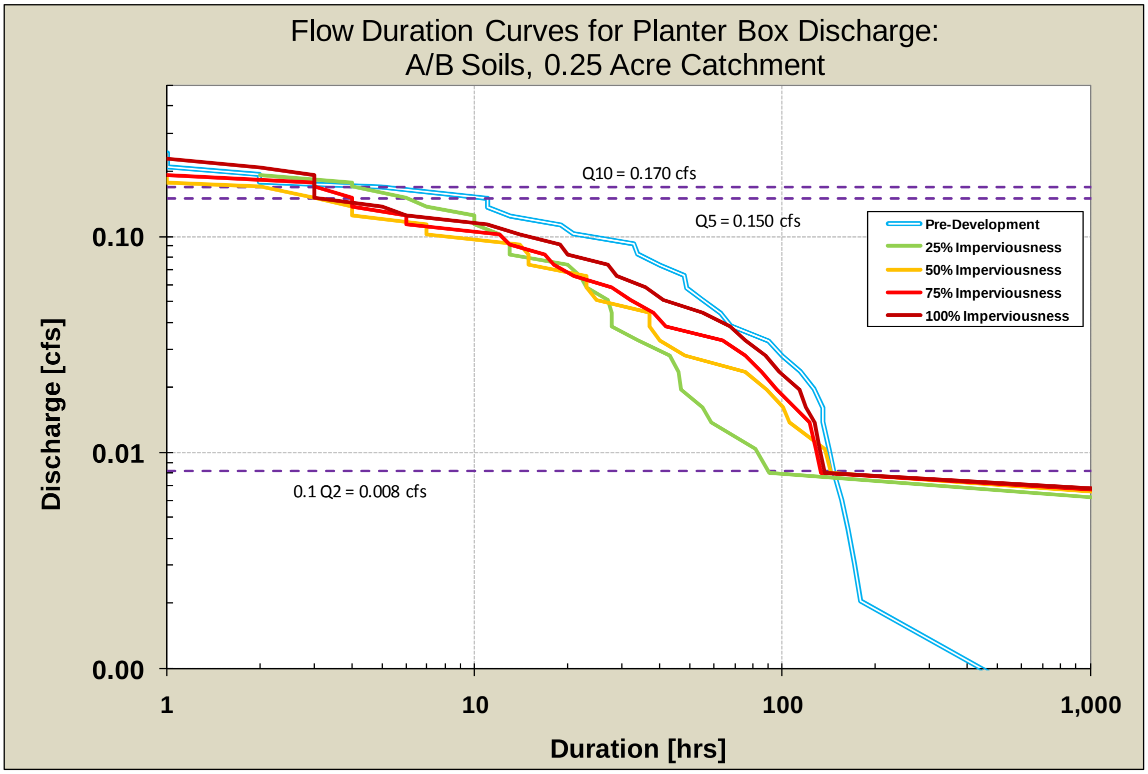

Figure A-8. Flow Duration Results for Planter Box BMP with A/B Soils