Appendix A: BMP Fact Sheets

June 2010 Version - Updates and errata will be published as necessary

BMP Fact Sheets

INTRODUCTION

The Fact Sheets in this appendix describe Stormwater Best Management Practices (BMPs), also known as stormwater controls or stormwater management facilities, that can be used to meet the stormwater management requirements in the *Guidelines*. The majority of BMPs included here are plant- and soil-based stormwater controls. These types of stormwater controls are multi-purpose: they not only provide the core stormwater management functions of pollutant removal, peak flow reduction, and runoff volume reduction, they also enhance urban habitat, improve overall watershed health, and provide aesthetic benefits.

This set of Fact Sheets is not intended to be exhaustive or prescriptive – creative design and future innovation will generate new kinds of BMPs to meet stormwater management requirements. Designers should keep in mind that the regulatory requirement for stormwater management lies with achievement of stormwater management performance measures, not with the use of particular BMPs. BMPs should be selected based upon site-specific variables such as soils, slopes, target pollutants, and urban design goals. For more information on selecting BMPs, see the BMP Decision Tree on page 85 of the *Guidelines*. SFPUC and Port project review staff will be happy to work with project teams who propose new design ideas that may not be included here.

Each Fact Sheet provides a labeled schematic diagram; a snapshot of the level of pollutant removal, volume reduction, and peak flow reduction provided by a given BMP; technical information about the benefits, limitations, siting, design considerations, operations and maintenance, and cost of the BMP; and a list of references and resources.

The Fact Sheets are aimed at informing planning-level design decisions, including the estimated dimensions and location of a proposed BMP. They are not meant to be used as the sole basis for creating construction drawings.

IMPORTANT DEFINITIONS

The following terms appear throughout the fact sheets:

- Water quality volume (WQv) – the runoff volume to be managed by the stormwater BMP such that treatment requirements are met.
- Water quality flow rate (WQf) – the required flow rate to be managed by the stormwater BMP such that the treatment requirements are met.

A rocky swale creates a creek-like environment at Roosevelt Community Center in Santa Clara.

Leland Avenue, San Francisco, under construction. Permeable pavement will be installed on the sidewalk and in the parking lane.

- Drawdown time – the time it takes for the storage area of the BMP to drain the water quality volume. In San Francisco, the maximum drawdown time is 48 hours.
- Offline – BMP is configured to receive only the design flow from the contributing area. Higher flows are bypassed to the collection system.
- Online – BMP is configured to receive all flows from the contributing drainage area (BMP typically also includes an overflow device to convey higher flows to the collection system).

MAXIMUM EXTENT PRACTICABLE

Most of the BMPs in this appendix meet the Regional Water Board's "Maximum Extent Practicable" (MEP) treatment standard (see page 12 of the *Guidelines* for a description of the MEP standard), meaning that they satisfy regulatory requirements when used to treat stormwater. However, the detention vault, swirl separator, drain insert, and water quality inlet do not meet the MEP standard when used alone. To meet the MEP standard, they must be used in combination with other BMPs – a concept called a treatment train.

DESIGN REQUIREMENTS

The *Guidelines* require that BMPs accommodate and treat the water quality volume or flow rate (as appropriate based on BMP selection) for a given contributing area. The performance measures that are used to calculate the water quality volume and flow rate for the Port and SFPUC are described on pages 57 and 63 of the *Guidelines*, respectively. Designers are also responsible for ensuring that larger flows are safely accommodated by the project, as described in further detail in the Offsite Conveyance Requirements section on page 120 of Appendix A.

INFILTRATION BMP DESIGN PARAMETERS AND SETBACKS

Many of the BMPs in the following fact sheets are infiltration-based BMPs. Infiltration-based BMPs are subject to the following design parameters:

- 4-foot minimum depth to bedrock
- 4-foot minimum depth to groundwater
- Native soil minimum infiltration rate of 0.5 inches per hour (general rule: soils should not have more than 30% clay content or 40% clay and silt combined)
- For infiltration basins, infiltration trenches, and dry wells: native soil maximum infiltration rate of 2.5 inches per hour or runoff must be treated prior to infiltration

- Not suitable in areas with contaminated groundwater or sediment
- Not suitable in Maher Ordinance areas, landslide hazard areas, or areas of known fill

Setbacks are measured as the horizontal distance from the edge of the stormwater facility to the adjacent boundary, structure, or facility. Under certain conditions, SFPUC or Port project review staff may approve reduced setbacks. The tables below summarize standard and conditional setback requirements for the City of San Francisco.

Standard Setbacks for Infiltration BMPs in San Francisco

Distance (ft)	Setback from	Conditions
5	Property line	Standard for all infiltration facilities
10	Downgradient from foundations	Standard for all infiltration facilities
100	Upgradient from foundations	Standard for all infiltration facilities
100	Upgradient from slopes 15% or greater	Standard for all infiltration facilities
150	Drinking water well	Standard for all infiltration facilities

Conditional Setbacks for Infiltration BMPs in San Francisco

Distance (ft)	Setback from	Conditions
0	Foundations	If the system is a waterproof, lined, flow-through facility OR if there is no run-on to the facility and a waterproof separation barrier is provided between the BMP drain rock and adjacent foundations
5	Downgradient from foundations	If the drainage area < 1000 ft^2 OR if drainage area < 5000 ft^2 and adjacent buildings do not have basements OR if an official request form is submitted to City Staff along with a geotechnical analysis showing that the decreased setback will not result in flooding or structural damage to adjacent foundations.
50	Upgradient from foundations	If the drainage area < 1000 ft^2 OR if drainage area < 5000 ft^2 and adjacent buildings do not have basements OR if an official request form is submitted to City Staff along with a geotechnical analysis showing that the decreased setback will not result in flooding or structural damage to adjacent foundations.

Dry Well

Also known as: roof runoff control, stormwater drainage well, stormwater injection well, bored well, infiltration gallery, seepage pit

Roof leader 1

Building foundation 2

Overflow pipe 3

Splash block 4

Observation well 5

1-foot soil cover typical 6

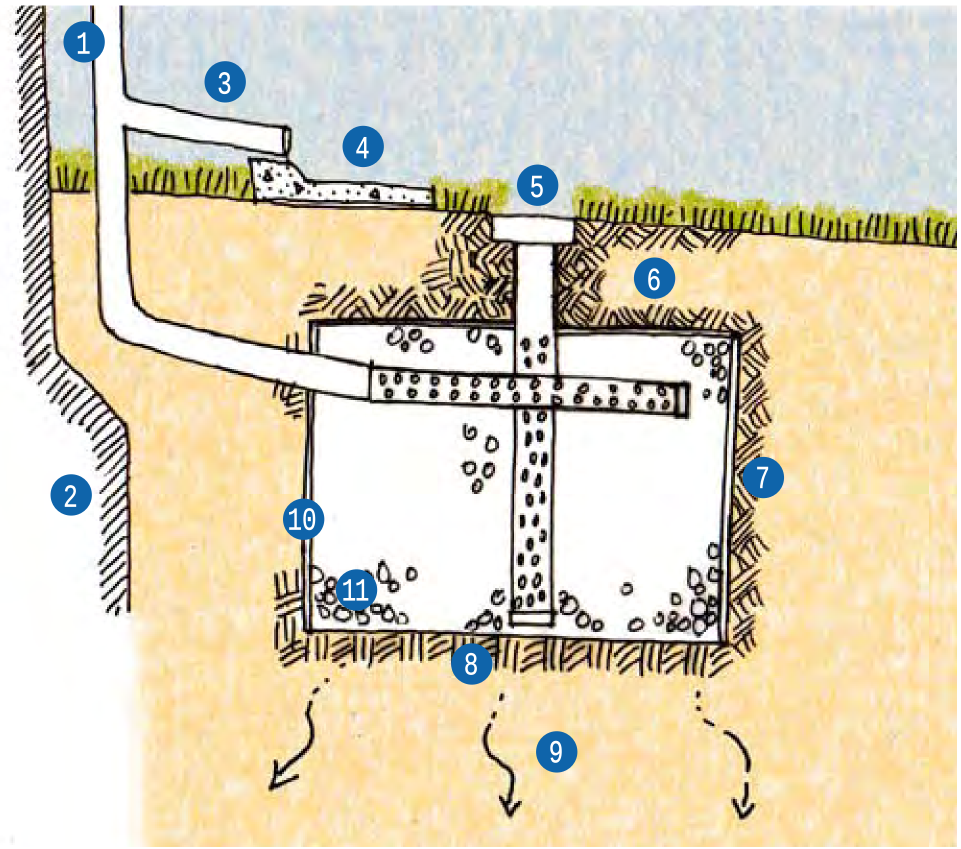
Minimum 2-foot depth 7

2 to 5-foot diameter typical 8

Minimum infiltration rate of 1/2-inch per hour 9

Non-woven geotextile fabric or well walls 10

1½ to 3-inch coarse aggregate 11

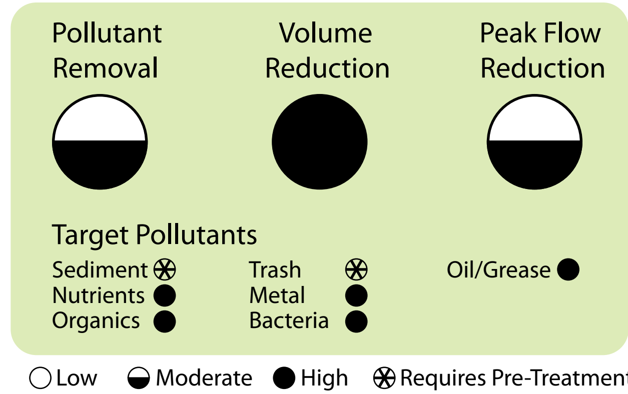


DESCRIPTION

A dry well is an underground stormwater storage structure with no outlet other than percolation to the soil. Dry wells collect stormwater and allow it to infiltrate into the surrounding soil for groundwater recharge, much like infiltration trenches. However, while infiltration trenches tend to be long narrow trenches at the surface, dry wells are vertical holes dug into the ground. According to the EPA, a drywell is considered to be a Class V stormwater drainage well if it is "any bored, drilled, or driven shaft, or dug hole that is deeper than its widest surface dimension, or an improved sinkhole, or a subsurface fluid distribution system (an infiltration system with piping to enhance infiltration capabilities)."

Dry wells that fall under the Class V injection well category must submit an inventory form to the EPA. There are two main types of dry wells:

- Unlined dry wells consist of an earthen pit filled with gravel or riprap (as described in Materials paragraph). Such pits resist collapse but their storage capacity is limited because their interior column is filled with crushed stone. These dry wells are more prone to sediment clogging, but are less expensive to construct.
- Lined dry wells are typically contained by a reinforced concrete cylinder with perforated sides and bottom, allowing greater storage volume. Lined dry wells achieve the same stormwater management function of volume reduction as infiltration basins, but differ from infiltration basins in that they are underground and tend to be smaller.



BENEFITS

- Reduces runoff volume and rate and attenuates peak flows.
- Improves water quality - good for removing fine sediment and adsorbed pollutants.
- Enhances groundwater recharge and contributes to stream base flow.
- Minimal space requirements.
- Visually unobtrusive.

LIMITATIONS

- Must have minimum soil infiltration rate of 0.5 inches/hour, not appropriate for Hydrologic Soil Types C and D (impermeable soils).
- If infiltration rates exceed 2.5 inches/hour, runoff should be fully treated prior to infiltration to protect groundwater quality.
- 4-foot minimum separation from basin bottom to groundwater is required, unless the Regional Water Quality Control Board approves otherwise.
- Depth to bedrock must be over 4 feet for infiltration-based systems.
- Not suitable in areas with contaminated groundwater or sediment.
- Siting challenges in urban areas (see "Setbacks" in Siting section).
- Potentially expensive in urban areas because they are underground.

SITING

Dry wells are often used to infiltrate stormwater runoff from roofs and parking lots, but can be used in a variety of other applications. Dry wells that infiltrate runoff from roof downspouts have been successful in the long term because roof runoff contains little sediment. Other applications often require pre-treatment screening.

Drainage area: Dry wells are recommended for small drainage areas with low pollutant loadings, such as rooftops less than 0.25 acres in size.

Setbacks: Dry wells should be placed a minimum of 10 feet downgradient or 100 feet upgradient of building foundations. If the drainage area is less than 1000 square feet or if the drainage area is less than 5000 square feet and adjacent buildings do not have basements, City of San Francisco staff may approve reduced setbacks of 5 and 50 feet, respectively. Infiltration-based BMPs must also be at least 5 feet from any property line, 100 feet from any downgradient slope greater than 15%, and 150 feet from any drinking water well.

Soils and infiltration rate: The infiltration rate of the native soil should be between 0.5 and 2.5 inches per hour. If the infiltration rate exceeds 2.5 inches per hour, then runoff should be fully treated (e.g., with one or more upstream BMPs) prior to infiltration to protect groundwater quality. As a general rule, soils should not have more than 30% clay content or 40% clay and silt combined. If they do, it may be necessary to choose a different BMP.

Groundwater protection: Because dry wells rely on infiltration, the potential for groundwater contamination must be carefully evaluated. Dry wells should not be used in areas where the seasonally high groundwater elevation is less than 4 feet beneath the dry well invert. They are also unsuitable for sites that use or store chemicals or hazardous materials, unless those materials are prevented from entering the dry well. In these areas, other BMPs that do not allow interaction with the groundwater should be considered. A geotechnical investigation should ascertain how the stormwater runoff will move in the soil both horizontally and vertically, accounting for any geological conditions that could inhibit water movement.

DESIGN CONSIDERATIONS

Materials: Pit-type dry wells should be filled with double-washed locally available rock with a diameter range of 1.5 to 3 inches (AASHTO size 2 or 3). To minimize sedimentation from lateral soil movement in simple dry wells, the sides and top of the dry well gravel matrix can be lined with a permeable filter fabric such as needled nonwoven polypropylene fiber filters (e.g., Mirafi 140N, Amoco 4547, or Geotex 451). The bottom of the dry well should remain open to maximize infiltration.

Pre-Treatment: Sediment and trash accumulation can markedly shorten the operating life of the well, requiring more frequent, large-scale rehabilitation. In areas with high sediment loads, a dry well may require pre-screening to prevent sediment and trash from clogging the well. They can also be paired with upstream BMPs such as vegetated buffer strips, vegetated swales, detention ponds, or vortex/swirl separators.

Overflow: Dry wells should be constructed to operate offline, allowing for flows exceeding storage capacity to bypass the dry well and enter the collection system or another BMP. Where possible, dry wells should have a drainage mechanism, such as an underdrain, in case of clogging.

Access: Dry wells should have a direct access path for inspection and maintenance activities. A perforated observation pipe can be inserted vertically into the dry well to allow inspectors to monitor the drawdown rate. If needed, the observation pipe may be used in conjunction with a suitable pump to drain the dry well.

Sizing: Dry wells should have a minimum depth of 2 feet. Usually they have a diameter no wider than 12 feet, typically with one foot of soil cover on top. The dry well should be designed to drain within 48 hours. Dry wells for San Francisco can be sized using the volume-based calculations described in Step 7 of the Stormwater Control Plan chapter of the *Guidelines*. An electronic sizing tool is also provided with the *Guidelines* and is hosted on the SFPUC website at http://stormwater.sfwater.org in the Stormwater Design Guidelines section. The sizing tool is the same as that for infiltration trenches, with due consideration for changed geometry. The tool should be used for planning purposes only, such as determining the general footprint and preliminary dimensions. This calculator is not intended to provide final detailed calculations or dimensions.

OPERATIONS AND MAINTENANCE

Dry well longevity can be increased by careful geotechnical evaluation prior to construction, and by designing and implementing an inspection and maintenance plan. Dry wells should only be constructed after the entire area draining to the facility has been stabilized. During construction, care should be taken to divert sediment-laden runoff away from the well. Good construction practices should minimize over-compaction, sediment generation, and smearing. The table below provides more information on typical post-construction inspection and maintenance activities.

Typical Inspection Activities for Dry Wells

Activity	*Schedule*
• Check observation wells 48 hours after the end of wet weather. Failure to percolate within this time period indicates clogging. • Inspect pretreatment devices and diversion structures for sediment build-up and structural damage.	Post-construction and semi-annually (beginning and end of rainy season)

Typical Maintenance Activities for Dry Wells

Activity	*Schedule*
• Remove sediment and oil / grease from pretreatment devices and overflow structures.	Semi-annually or as needed
• If dry well has not drained within 48 hours after end of storm, drain well via pumping, clean perforated piping and gravel media, and excavate soil walls of unlined dry well to expose clean soil (typically 2 inches).	Upon failure (expected to be > 10 years)

COST

Dry well construction costs can range from $4-$9 per cubic foot of storage volume, but costs vary widely depending on design configuration, location, soils, and material availability. Annual maintenance costs have been reported to be around 5 to 10% of capital costs.

REFERENCES AND RESOURCES

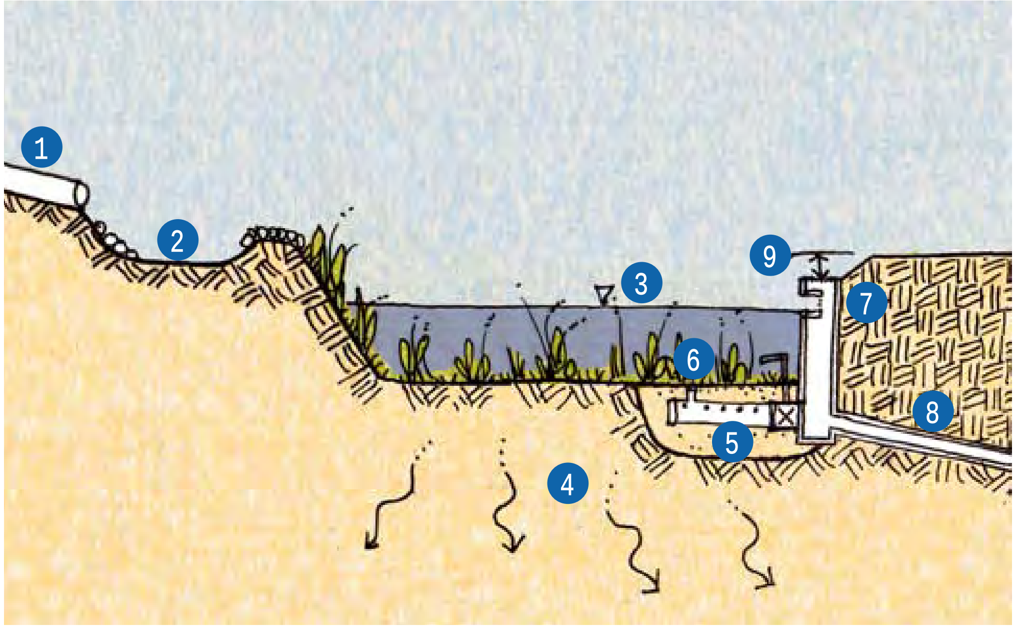
California Stormwater Quality Association. 2004. *Stormwater Best Management Practice Handbook: New and Redevelopment.*

Environmental Protection Agency. "Storm Water Injection Well Best Management Practices." 2 June 2008 <http://www.epa.gov/safewater/uic/class5/types_stormwater.html>.

Tredyffrin Township, Chester County, Pennsylvania. "Stormwater Management: Front Yard / Back Yard Watershed Solutions." 2 June 2008 <http://www.tredyffrin.org/departments/stormwater/>.

Infiltration Basin

Also known as: soakage basin, infiltration pond



1. Inlet
2. Forebay (pretreatment and energy dissipation)
3. Water quality volume level
4. Minimum infiltration rate of 1/2-inch per hour
5. Underdrain with shut-off valve (for maintenance if bottom clogs)
6. Underdrain cleanout
7. Overflow structure with screened inlets
8. Outlet to collection system, catch basin, or receiving water
9. Minimum 1 foot freeboard

DESCRIPTION

An infiltration basin is a shallow impoundment over permeable soil that captures stormwater, stores it, and allows it to infiltrate, using the natural filtering ability of the soil to remove stormwater pollutants. This practice has a high removal efficiency for fine sediment and associated pollutants. However, coarse sediment and oils will plug the basin and should be removed using appropriate pretreatment practices, such as vegetated swales, before runoff reaches the basin. A forebay at the entrance to the basin will also extend the basin's longevity and reduce maintenance costs. In addition to removing pollutants, infiltration basins also help recharge groundwater. As with any infiltration BMP, the potential for groundwater contamination must be carefully considered, especially if groundwater is used for human consumption or agricultural purposes.

A key feature of an infiltration basin is its vegetation. Deep-rooted plants on the basin bottom reduce the risk of clogging and increase the infiltration capacity by creating small conduits through which water can infiltrate. Dense vegetation also impedes soil erosion and scouring of the basin floor.

In addition to stormwater treatment, infiltration basins can provide recreational, wildlife habitat, and aesthetic benefits. Infiltration basins can be challenging to apply on many sites because of soil requirements. In addition, some studies have shown relatively high failure rates for infiltration-based practices compared with other types of BMPs.

Pollutant Removal	Volume Reduction	Peak Flow Reduction
●	●	●

Target Pollutants

Sediment ○ ⊛	Trash ○ ⊛	Oil/Grease ●
Nutrients ●	Metal ●	
Organics ●	Bacteria ●	

○ Low ◒ Moderate ● High ⊛ Requires Pre-Treatment

BENEFITS

- Improves water quality by removing sediment, nutrients, organic matter, and trace metals.
- Reduces runoff volume and attenuates peak flows.
- Improves urban hydrology and facilitates groundwater recharge.
- Creates habitat and increases biodiversity in the city.
- Can provide open space, aesthetic, and recreational amenities.
- Can function as regional facility treating large volumes of water.
- Low construction and maintenance costs.

LIMITATIONS

- Must have minimum soil infiltration rate of 0.5 inches/hour, not appropriate for Hydrologic Soil Types C and D (impermeable soils).
- If infiltration rates exceed 2.5 inches/hour, runoff should be fully treated prior to infiltration to protect groundwater quality.
- 4-foot minimum separation from basin bottom to groundwater is required, unless the Regional Water Quality Control Board approves otherwise.
- Depth to bedrock must be over 4 feet for infiltration-based systems.
- Not suitable on fill sites, steep slopes, contaminated soils, industrial sites, or sites where spills are likely to occur.

SITING

Drainage area: Infiltration basins are most successful when receiving runoff from relatively small drainage areas, typically less than 10 acres, and designed exclusively for water quality treatment and infiltration. They can be designed as larger, regional facilities that provide both water quality treatment and flood control in areas with sufficient soil infiltration

An infiltration basin in Waterworks Gardens at the King County East Division Reclamation Plant, Renton, WA, is part of an environmental art park that treats stormwater. Runoff flows through stormwater treatment ponds, and the wetlands form an earth/water sculpture that funnels, captures and releases water.

rates; however, past experience indicates higher failures rates when they are used in this manner.

Soils and infiltration rate: Infiltration basins can be implemented where the infiltration rates of native soils are 0.5 inches per hour or greater. However, if infiltration rates are greater than 2.5 inches per hour, runoff should be fully treated (e.g., with one or more upstream BMPs) prior to infiltration to protect groundwater quality. Infiltration rates can be determined through geotechnical investigations. Geotechnical reports must be used to determine how stormwater runoff will move in the soil (horizontally and vertically), and whether there are any geological conditions that could inhibit the movement of water. As a general rule, soils should not have more than 30% clay content or 40% clay and silt combined. If they do, it may be necessary to choose a different BMP.

Setbacks: Infiltration basins should be placed a minimum of 10 feet downgradient or 100 feet upgradient of building foundations. If the drainage area is less than 1000 square feet or if the drainage area is less than 5000 square feet and adjacent buildings do not have basements, City of San Francisco staff may approve reduced setbacks of 5 and 50 feet, respectively. Infiltration-based BMPs must also be at least 5 feet from any property line, 100 feet from any downgradient slope greater than 15%, and 150 feet from any drinking water well.

Groundwater protection: The seasonally high groundwater elevation and depth to bedrock should both be at least 4 feet from the basin invert to protect groundwater quality. If hazardous materials and other harmful substances are stored or used within the contributing drainage area, an infiltration basin should not be used unless these materials can be effectively prevented from entering stormwater draining to the basin. If this cannot be accomplished, other BMPs that do not allow interaction with the groundwater should be considered.

DESIGN CONSIDERATIONS

Dimensions: Infiltration basins are generally between 1 and 3 feet deep with earthen side slopes no steeper than 3H:1V to provide bank stability and allow for mowing. The bottom of the basin should be graded as flat as possible to provide uniform ponding and infiltration across the basin bottom.

Vegetation: Vegetation on the basin bottom and sides must be capable of surviving up to 48 hours under water. Native vegetation is preferred.

Pretreatment: Pretreatment measures should be used to prevent clogging of the basin bottom if runoff is expected to contain heavy sediment loads or oils and greases. Vegetated swales and sediment basins provide effective pretreatment, especially if implemented as a treatment train. The upstream drainage should be completely stabilized before the basin is constructed and construction techniques should minimize sedimentation and compaction of the basin bottom.

Online vs. offline configuration: Infiltration basins can be constructed such that they operate offline (high flows bypass the basin) or online (all flows are directed to the infiltration basin). When basins are constructed online, an overflow structure must be included in the design to convey flows exceeding the basin capacity to the collection system.

Access: Infiltration basin design should emphasize accessibility and ease of maintenance. Where possible the basin should have an underdrain with a shutoff valve, which allows the basin to be drained and accessed for maintenance in the event that clogging or soil saturation occurs.

Sizing: Infiltration basins are sized using the volume-based calculations described in Step 7 of the Stormwater Control Plan chapter of the *Guidelines*. Infiltration basins should be designed to infiltrate all stored runoff within 48 hours. An electronic sizing tool is also provided with the *Guidelines* and is hosted on the SFPUC website at http://stormwater.sfwater.org in the Stormwater Design Guidelines section. The tool should be used for planning purposes only, such as determining the general footprint and preliminary dimensions. This calculator is not intended to provide final detailed calculations or dimensions.

OPERATIONS AND MAINTENANCE

Proper soil conditions, sufficient pretreatment measures, and well-designed operations and maintenance programs are the key to implementing successful and long-lasting infiltration basins. As described above, maintenance reduction features should be incorporated into infiltration basins and, as with all BMPs, infiltration basins should have a direct access path for maintenance activities. A spill response plan must be developed which clearly identifies

Typical Inspection Activities for Infiltration Basins

Activity	Schedule
• Check for ponding 48 hours after the end of wet weather. Failure to percolate within this time period indicates clogging. Dead or dying grass is another indication of inadequate percolation. • Inspect pretreatment devices and diversion structures for sediment build-up and structural damage. • Check for erosion of side slopes and around invert. • Check for signs of petroleum hydrocarbon contamination.	Post-construction and semi-annually (beginning and end of rainy season)

Typical Maintenance Activities for Infiltration Basins

Activity	Schedule
• Mow / maintain vegetation and remove litter. • Remove sediment and oil / grease from pretreatment devices and overflow structures.	At least semi-annually
• Dethatch basin bottom when drain time exceeds 48 hours. • Stabilize eroded banks with erosion control mat or mulch and revegetate. • If petroleum hydrocarbon contamination identified, implement appropriate source control and pretreatment measures. • If clogging occurs, remove accumulated sediment, the disc or otherwise aerate bottom of basin. Avoid soil compaction during the process.	As needed
• Remove sediment from forebay when depth exceeds 6 inches or 50% of storage capacity.	As needed (expected frequency every 3 to 5 years)
• Remove sediment when the pond volume has been reduced by 10%. This can be measured with a barrel thief or on a sediment gauge installed near the basin outlet.	As needed (expected frequency every 10 to 20 years)
• Rehabilitate basin to original storage capacity and 48-hour drain time by excavating basin bottom to expose clean soil (typically 2 inches) and replanting.	Upon failure

the emergency steps to be taken in the event of an accidental release of large quantities of hazardous or harmful substances to the basin. The table on the previous page provides more information on typical post-construction inspection and maintenance activities.

COST

If adequate space is available, infiltration basins are relatively cost-effective stormwater treatment measures because little infrastructure is needed for their construction. However, site-specific conditions such as excavation, reconfiguration of existing storm drain systems to route runoff to basins, and other logistical considerations can cause significant variations in cost. CASQA (2003) cites examples of costs ranging from approximately $3 to $18 per cubic foot of storage. Annual maintenance costs are estimated to be approximately 5% to 10% of construction costs (EPA 2006). Adherence to siting, design, and maintenance guidelines will prevent early clogging and failure and reduce costs later on.

REFERENCES AND RESOURCES

California Stormwater Quality Association. 2003. "TC-11: Infiltration Basin." *California BMP Handbook- New Development and Redevelopment*.

Emmons & Olivier Resources. Presentation: "Minnesota Low Impact Development Comparison Study – Cost Comparison." 18 June 2008 <http://www.eorinc.com/PDFs/Resources/LID/Development_&_Maintenance_Cost.pdf>.

Environmental Protection Agency. "National Pollutant Discharge Elimination System Menu of Stormwater BMPs: Infiltration Basin." 18 June 2008 <http://cfpub.epa.gov/npdes/stormwater/menuofbmps/index.cfm?action=browse>.

Lee, G. Fred. 2000. "The Right BMPs?" *Stormwater 1*:64-72. 18 June 2008 <http://www.gfredlee.com/stormwater_bmp_1000.pdf>.

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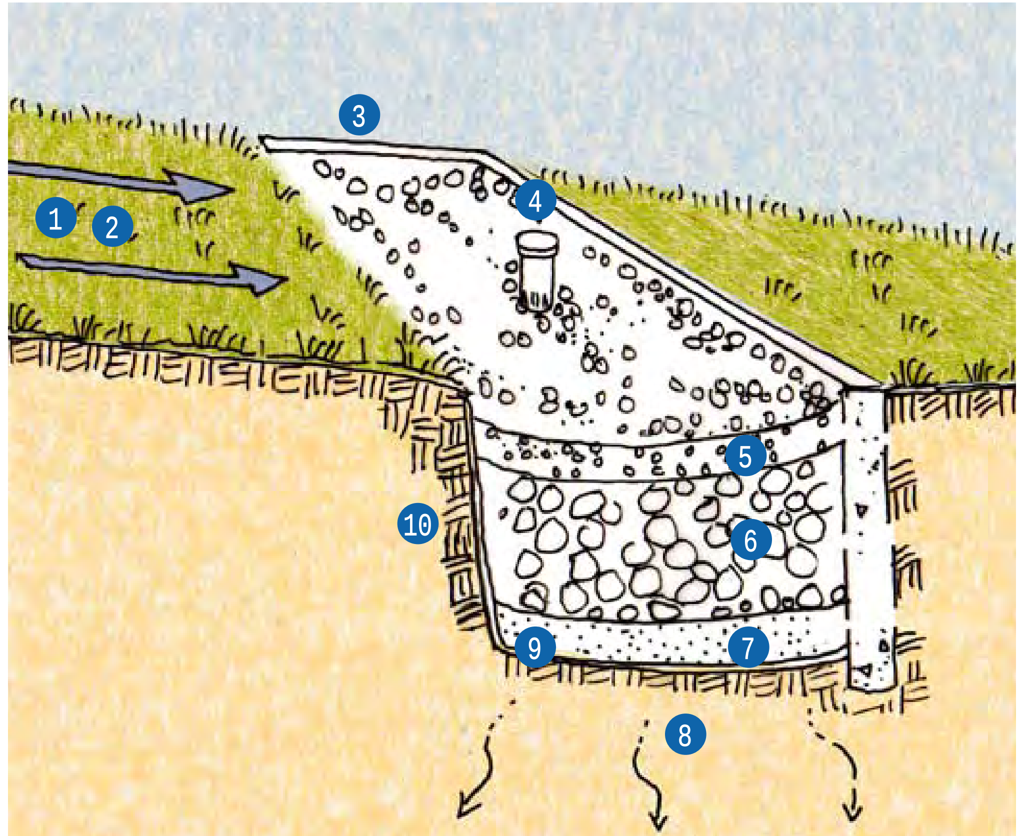
Infiltration Trench

Also known as: infiltration gallery, soakage trench

1. Pre-treatment required to limit large particle sedimentation
2. Surface flow
3. 25-foot maximum trench width
4. Observation well
5. Pea gravel surface
6. Coarse gravel
7. 6-inch sand filter
8. Minimum infiltration rate of 1/2-inch per hour
9. Optional filter fabric
10. 3- to 8-foot trench depth



DESCRIPTION

An infiltration trench is a long, narrow, rock-filled trench that receives stormwater runoff and allows it to infiltrate. Infiltration trenches have no outlet. Before entering the trench, runoff should pass through stormwater pretreatment measures, such as vegetated swales, sediment basins, or swirl separators, to remove coarse sediment that can clog the void spaces between the stones and render the trench ineffective. Pretreated runoff is stored in the void spaces and slowly infiltrates through the bottom of the trench into the soil matrix, thus contributing to groundwater recharge.

Infiltration trenches perform well for removal of fine sediment and associated pollutants. As with any infiltration BMP, the potential for groundwater contamination must be assessed.

Pollutant Removal	Volume Reduction	Peak Flow Reduction
●	●	●

Target Pollutants

Sediment	○ ⊛	Trash	○ ⊛	Oil/Grease	●
Nutrients	●	Metal	●		
Organics	●	Bacteria	●		

○ Low ◒ Moderate ● High ⊛ Requires Pre-Treatment

BENEFITS

- Improves water quality by removing sediment, nutrients, organic matter, and trace metals.
- Reduces runoff volume and attenuates peak flows.
- Improves urban hydrology and facilitates groundwater recharge.
- Low construction and maintenance costs.

LIMITATIONS

- Suitable for drainage areas of approximately 5 acres or less.
- Must have minimum soil infiltration rate of 0.5 inches/hour, not appropriate for Hydrologic Soil Types C and D (impermeable soils).
- If infiltration rates exceed 2.5 inches/hour, runoff should be fully treated prior to infiltration to protect groundwater quality.
- 4-foot minimum separation from trench bottom to groundwater is required, unless the Regional Water Quality Control Board approves otherwise.
- Depth to bedrock must be over 4 feet for infiltration-based systems.
- Not suitable on fill sites, steep slopes, contaminated soils, industrial sites, or sites where spills are likely to occur.

SITING

Siting considerations for infiltration trenches are essentially the same as those for infiltration basins, with the exception of smaller drainage area limitations.

<u>Drainage area</u>: Infiltration trenches are most successful when used for relatively small drainage areas, typically less than 5 acres. These areas can have high impervious cover.

This infiltration trench doubles as a parking strip along the Sustainable Streetscapes and Fish Habitat Enhancement Project: Crown Street, Vancouver, British Columbia.

Soils and infiltration rate: Infiltration trenches can be implemented where infiltration rates are 0.5 inches per hour or greater. However, if infiltration rates are greater than 2.5 inches per hour, runoff should be fully treated (e.g., with one or more upstream BMPs) prior to infiltration to protect groundwater quality. Infiltration rates can be determined through geotechnical investigations. Geotechnical reports should also be used to determine how stormwater runoff will move in the soil (horizontally and vertically), and whether there are any geological conditions that could inhibit the movement of water. As a general rule, soils should not have more than 30% clay content or 40% clay and silt combined. If they do, it may be necessary to choose a different BMP.

Setbacks: Infiltration trenches should be placed a minimum of 10 feet downgradient or 100 feet upgradient of building foundations. If the drainage area is less than 1000 square feet or if the drainage area is less than 5000 square feet and adjacent buildings do not have basements, City of San Francisco staff may approve reduced setbacks of 5 and 50 feet, respectively. Infiltration-based BMPs must also be at least 5 feet from any property line, 100 feet from any downgradient slope greater than 15%, and 150 feet from any drinking water well.

Groundwater protection: The seasonally high groundwater elevation and depth to bedrock should both be at least 4 feet from the basin invert to protect groundwater quality. If hazardous materials and other harmful substances are stored or used within the contributing drainage area, an infiltration trench should not be used unless these materials can be effectively prevented from entering stormwater draining to the trench. If this cannot be accomplished, other BMPs that do not allow interaction with the groundwater should be considered.

DESIGN CONSIDERATIONS

Dimensions: Infiltration trenches are generally between 3 and 8 feet deep and not more that 25 feet wide. They should have a flat surface and bottom to promote uniform infiltration across the trench. The top two inches should be a pea gravel filter layer with optional filter fabric below. Trench fill material should be double washed locally available rock with a diameter range of 1.5 to 2.5 inches and a porosity of about 35%. Below the rock layer is a 6-inch deep sand filter layer. There should be no vertical piping in an infiltration trench to avoid classification as a Class V injection well. The sides of the trench can be lined with filter fabric to prevent adjacent soils from clogging the rock.

Pretreatment: Pretreatment measures to remove coarse sediment, oils, and greases before runoff reaches the infiltration trench are critical to prevent clogging and failure. Whether the trench is configured to receive concentrated inflow from a pipe or channel or to receive overland sheet flow, one or more pretreatment practices should be used to remove gross solids before runoff reaches the trench. Pretreatment measures may include swirl separators, vegetated swales, and sediment basins. The upstream drainage should be completely stabilized before the trench is constructed, and construction techniques should minimize compaction of trench bottom.

Overflow: Infiltration trenches should be designed to operate offline, such that only design flows are diverted to the trench and the remainder are bypassed.

Access: Designs for infiltration trenches should emphasize accessibility and ease of maintenance. Where possible the trench should have an underdrain with a shutoff valve to allow drainage in case the rock becomes clogged. An observation well (a perforated PVC leading to the bottom of the trench) should be included in the design to allow monitoring of the drawdown rate.

Sizing: Infiltration trenches are sized using the volume-based calculations described in Step 7 of the Stormwater Control Plan chapter of the *Guidelines*. They should hold the design volume within the void space of the rock layer and should infiltrate all stored runoff within 48 hours. An electronic sizing tool is also provided with the *Guidelines* and is hosted on the SFPUC website at http://stormwater.sfwater.org in the Stormwater Design Guidelines section. A dimension-based formula is also included with the sizing tool, which allows the user to specify dimensions based on site constraints. The tool will then calculate the volume of water treated and will indicate whether the performance measure has been met. The tools should be used for planning purposes only, such as determining the general footprint and preliminary dimensions. This calculator is not intended to provide final detailed calculations or dimensions.

OPERATIONS AND MAINTENANCE

Proper soil conditions, sufficient pretreatment measures, and well-designed operations and maintenance programs are the key to implementing successful and long-lasting infiltration trenches. As described above, maintenance reduction features should be incorporated into infiltration trenches and, as with all BMPs, infiltration trenches should have a direct access path for maintenance activities. A spill response plan must be developed which clearly identifies the emergency steps to be taken in the event of an accidental release of large quantities of hazardous or harmful substances to the trench. The table below provides more information on typical post-construction inspection and maintenance activities.

Typical Inspection Activities for Infiltration Trenches

Activity	Schedule
• Check observation wells 48 hours after the end of wet weather. Failure to drain within this time period indicates clogging. • Inspect pretreatment devices and diversion structures for sediment build-up and structural damage.	Post-construction and semi-annually (beginning and end of rainy season)

Typical Maintenance Activities for Infiltration Trenches

Activity	Schedule
• Remove sediment and oil / grease from pretreatment devices and overflow structures. • Replace pea gravel when clogged.	As needed
• Rehabilitate trench to original storage capacity and 48-hour drain rate by removing trench rock, tilling the bottom of the trench, and replacing the bottom layer of sand.	Upon failure

COST

Typical construction costs, including contingency and design costs, have been estimated at $5 per cubic foot of runoff treated; however, Caltrans has reported costs as high as $50 per cubic foot of runoff for trenches installed as retrofit measures (CASQA, 2003). Annual maintenance costs are estimated at between 5% and 20% of construction costs. Fairfax (2005) estimates the lifespan of an infiltration trench at 10 years for its cost analysis; however, the lifespan may be increased by adhering to pretreatment and maintenance protocols.

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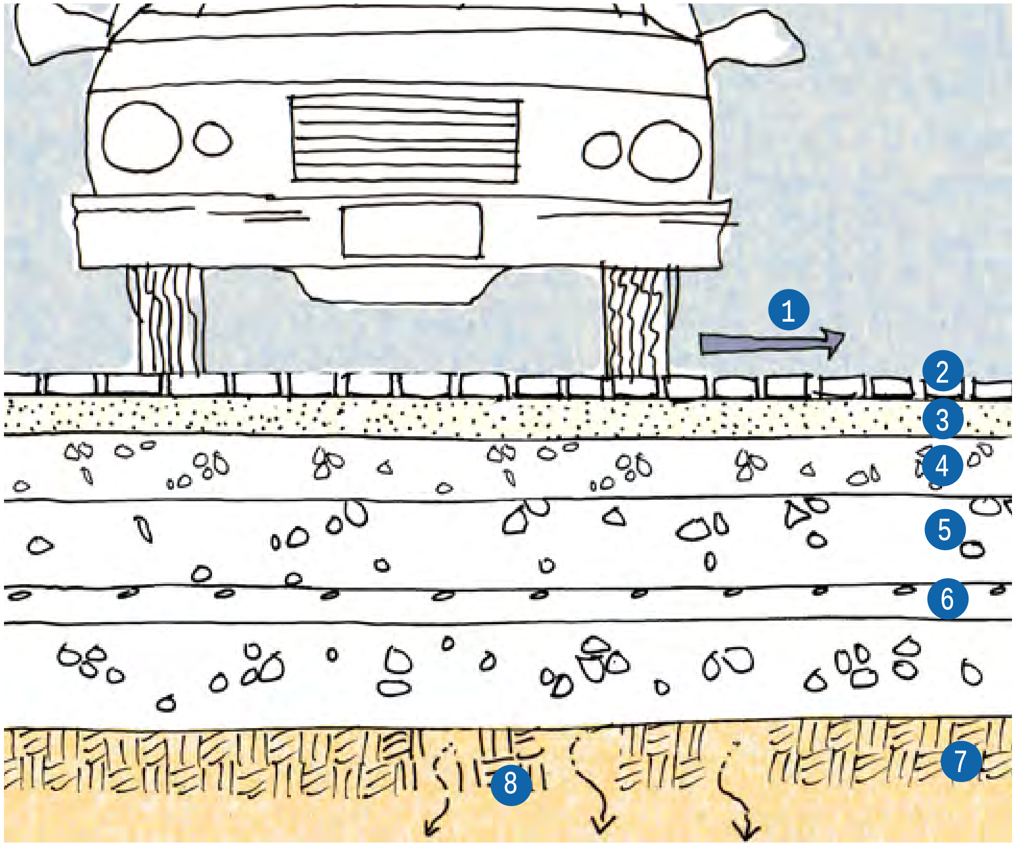
H. Barbaro and C. Kurison. 2005. "Evaluating Hydrodynamic Separators, Massachussets Highway Department."

The Stormwater Manager's Resource Center. "Stormwater Management Fact Sheet: Infiltration Trench." 18 June 2008 <http://www.stormwatercenter.net/>.

Permeable Pavement

Also known as: pervious paving, porous pavement, grass pavers, green parking, pervious concrete, pervious asphalt, turf blocks, unit pavers, ungrouted brick/stone, crushed aggregate



Overflow to collection system 1

Pavers with open spaces filled with gravel or sand 2

Fine gravel or coarse sand bedding layer 3

Transition layer (medium gravel) 4

Coarse gravel storage layer 5

Underdrain (if necessary) 6

Subgrade 7

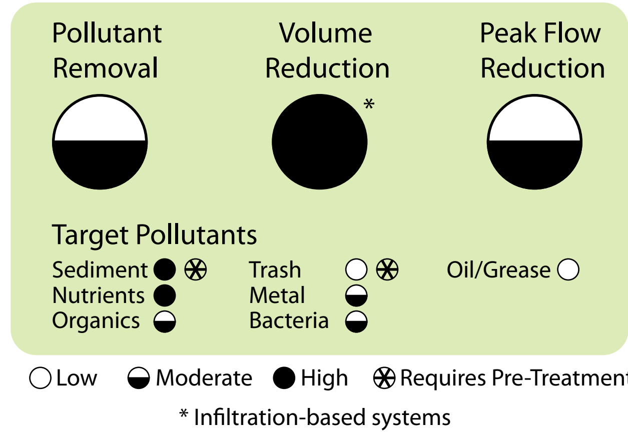
Infiltration where feasible 8

DESCRIPTION

Permeable pavement is any porous load-bearing surface that temporarily stores rainwater prior to infiltration or drainage to a controlled outlet. Stormwater is stored in an underlying aggregate layer until it either infiltrates into the soil below, facilitating groundwater recharge, or is routed to the collection system. Research and monitoring projects have shown that permeable pavement reduces annual runoff volumes by approximately 60%, attenuates peak flows, and improves water quality by removing oil and grease, metals, and suspended solids. It does not typically remove nutrients.

Permeable pavement systems are appropriate in areas with light to medium-duty loads, such as parking lots, street-side parking areas, driveways, bike paths, patios, and sidewalks. They are also allowed on alleyway traffic lanes with prior approval from the Department of Public Works, but not allowed on traffic lanes on streets classified as arterials or collectors. Infiltration rates of permeable surfaces may decline over time to varying degrees depending on design and installation, sediment loads, and consistency of maintenance.

To be considered a "permeable pavement," the system must meet two criteria: (1) the depth of the aggregate layer must be sufficient to store the water quality volume and (2) the underlying soils must be able to drain the stored stormwater in less than 48 hours or an underdrain must drain the stored stormwater in 48 hours. Systems that do not meet these criteria are not considered "permeable pavement" and are instead considered a simple "pervious surface."



BENEFITS

- Reduces runoff volume and attenuates peak flows.
- Improves water quality by reducing fine grain sediment, organic matter, and trace metals.
- Reduces the heat island effect.
- Facilitates groundwater recharge.
- Provides noise reduction.
- May increase driving safety by reducing ponding.
- May increase safety for persons with disabilities by providing textured, non-slip surfaces and reducing ponding.
- Can be used as a design element to provide aesthetic benefits.
- Construction costs can be comparable or less than traditional paving.

LIMITATIONS

- Limited to paved areas with slow and low traffic volumes.
- Maintenance costs can be greater than for traditional paving.
- Depth to bedrock and groundwater must be greater than 4 feet for infiltration-based systems.

"Country Lanes" in Vancouver, Brtitish Columbia enhance the alley's aesthetic quality and reduce stormwater discharge to the City's stormsewer system by allowing runoff to flow over vegetation and infiltrate into the ground.

SITING

Site conditions, including soil type, depth to bedrock, slope, and adjacent land uses, should be assessed to determine whether infiltration is appropriate beneath permeable pavement and to ensure that off-site sediment and pollutants are not directed onto the permeable surface.

<u>Drainage area and slope</u>: Permeable pavement should be used on relatively flat sites to facilitate infiltration and minimize erosion. Typically, permeable pavement is not recommended for slopes greater than 5%. It is best suited for receiving runoff from impervious areas; if non-paved areas will drain to permeable pavement, it is important to filter sediment out of runoff before it reaches the permeable pavement to prevent the surface from clogging. Permeable pavement can receive run-on from adjacent areas but should be at least 40% of the total drainage area.

<u>Soils</u>: The infiltration rate of the underlying soil should be at least 0.5 inches per hour if the system is designed for infiltration. Permeable pavement can also be installed over soils which have an infiltration rate less than 0.5 in/hr or even over contaminated soil or groundwater as long as a liner system (if required due to contamination) and underdrain are used to direct the stored water to the collection system. Soils should also able to sustain traffic loading without excessive deformation.

<u>Setbacks</u>: Infiltration-based permeable pavement systems should be placed a minimum of 10 feet downgradient or 100 feet upgradient of building foundations. If the drainage area is less than 1000 square feet or if the drainage area is less than 5000 square feet and adjacent buildings do not have basements, City of San Francisco staff may approve reduced setbacks of 5 and 50 feet, respectively. Infiltration-based BMPs must also be at least 5 feet from any property line, 100 feet from any downgradient slope greater than 15%, and 150 feet from any drinking water well.

<u>Groundwater protection</u>: If intended to infiltrate stormwater, permeable pavement should not be installed within 4 feet of bedrock or the seasonally high water table. To minimize risk of groundwater contamination, permeable pavement should not be used in areas with potentially hazardous materials or high pollutant loading, such as fueling stations, maintenance yards, industrial sites, or chemical storage areas.

DESIGN CONSIDERATIONS

Permeable pavement can be integrated into a variety of landscapes such as roads (both in driving lanes and parking lanes), sidewalks, plazas, terraces and patios, and other hardscape features. These materials are supplied in a variety of colors and patterns to aesthetically enhance public spaces. Permeable pavement pairs effectively with other BMPs, including planter boxes, rain gardens and vegetated swales.

Materials: Permeable pavement consists of a series of layered elements that allows percolation of stormwater. From top to bottom these layers are: a surface material, a bedding layer (also called a choking layer), a transition (or base) layer and a storage (or subbase) layer of permeable base rock, and the native soil. Common materials for the paving surface include:

- Permeable hot-mix asphalt: similar to standard hot-mix asphalt but with reduced aggregate fines (typically 2.5 inches deep)
- Permeable concrete: similar to standard concrete, but without the fine aggregate (sand and finer) and with optional special admixtures incorporated (typically 4 to 8 inches deep depending on loading)
- Interlocking block pavers: either cast-in-place or pre-cast concrete blocks with small joints or openings that can be filled with soil and grass or gravel
- Plastic grid systems: Grid of plastic rings that interlock and are covered with soil and grass or gravel

Beneath this top layer is a 2 to 3-inch deep bedding layer (i.e., choker course) of fine gravel (AASHTO No. 8). The fine gravel provides some filtration of runoff without significantly reducing the surface infiltration rate of the overlying pavement. Below the bedding layer is a 3 to 4-inch deep transition (i.e., base) layer of ⅜-inch to ¾-inch diameter crushed stone (AASHTO No. 57). Underneath this layer is a storage (i.e., subbase) layer of ¾-inch to 1½-inch diameter crushed stone (AASHTO No. 3). The storage layer should be as deep as needed to store the water quality volume, with a minimum depth of 6 inches. To increase porosity, reduce the presence of fines in the aggregate, and improve structural stability, all media should be clean, washed, open-graded crushed stone. Generally filter fabric is not recommended underneath the storage layer, but may be advisable in specific cases to prevent fines in the subgrade from moving into the storage layer. A perforated underdrain

Permeable pavers are used in parking spaces in Germany

Pervious asphalt in Portland, OR.

should be used if the infiltration rate of the underlying soils is less than 0.5 inches per hour. An underdrain and impermeable liner should be used if the underlying soils or groundwater are contaminated.

Pretreatment: To minimize clogging, sediment and trash should be screened prior to flow through permeable pavement and surfaces should undergo regular street cleaning and/or vacuuming. Other techniques, such as the use of a vegetated buffer strip around the pervious pavement where it receives runoff from off-site, can also help reduce sediment loads.

Overflow: To accommodate large storm flows that exceed the capacity of the subsurface storage layer, the permeable pavement surface should have a perimeter trench called an "overflow edge." This trench collects sheet flow from the saturated pavement surface, either directing it to the collection system or to an infiltration BMP such as an infiltration basin or trench. Where infiltration is not advisable, permeable pavement designs can incorporate a perforated underdrain beneath the paving layer. After stormwater percolates through the paving and subsurface media, the underdrain conveys flows to another BMP or to the collection system.

Sizing: Permeable pavement can be sized using the volume-based calculations described in Step 7 of the Stormwater Control Plan chapter of the *Guidelines*. An electronic sizing tool is also provided with the *Guidelines* and is hosted on the SFPUC website at http://stormwater.sfwater.org in the Stormwater Design Guidelines section. The tool should be used for planning purposes only, such as determining the general footprint and preliminary dimensions. This calculator is not intended to provide final detailed calculations or dimensions.

OPERATIONS AND MAINTENANCE

Permeable pavement requires periodic maintenance to retain its infiltration capacity. Permeable pavement should be vaccuumed once or twice annually. Vaccuuming has been found to be most effective when sediments are dry. If routine cleaning does not restore infiltration rates, then partial or full reconstruction of the pervious surface may be required. Also, broken or damaged pavement needs to be removed and replaced. Once a year, the paving should be tested to determine if it is clogged. The table on the following page provides more information on typical post-construction inspection and maintenance activities.

Typical Inspection Activities for Permeable Pavement

Activity	Schedule
• Inspect to ensure pavement is functioning properly. • Inspect adjacent areas for potential erosion or vegetation damage.	Post-construction
• Inspect porous areas for clogging with sediment, debris, or trash. • Ensure that paving dewaters between storms. • If planted, monitor health of vegetation.	Semi-annually
• Inspect surface for structural deterioration. • Inspect outlets for clogging. • Measure infiltration rate.	Annually

Typical Maintenance Activities for Permeable Pavement

Activity	Schedule
• Vacuum permeable surface.	Semi-annually (beginning and end of rainy season)
• Reseed or replant bare areas in systems that include vegetation. • Replace or repair damaged pavement. • Maintain planted areas adjacent to pavement	Annually or as needed
• Lift surface paving units to clean and/or replace underlying aggregate - may require special disposal if containing metals or hazardous materials.	Every 10-15 years or as needed
• If routine maintenance does not restore the infiltration rate, rehabilitate pavement by removing and replacing clogged section.	Upon failure (expected to be > 20 years)

COST

Permeable pavement can be up to 25% cheaper than traditional pavement when all construction and drainage costs are included. City of Portland staff estimate $2.45 per square foot for porous asphalt; not including construction. Porous concrete costs between $2 and $8.00 per square foot. The California Stormwater Management Association estimates a one-acre permeable pavement surface to incur $10,000 in total construction costs, and $4,000 in annual maintenance costs. Other estimates for installation costs average $10 per square foot. Permeable paving surfaces are expected to last for up to 25 years if properly maintained.

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California Stormwater Quality Association. 2004. "TC-50: Water Quality Inlet." *Stormwater Best Management Practice Handbook: New and Redevelopment.*

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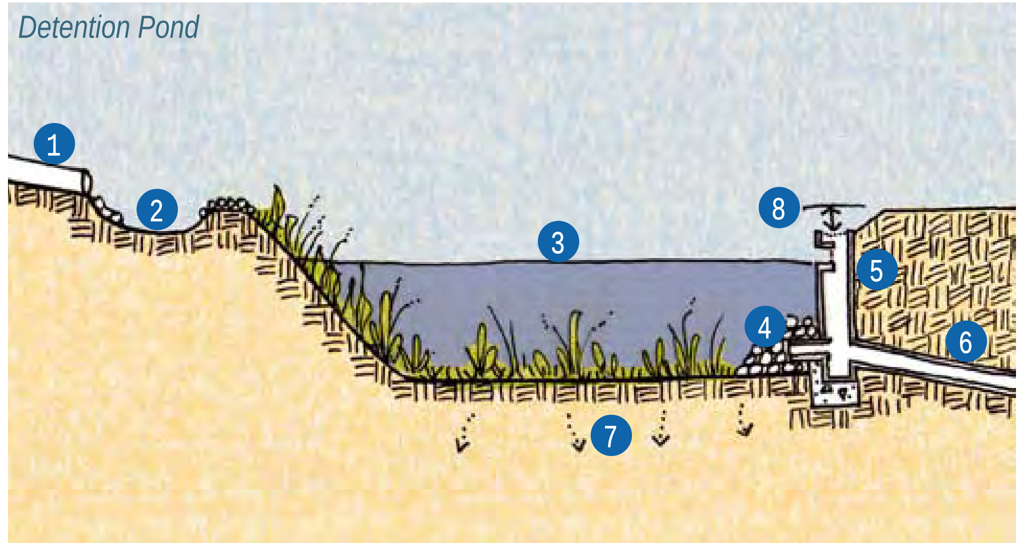
Stormwater Management Fact Sheet: Porous Pavement. 9 Jun 2008 <http://www.stormwatercenter.net/>.

Detention Pond

Also known as: detention basin, dry pond, dry detention basin, extended detention basin

1. Inlet
2. Forebay (pretreatment and energy dissipation)
3. Water quality volume level
4. Water quality orifice (primary outlet)
5. Overflow structure with screened inlets
6. Outlet to collection system, catch basin, or receiving water
7. Infiltration where feasible
8. Minimum 1 foot freeboard



DESCRIPTION

Detention ponds are temporary holding areas for stormwater that store peak flows and slowly release them, lessening the demand on treatment facilities during storm events and preventing flooding. Generally, detention ponds are designed to fill and empty within 48 hours of a storm event and therefore could reduce peak flows and runoff volumes. If designed with vegetation, ponds can also create wildlife habitat and improve air quality. They can also be used to provide flood control by including additional flood detention storage. Detention ponds are also known as "dry detention ponds" because unlike wet ponds or retention basins, which are designed to have a permanent pool of water, they drain completely between storms.

In order to meet performance requirements outlined in the *Stormwater Design Guidelines*, the drawdown time for detention ponds should be 48 hours, with no more than 50% of the total volume draining in the first 16 hours. These drawdown requirements provide water quality benefits by allowing sediment particles to settle to the bottom of the pond. This type of detention pond is sometimes known as an "extended detention pond;" in this fact sheet it will be referred to simply as a detention pond.

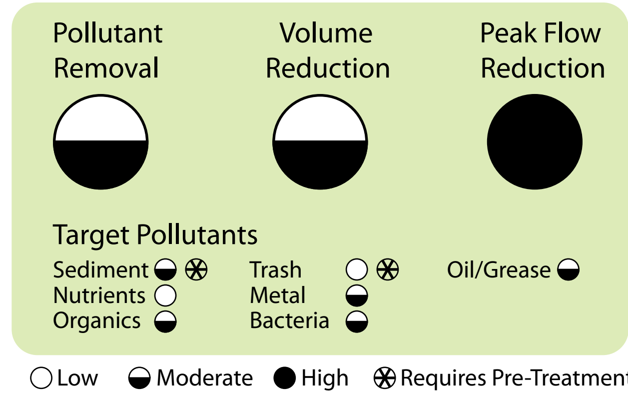
Another detention pond variation is the multi-purpose detention pond, which is only filled with water during storm events and can act as an open space such as a play area, dog park, or athletic field during dry weather.

BENEFITS

- Reduces runoff volume and attenuates peak flows.
- Improves water quality by removing particulate matter and sediment.
- Removes trash and debris.
- Reduces flooding.
- Low construction and maintenance costs.
- Good for sites where infiltration is not an option.
- Multi-purpose detention ponds create habitat and increase biodiversity in the city.
- Multi-purpose detention ponds provide open space and aesthetic amenity.

LIMITATIONS

- Ineffective at removing soluble pollutants.
- 5-acre minimum drainage area (see Siting section for more details).
- If infiltration will occur, 4-foot minimum separation from pond bottom to ground-water and bedrock is required, unless the Regional Water Quality Control Board approves otherwise.



Detention Pond

A dry detention pond in the Algeurao Mem-Martins, located outside of Lisbon, Portugal, provides flood control during the short, wet season and serves as a neighborhood park with picnic tables, frequented by children riding bicycles and skateboards, during the rest of the year.

Detention ponds can take on a formal arrangement in a courtyard space such as this one.

A dry detention pond sited within a Children's play space in Augustenborg, Malmö/Sweden tests different methods of reducing and detaining peak stormwater flows while enhancing the neighborhood.

- Site must have no risk of land slippage if soils are heavily saturated.
- Must be sited with sufficient distance from existing foundations, roads, subsurface infrastructure, drinking water wells, septic tanks, and drain fields.

SITING

There are relatively few siting constraints for detention ponds, making them one of the most applicable technologies for stormwater management.

Drainage area and slope: Detention ponds should be used at sites with a minimum drainage area of five acres. They can be used at smaller sites provided that the minimum outlet orifice diameter is at least 1 inch. In addition, it is generally more cost-effective to control larger drainage areas due to the economies of scale in pond construction. The slope downstream of all types of detention ponds should not exceed 15%. The local slope in the immediate pond area needs to be relatively flat, however, in order to maintain reasonably flat side slopes.

Soils and infiltration rate: Detention ponds can be used on almost all soil types and geology. In areas with rapidly percolating soils (over 2.5 inches per hour) such as coarse sands, runoff should be fully treated prior to reaching the detention pond or the pond should be lined to prevent groundwater contamination.

Setbacks: If infiltration is occurring, the detention pond should be placed a minimum of 10 feet downgradient or 100 feet upgradient of building foundations. If the drainage area is less than 1000 square feet or if the drainage area is less than 5000 square feet and adjacent buildings do not have basements, City of San Francisco staff may approve reduced setbacks of 5 and 50 feet, respectively. Infiltration-based BMPs must also be at least 5 feet from any property line, 100 feet from any downgradient slope greater than 15%, and 150 feet from any drinking water well.

Depth to groundwater: The base of the pond should not intersect the groundwater table to avoid creating a permanent pool where mosquitoes could breed. If infiltration is occurring, the depth to groundwater must be at least 4 feet to prevent groundwater contamination.

DESIGN CONSIDERATIONS

Dimensions: Detention ponds generally consist of a depressed area of land, or an area that is surrounded by earthen berms, where stormwater is directed and stored during storm events. They have greatest pollutant removal capability when designed with a long flow path from inlet to outlet; a length to width ratio of at least 1.5:1 is recommended. No minimum or maximum slope requirements for the pond bottom have been set; however, the slope should be flat enough in the direction of flow to maintain a low flow velocity, but with enough elevation drop to avoid stagnant water and ensure that flow can move through the system. A rock-lined channel from inlet to outlet, called a "pilot channel," should be included to convey low flows through the pond. Detention ponds with earther walls should have side slopes of 3:1 (H:V) or flatter to minimize erosion and safety concerns and facilitate mowing. Detention ponds can also be hardscape architectural elements, in which case vertical walls are acceptable. Pond depths of 2 to 5 feet are considered optimal.

Vegetation: Vegetation within the detention zone (up to the elevation of the design storm) appears to increase pollutant removal and decrease resuspension of accumulated sediment. Plants selected for this zone should be able to withstand both wet and dry periods. Woody plants can be used, but they are better suited to the areas above the elevation of the design storm, as they may cause accumulation of debris or block the flow path, thereby increasing the potential for standing water. If sufficient space is available, a vegetated buffer around the pond can be used to slow overland runoff entering via the side slopes and can help prevent access to the pond if desired.

Pretreatment: Pond maintenance is reduced when runoff passes through a forebay or sedimentation basin that allows coarse sediment particles to settle before reaching the main pond. The forebay is typically 10% of the detention basin volume.

Inlet structures: An energy dissipation structure should be included at the pond inlet to prevent erosion and resuspension of accumulated sediment. Stilling basins should not be used for this purpose because they create a pool of standing water where mosquitoes can breed.

Outlet structures: A typical detention pond outlet system includes a water quality orifice that regulates the drawdown time of the pond (48 hours is recommended for optimal pollutant removal and prevention of mosquito breeding), an overflow device for storms greater than the design storm, and an emergency overflow for large flood events. An overflow weir or

In urban commercial centers, detention ponds serve as a visual amenity and natural oasis.

Next to a workplace or school, a detention pond can provide a place for relaxation and repose.

A detention pond can support water-loving plants, even in an urban setting.

riser should be set at the elevation of the design storm for all online ponds. Additionally, online ponds must include a separate emergency weir or spillway to safely pass runoff from large flood events. A trash rack should be used to prevent clogging of outlet structures. The outlet should include a valve that can stop outflows from the pond in case of a spill in the watershed; this valve can be the same valve that is used to regulate pond drawdown time. Any outfall pipes greater than 48 inches in diameter must be fenced for safety. Finally, if the pond discharges to a natural waterway, the pond outfall should be stabilized to prevent erosion.

Access: A ramp and perimeter access to the main pond and sediment forebay should be included in the design of detention ponds to facilitate access for inspection and maintenance.

Sizing: Detention ponds are sized using the volume-based calculations described in Step 7 of the Stormwater Control Plan chapter of the *Guidelines*. An electronic sizing tool is also provided with the *Guidelines* and is hosted on the SFPUC website at http://stormwater.sfwater.org in the Stormwater Design Guidelines section. The tool should be used for planning purposes only, such as determining the general footprint and preliminary dimensions. This calculator is not intended to provide final detailed calculations or dimensions. Detention ponds are typically sized for a drawdown time of 48 hours, with less than 50% of the total volume draining in the first 16 hours. Any runoff that exceeds the holding capacity is discharged back into the collection system.

OPERATIONS AND MAINTENANCE

Maintenance requirements for detention ponds consist mainly of periodic sediment removal, vegetation management, and vector abatement if needed. The table on the following page provides more information on typical post-construction inspection and maintenance activities.

COST

The construction, design, and permitting costs for an above ground detention pond with a one acre-foot storage volume are estimated at approximately $42,000 (CASQA, 2003; SMRC). However, CASQA (2003) also cites an example of a 0.3 acre-foot Caltrans detention pond that cost $160,000, highlighting the difficulty in developing construction cost estimates. The annual cost of routine maintenance is typically estimated at about 3 to 5% of construction costs.

Typical Inspection Activities for Detention Ponds

Activity	*Schedule*
• Inspect pond for standing water to confirm drawdown time of no more than 48 hours after end of wet weather. • Inspect for erosion of banks or bottom and for presence of burrows or other damage to embankments. • Confirm that inlet and outlet structures are operational and free of debris.	Semi-annually (beginning and end of rainy season)
• Monitor sediment accumulation in the main pond and forebay.	Annually (end of rainy season)

Typical Maintenance Activities for Detention Ponds

Activity	*Schedule*
• If standing water present more than 48 hours, adjust outflow devices or regrade pond bottom. • Remove trash and debris, especially at outlet structures. • Correct erosion or damage to banks and bottom. • Repair inlet and outlet structures as needed. • Mow to prevent establishment of woody vegetation in areas below the elevation of the design storm.	Semi-annually (beginning and end of rainy season)
• Seed or sod to restore dead or damaged vegetation.	Annually
• Remove sediment from forebay when depth exceeds 6 inches or 50% of storage capacity.	As needed (expected frequency every 3-5 yrs)
• Remove sediment when the pond volume has been reduced by 10%. This can be measured with a barrel thief or on a sediment gauge installed near the basin outlet.	As needed (expected frequency every 10-25 yrs)

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Detention Vault *

Also known as: wet vault, detention tank

Inlet 1

Maintenance access and ladders 2

Live storage 3

Permanent pool 4

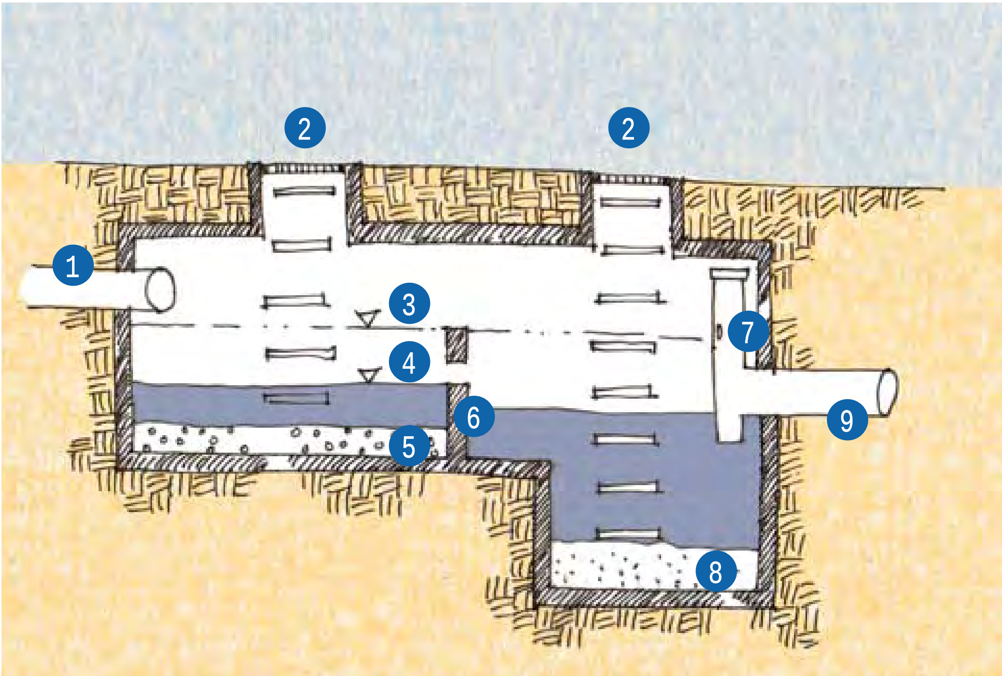
Coarse sediment 5

Baffle at 25 to 50% of volume 6

Flow restrictor sized to drain in 48 hours 7

Fine sediment 8

Outflow to collection system 9



DESCRIPTION

A detention vault is an underground stormwater storage tank typically made of reinforced concrete that is designed to accommodate a permanent water pool. For extended detention, the vault may have a constricted outlet that causes a temporary rise of the water level, which drains over the course of 48 hours following the end of each storm. Inflow can come from runoff from a drain grate located at the ground surface, or from a subsurface storm drain pipe. Only slight, if any, removal of nutrients, metals, and organic pollutants is typically achieved. To achieve higher levels of treatment, detention vaults should be used along with other BMPs as part of a treatment train.

Detention tanks are a form of detention vaults that utilize oversized pipes to detain runoff. The minimum pipe diameter used for the detention tank is generally 36 inches. A flow restrictor at the downstream end of the tank limits outflow, causing runoff to be temporarily "stored" in the tank. The tank bottom is typically at least 0.5 feet below the inlet and outlet to provide dead storage for sediment. A manhole with a sump is located immediately upstream of the tank to control inflow and capture larger sediment.

** Detention vaults alone do not constitute compliance with San Francisco's stormwater requirements and are generally not considered treatment to the Maximum Extent Practicable (MEP) by the Regional Water Board. They are best used as part of a treatment train.*

Detention Vault

Pollutant Removal	Volume Reduction	Peak Flow Reduction
○	○	◒

Target Pollutants

Sediment ◒	Trash ◒	Oil/Grease ◒
Nutrients ○	Metal ○	
Organics ○	Bacteria ○	

○ Low ◒ Moderate ● High ⊛ Requires Pre-Treatment

BENEFITS

- Reduces flooding and peak flow rate.
- Removes solids, floatables, and other particulate pollutants.
- Few space limitations – can be placed underground in most areas.
- Advantageous in areas unsuitable for infiltration.
- Versatile, wide variety of appropriate scales and locations.

LIMITATIONS

- Potentially high excavation and installation costs.
- Minimal water quality treatment achieved.
- Single purpose – not beneficial to wildlife or community at large.
- Vault must be large enough to meet minimum OSHA confined space entry requirements.

SITING

Detention vaults can be sized to treat any drainage area, but are most practical for drainage areas less than 10 acres. They are typically constructed using at least 3,000 psi structural reinforced concrete and are designed for H-20 traffic loading, which enables them to be installed beneath streets and parking lots. Designs often include baffles and peak flow bypasses to improve retention of solids and floatables. Because they are underground, they may be more expensive, and can be expensive to retrofit in existing built areas. However, detention vaults can detain a significant volume of stormwater, more so than many other BMPs.

DESIGN CONSIDERATIONS

Dimensions: Detention tanks are typically greater than 3 feet in diameter. Detention vaults are usually greater than 7 feet in internal height and typically range from 4 to 10 feet in width, but these dimensions can vary significantly based on site conditions, project resources, and design intent. The vault shape is usually rectangular with a length to width ratio of 2:1 or greater; however, some designs employ a circular vault shape. Manhole covers over the inlet and outlet of the vault allow entry for maintenance. Vault floors should be sloped at least 5% from the edges towards the center axis, and should be sloped longitudinally towards the inlet to facilitate sediment removal. Inlets and outlets should be placed at opposite corners of the vault to maximize the flow path length. To facilitate access, ladders should be built into vault walls, and ventilation pipes must allow air into the space before maintenance workers can be allowed to enter.

Treatment: Detention vaults do not target removal of dissolved nutrients, metals, or organic material. As sediment levels increase in the vault, resuspension can occur, which reduces the treatment efficiency of the BMP. Without pretreatment screening, vaults can fill up quickly and clog with large solids. A vegetated swale can be used to remove larger solids and to convey flow to the detention vault. If a higher level of treatment is required, a detention vault can be paired with a downstream filtration device. Some media filters, such as the Delaware and DC Sand Filters, utilize a wet vault followed by a filter chamber.

Flow Configuration: Wet vaults can be designed as offline or online devices. In the offline configuration, only flows less than or equal to the design treatment capacity are directed to the vault. In the online configuration, all flows are routed to the device, but the vault typically contains an internal bypass to direct high flows around the sedimentation area. This helps to prevent re-suspension of settled sediment.

Sizing: Detention vaults are sized using the volume-based calculations described in Step 7 of the Stormwater Control Plan chapter of the *Guidelines*. An electronic sizing tool is also provided with the *Guidelines* and is hosted on the SFPUC website at http://stormwater.sfwater.org in the Stormwater Design Guidelines section. The tool should be used for planning purposes only, such as determining the general footprint and preliminary dimensions. This calculator is not intended to provide final detailed calculations or dimensions.

OPERATIONS AND MAINTENANCE

Maintenance of detention vaults includes post-construction and annual inspections. During the first wet season of operation following construction, inspect the vault twice for debris, sediment, and petroleum product accumulation. Use these findings to establish an annual inspection and removal schedule.

Because accumulated sediment reduces treatment efficiency over time, removal of accumulated material with an eductor or vactor truck may be required every one to two years. Floatables may need to be removed separately due to the presence of petroleum products. The table on the following page provides more information on typical post-construction inspection and maintenance activities.

Typical Inspection Activities for Detention Vaults

Activity	*Schedule*
· Inspect vault twice during first wet season of operation, setting cleaning frequency accordingly.	Post-construction
· Inspect for cracks, inlet or outlet area erosion, and clogging.	Semi-annually

Typical Maintenance Activities for Detention Vaults

Activity	*Schedule*
· Remove litter, oil, and grease from inlet and outlet areas.	Semi-annually (beginning and end of rainy season)
· Remove accumulated sediment when the 0.5 to 1-ft deep sediment storage zone is full – may require special disposal if sediment contains metals or trace organic compounds.	Bi-annually or as needed

COST

Detention vaults can be more expensive than other BMPs because they require excavation and concrete lining, but they can achieve significant reduction in stormwater peak flow. In Denver, Colorado, a 14,000-square foot detention vault with a sand filter and pump cost $15,000 for installation, including permits, fees, and labor, and an estimated $10,000 per year in maintenance costs.

REFERENCES AND RESOURCES

California Stormwater Quality Association. 2003. "MP-50: Wet Vault." *California Best Management Practice Handbook- Municipal*.

City of Seattle. 2000. "Title 22.800 Stormwater, Grading, and Drainage Control." *Stormwater Treatment Technical Requirements Manual Vol. 4*.

Department of Natural Resources and Parks, King County, Washington. 2005. "Surface Water Design Manual."

Wet Pond

Also known as: stormwater pond, retention pond, wet extended detention pond

Inlet 1

Forebay (pretreatment and energy dissipation) 2

Aquatic bench 3

Water quality volume level 4

Live storage 5

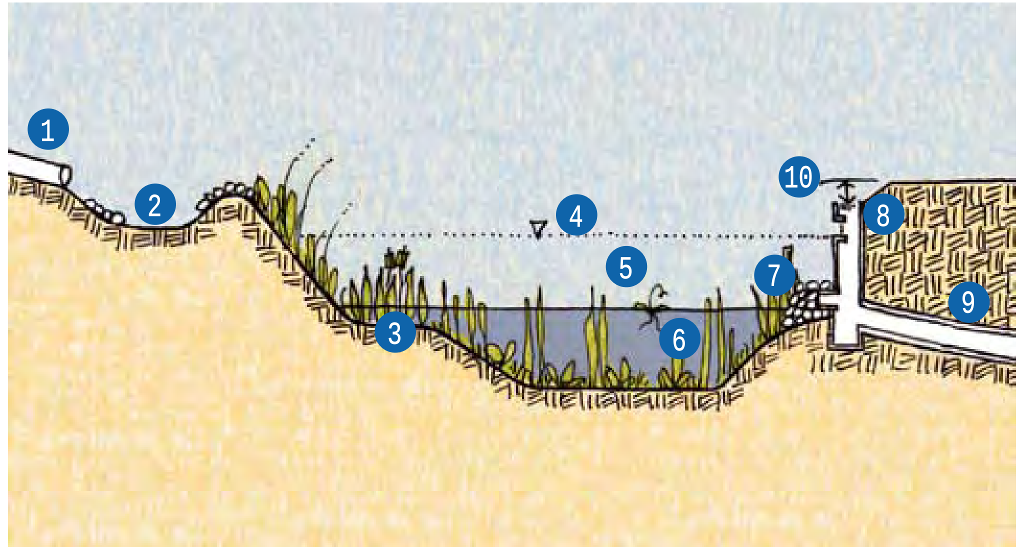
Permanent storage: 4 to 6 foot pool depth 6

Primary outlet with sediment filter 7

Overflow structure with screened inlets 8

Outlet to collection system, catch basin, or receiving water 9

Minimum 1 foot freeboard 10



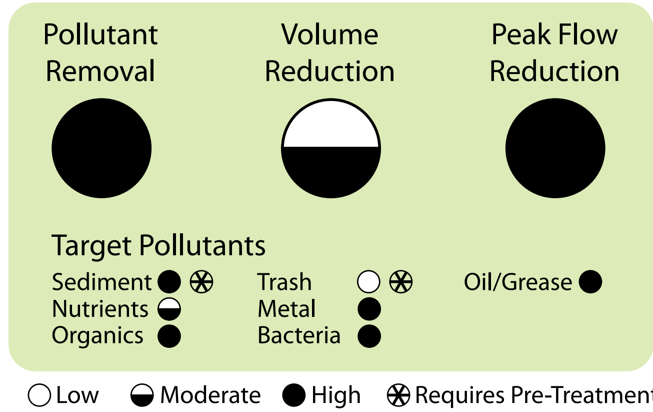
DESCRIPTION

Wet ponds are constructed basins that have a permanent pool of water throughout the wet season, potentially extending throughout the year. The primary removal mechanism is settling while stormwater runoff resides in the pool. Where algae is present, algal uptake also aids stormwater treatment. Nutrient uptake also occurs through biological activity in the sediment and water. Wet ponds differ from constructed wetlands in that they are typically deeper, ranging from 4 to 6 feet, and have less vegetative cover. Wet ponds are among the most cost-effective and widely used stormwater treatment practices.

The typical configuration of a wet pond includes forebay storage, permanent storage, and live storage areas. The forebay is a small inlet pool that allows settling of coarse and medium grained sediment. Permanent storage refers to the permanent pool of water remaining in the wet pond between storm events and during dry weather. If intended as wildlife habitat or permanent water feature, supplemental water and the installation of an impermeable liner may be required to maintain the permanent pool during the dry season. Live storage refers to the remaining storage capacity in the wet pond that will vary based on stormwater influx. The stormwater in the live storage area will generally drain from the pond 24 to 48 hours after the end of a storm event.

BENEFITS

- Reduces stormwater volume and attenuates peak flow.
- Removes many stormwater pollutants via sedimentation and biological transformation.
- Can be an attractive and recreational public park amenity.
- Creates wildlife and wetland habitat.
- Suitable for sites with poor infiltration rates.
- Suitable for large drainage areas.



LIMITATIONS

- Requires relatively large land area and large drainage area (at least 5 acres), thus making it a good choice for master-planned and multi-parcel developments.
- Supplemental water required to maintain permanent pool may outweigh volume reduction benefits.
- If seasonally dry, may appear dusty or unsightly.

SITING

Drainage area and slope: Though they only occupy 2 to 3% of their contributing drainage area, wet ponds require sufficient drainage to maintain a permanent pool, typically around 25 acres or more. Wet ponds can be used at sites with drainage areas as small as 5 acres provided that the permanent pool is maintained during the rainy season, either through use of a liner or addition of supplemental non-potable water if necessary. Wet ponds must be sited on a relatively flat area with less than 2% slope. While there is no minimum slope requirement, there must be enough elevation drop from the pond inlet to the pond outlet to ensure that water can flow through the system by gravity. The slope downstream of wet ponds should not exceed 15%.

Soils and infiltration rate: Because they are not designed to reduce runoff by infiltration, wet ponds can be used in almost all soil types. In Mediterranean climates like San Francisco, wet ponds may either be allowed to evaporate in the dry season, or may be supplemented with an alternative source of influent water. Dry-weather water sources could be street and irrigation runoff, recycled water, groundwater, or other urban water applications.

A wet pond serves as a focal point in this residential courtyard, providing air and water-quality benefits, as well as enhancing the aesthetic appeal of the courtyard.

Larger wet ponds may provide an opportunity for recreation.

Groundwater protection: Wet ponds may intersect the groundwater table, though this should be avoided in areas where either the stormwater or the groundwater could be contaminated.

DESIGN CONSIDERATIONS

Vegetation: Though most of the pond is deeper than wetland plant rooting depth, wet ponds should incorporate an aquatic bench around their perimeter. The aquatic bench is a shallow shelf up to 18 inches deep that supports wetland vegetation. In addition to facilitating stormwater treatment via biofiltration, this feature also helps to stabilize the soil at the edge of the pond and enhances habitat and aesthetic value. Native species that can tolerate drought and inundation should be used wherever possible. Common stormwater wetland plant species include cattail (Typha latifolia), bulrush (Scirpus spp.), and reeds (Phragmites spp.). However, cattails tend to require more maintenance because they can easily spread to nearby areas and become a nuisance.

Pretreatment: A pretreatment forebay should be used to settle out coarse sediment before it reaches the main pool. Forebays are separate small ponds located between the inlet and the main pool that typically about 10% of the live storage volume of the pond. They can provide up to 6 inches of storage temporarily, and are located near the pond inlet. This can greatly reduce regular maintenance costs. Accumulated sediment should be removed from the forebay when its depth exceeds 6 inches or 50% of the forebay storage capacity, typically every 3 to 5 years. A vegetated buffer should be created around the pond to protect the banks from erosion, and to provide some pollutant removal before runoff enters the pond by overland flow. This landscaping also provides aesthetic and habitat amenities for the community.

Treatment: Wet ponds, along with constructed wetlands, are among the most effective BMPs in removing pollutants from stormwater. While the degree of treatment varies with the volume and retention time of the permanent pool, wet ponds have been shown to remove on average 80% of suspended solids, 30 to 50% of nitrogen and phosphorus, 70% of bacteria, and 30% of metals.

Drainage: Stormwater should be conveyed to and from wet ponds safely and in a manner that minimizes downstream erosion potential. The wet pond outfall should always be stabilized to prevent scour. An emergency spillway should be provided to safely convey large flood events into the collection system or a receiving water body. If discharging to streams, lakes, or the bay or ocean, designers should provide shade around the outflow channel to prevent warming that could adversely affect aquatic species.

Overflow: Wet ponds should be designed with a non-clogging outlet such as a weir outlet with a trash rack or a reverse slope pipe that is at least 3 inches in diameter. Because reverse slope pipes draw water from below the surface of the permanent pool, they are less likely to be clogged by floating debris. If the wet pond is online, meaning it receives continuous flow that cannot be diverted, principle and emergency spillways should provide at least 1 foot of freeboard.

Access: For ease of maintenance, wet ponds should incorporate direct access to both the forebay and the main pool of ponds. In addition, ponds should generally have a drain to draw down the pond or forebay to facilitate periodic sediment removal.

Sizing: Wet ponds are sized using the volume based calculations described in Step 7 of the Stormwater Control Plan chapter of the *Guidelines*. An electronic sizing tool is also provided with the *Guidelines* and is hosted on the SFPUC website at http://stormwater.sfwater.org in the Stormwater Design Guidelines section. The tool should be used for planning purposes only, such as determining the general footprint and preliminary dimensions. This calculator is not intended to provide final detailed calculations or dimensions. To minimize short circuiting, wet ponds should always be designed with a length to width ratio of at least 1.5:1. In addition, the design should incorporate features to lengthen the flow path through the pond, such as baffles or underwater berms. Combining these two measures helps ensure that the entire pond volume is used to treat stormwater. Another feature that can improve treatment is to use multiple ponds in series as part of a "treatment train" approach to pollutant removal. This redundant treatment can also help slow the rate of flow through the system.

OPERATIONS AND MAINTENANCE

In addition to incorporating features into the pond design to minimize maintenance, some regular maintenance and inspection practices are needed on a seasonal and an annual basis. The table on the following page provides more information on typical post-construction inspection and maintenance activities.

Typical Inspection Activities for Wet Ponds

Activity	*Schedule*
• Inspect for erosion damage, animal burrows, and structural integrity, especially of pond outlet. • Inspect for signs of hydrocarbon build-up and deal with appropriately. • Monitor for sediment accumulation in the forebay and main pond. • Examine to ensure that inlet and outlet devices are operational and free of debris.	Semi-annually (beginning and end of rainy season)

Typical Maintenance Activities for Wet Ponds

Activity	*Schedule*
• Remove debris from and clean inlet and outlet structures. • Remove accumulated trash and debris from forebay and edges of main pond. • Mow or trim side slopes if vegetated. • Repair undercut or eroded areas. • Stock permanent pool with mosquitofish *(Gambusia spp.).*	Semi-annually (beginning and end of rainy season)
• Remove sediment from forebay when depth exceeds 6 inches or 50% of storage capacity. • Replant vegetation as necessary.	As needed (expected frequency every 3 to 5 years)
• Remove sediment when the pond volume has been reduced by 25% or if the pond becomes eutrophic. This can be measured with a barrel thief or on a sediment gauge installed near the basin outlet.	As needed (expected frequency every 25 to 50 years)

COST

Typical wet pond costs range from $0.50 to $1.00 per cubic foot ($17.50-$35.00 per cubic meter) of storage area, but vary by size and site location. New wet ponds in undeveloped areas are easier and cheaper to construct than retrofit ponds in developed areas. Operations and maintenance costs should be low, typically between 3 and 5% of construction costs, and wet ponds can last well over 20 years. Caltrans estimates annual maintenance costs for a wet pond treating 4.2 acres to be $17,000 per year; in contrast, King County estimates annual wet pond maintenance costs to be $3,000 per pond. On-site disposal can reduce sediment removal costs by up to 50%.

REFERENCES AND RESOURCES

California Stormwater Quality Association. 2003. "TC-20: Wet Pond." *California Best Management Practice Handbook- Municipal.*

Center for Watershed Protection. 2001. "Stormwater Management Fact Sheet: Wet Pond." 5 Jun 2008 <www.stormwatercenter.net>.

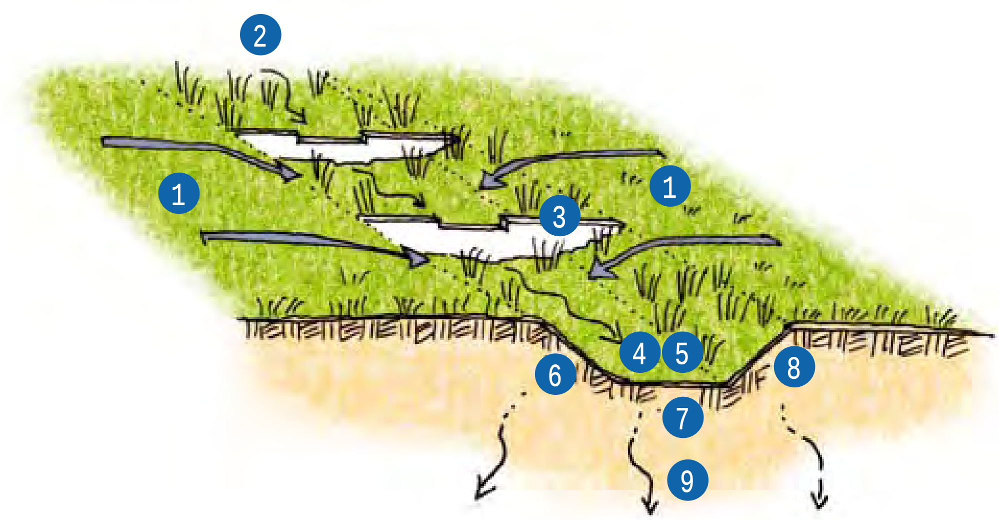
City of Seattle. 2000. "Title 22.800 Stormwater, Grading & Drainage Control Code." *Stormwater Treatment Technical Requirements Manual Vol. 4.*

United States Environmental Protection Agency.1999. "NPDES Stormwater Technology Fact Sheet: Wet Detention Pond Fact Sheet (EPA 832-F-99-048)." 5 June 2008 <http://www.epa.gov/owmitnet/mtb/wetdtnpn.pdf>.

Vegetated Swale

Also known as: grassed channel, grassy swale, dry swale, wet swale, biofilter.

- Stormwater runoff 1
- Maximum 5% channel slope 2
- Check dams recommended for slopes over 5% 3
- 6-inch grass height recommended 4
- Maximum treatment depth 2/3 of grass height 5
- Trapezoidal form 6
- 10-foot maximum channel bottom width 7
- 3:1 maximum channel bank slope 8
- Infiltration where feasible 9



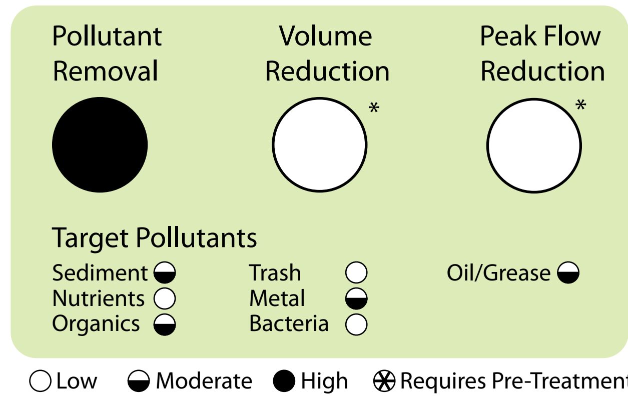
DESCRIPTION

A vegetated swale is a broad, shallow channel with dense vegetation covering the side slopes and bottom. The vegetation in the channel provides filtration and solids removal and reduces flow velocities as the flow is conveyed through the system. Depending on the native soils, some infiltration may also occur, which decreases runoff volume and provides additional filtering.

Vegetated swales can be designed as part of the stormwater conveyance system and can potentially eliminate the need for curbs, gutters and storm drains. They are also well-suited to treat runoff from roads and highways because of their linear nature. Swales can be paired with many other treatment measures, such as wet ponds, infiltration basins, and wetlands.

Vegetated swales (also known as grassy swales or biofiltration swales) are flow-based systems sized to treat the water quality flow rate. The treatment effectiveness is correlated to the residence time of the runoff in the swale, and therefore, flow-based swales can be considerably longer than a typical treatment BMP.

Two other design variations of the vegetated swale - the dry swale and the wet swale - are mentioned below to clarify the distinction between the vegetated swale described in this fact sheet versus volume-based BMPs that are also commonly called swales. In contrast to the flow-based grassy swale, dry swales and wet swales are volume-based (i.e., designed to capture the water quality volume). Dry swales are actually linear, sloped bioretention systems (see Bioretention fact sheet). Wet swales are linear, sloped wet basins. There is a permanent pool of water at the base of the swale that can lead to vector concerns, and therefore wet swales are not generally recommended for residential applications.



* Moderate if designed as a dry swale (bioretention swale)

BENEFITS

- Improves water quality by removing sediment, particulate matter, and trace metals.
- Creates habitat and increases biodiversity in the city.
- Infiltration of runoff improves urban hydrology and facilitates groundwater recharge.
- Provides aesthetic amenities.
- Improves air quality.
- Low installation costs.
- Low maintenance requirements.

LIMITATIONS

- Limited volume reduction and peak flow attenuation unless designed as a dry (bioretention) swale.
- Impractical in areas with very flat or very steep topography or with erosive or poorly drained soils.
- Little removal of dissolved pollutants and bacteria.
- Poor pollutant removal and vulnerable to erosion when flow velocities are high.
- Limited to relatively small drainage areas.

SITING

<u>Drainage area and slope</u>: Vegetated swales can be used to treat runoff from small drainage areas with up to 5 acres of impervious surface. Swales are best used on sites with relatively flat slopes. Larger drainage areas and steeper slopes result in flow velocities that are too high to allow adequate treatment and may cause erosion of the swale bottom and side slopes.

Soils and infiltration rate: Vegetated swales are most effective on soils that allow infiltration. Care should be taken to avoid soil compaction. If infiltration is desired, the underlying soil drainage rate should exceed 0.5 inches per hour. In some cases, however, swales can be installed on top of impermeable soils by excavating the native soil and replacing it with a layer of well-drained planting medium and an underdrain. Soils that consist mainly of gravels and coarse sands may also be problematic if they cannot support dense enough vegetation growth to adequately treat runoff. If there is a concern about groundwater contamination in an area with coarse soils, the swale may be lined.

Setbacks: If infiltration is occurring, the swale should be placed a minimum of 10 feet downgradient or 100 feet upgradient of building foundations. If the drainage area is less than 1000 square feet or if the drainage area is less than 5000 square feet and adjacent buildings do not have basements, City of San Francisco staff may approve reduced setbacks of 5 and 50 feet, respectively. Infiltration-based BMPs must also be at least 5 feet from any property line, 100 feet from any downgradient slope greater than 15%, and 150 feet from any drinking water well.

Depth to groundwater: There should be at least 4 feet of separation between the bottom of the swale and the water table to prevent a moist swale bottom, which impacts the growth of grass and other plants not accustomed to long periods of root inundation. This separation also helps prevent groundwater contamination and mosquito breeding.

DESIGN CONSIDERATIONS

Dimensions: Swales should generally have a trapezoidal shape with a flat bottom (in the direction perpendicular to flow) to promote even flow across the whole width of the swale. The bottom width should be between 2 and 10 feet. The minimum allows for ease of mowing if grass is used and ensures adequate planted area for water quality treatment; the maximum prevents the formation of small channels within the swale bottom. Side slopes are generally designed to be 3:1 (H:V) or greater to increase the treatment area, prevent erosion, accommodate mowing, and slow runoff entering the swale from the sides. However, if an architectural edge is desired and runoff does not enter from the swale sides, hardscaped vertical sides and a broad, flat bottom may be designed. The length of flow-based swales is typically determined by providing 5 to 10 minutes of residence time for pollutant removal, with a minimum length requirement of 100 feet. There is no maximum length.

The recommended longitudinal slope for swales is typically between 1% and 6%, with a slope around 2% being preferred. Limiting the longitudinal slope helps maintain a low flow velocity. Check dams can be installed in swales to promote additional infiltration and should be used if the longitudinal slope exceeds 5%.

Vegetation: A dense vegetative cover on the swale bottom and side slopes filters pollutants out of runoff and helps reduce flow velocities and protect the swale from erosion. Fine, close-growing grasses are ideal because increasing the surface area of the vegetation exposed to runoff improves the effectiveness of the swale. Native wildflowers and ground covers can also be used. Vegetation that can tolerate both wet and dry conditions as well as accumulations of sediment and debris are best-suited for swales. No runoff shall be allowed to flow in the swale until the vegetation is established. Irrigation may be required until vegetation is established.

Because swales rely on dense vegetation for pollutant removal and flow attenuation, proper sun exposure for selected plantings must be carefully considered. If grasses are used, the swale should receive a minimum of 6 hours of sunlight daily during the summer months throughout the length of the swale. Alternative vegetation should be considered if sun exposure is limited. Examples of vegetation appropriate for swales can be found in the Vegetation Palette, Appendix D of the *Guidelines*.

Flow: Flow depth should be limited to 4 to 6 inches to facilitate pollutant removal. The maximum flow velocity in a vegetated swale should be 1 foot per second under flow conditions designed to provide water quality treatment. Under higher flow conditions, the maximum velocity should be 3 feet per second to avoid erosion. A high-flow bypass should be used if velocities will exceed this value. A flow spreader should be used at the swale inlet to dissipate energy and spread runoff evenly across the swale bottom. If a swale discharges to a slope rather than to a piped system or confined channel, an energy dissipater should be used at the outlet.

Sizing: Vegetated swales are sized using the flow-based or volume-based calculations described in Step 7 of the Stormwater Control Plan chapter of the *Guidelines*. An electronic sizing tool is also provided with the *Guidelines* and is hosted on the SFPUC website at http://stormwater.sfwater.org in the Stormwater Design Guidelines section. The tool should be used for planning purposes only, such as determining the general footprint and preliminary dimensions. This calculator is not intended to provide final detailed calculations or dimensions.

Typical Inspection Activities for Vegetated Swales

Activity	Schedule
• Check that the swale drains within the design drawdown time (typically 48 hours).	Post-construction and semi-annually (beginning and end of rainy season)
• Inspect for erosion, damage to vegetation, channelization of flow, debris and litter, and sediment accumulation.	Semi-annually (beginning and end of rainy season)
• Inspect level spreader for clogging and correct as necessary.	Annually

Typical Maintenance Activities for Vegetated Swales

Activity	Schedule
• Regularly water during the first three months as vegetation establishes roots.	Post-construction
• Mow grass to maintain a height of 3-4 inches. Remove litter prior to mowing. • Provide weed control, if necessary, to control invasive species.	As needed (frequently)
• Remove litter, branches, rocks, blockages, and other debris. • Repair any erosion rills, gullies, or damaged areas within channel and replant bare areas as necessary.	Semi-annually (beginning and end of rainy season)
• Remove sediment from head of swale if vegetation growth is inhibited or if the sediment is blocking the even spreading of water to the rest of the swale. • Plant alternative vegetation if original vegetation is not successfully established. Reseed and apply mulch to damaged areas.	Annually
• Rototill or cultivate the surface of the soil bed if the swale does not drain within 48 hours after the end of wet weather. • Remove sediment build-up from the bottom of the swale once it has accumulated to 10% of the original design volume.	As needed (infrequently)

OPERATIONS AND MAINTENANCE

If properly designed and regularly maintained, vegetated swales can last indefinitely. Pretreatment designed to remove trash and coarse sediment will reduce the maintenance burden for the swale itself. The primary maintenance objective for vegetated swales is to maintain the hydraulic and removal efficiency of the channel with a dense, healthy vegetative cover. During construction, it is important to stabilize the swale before the vegetation has been established, either with a temporary grass cover, or the use of natural or synthetic erosion control products. The table on the previous page provides more information on typical post-construction inspection and maintenance activities.

COST

Construction costs range from $5 to $9 per linear foot for a 15-foot wide (top width) swale or approximately $0.50 per square foot. EPA (1999) provides tables showing capital costs and annual operations and maintenance costs for swales. Construction of vegetated swales can be less expensive than other more traditional conveyance systems such as concrete ditches or sewers. Annual maintenance costs are estimated at about 6% of construction costs.

REFERENCES AND RESOURCES

California Stormwater Quality Association. 2003. "TC-30: Vegetated Swale." *California BMP Handbook- New Development and Redevelopment*.

City of Seattle. 2000. "Title 22.800 Stormwater, Grading, and Drainage Control." *Stormwater Treatment Technical Requirements Manual Vol. 4*.

Environmental Protection Agency. "National Pollutant Discharge Elimination System Menu of Best Management Practices Fact Sheets: Grassed Swales." 18 June 2008 <http://cfpub.epa.gov/npdes/stormwater/menuofbmps/index.cfm?action=browse>.

Environmental Protection Agency. 1999. "Stormwater Technology Fact Sheet: Vegetated Swales (EPA 832-F-99-006)."

Portland Bureau of Environmental Services. 2004. "Stormwater Management Manual."

Vegetated Buffer Strip

Also known as: grassed filter strip, vegetated filter, infiltration planter strip

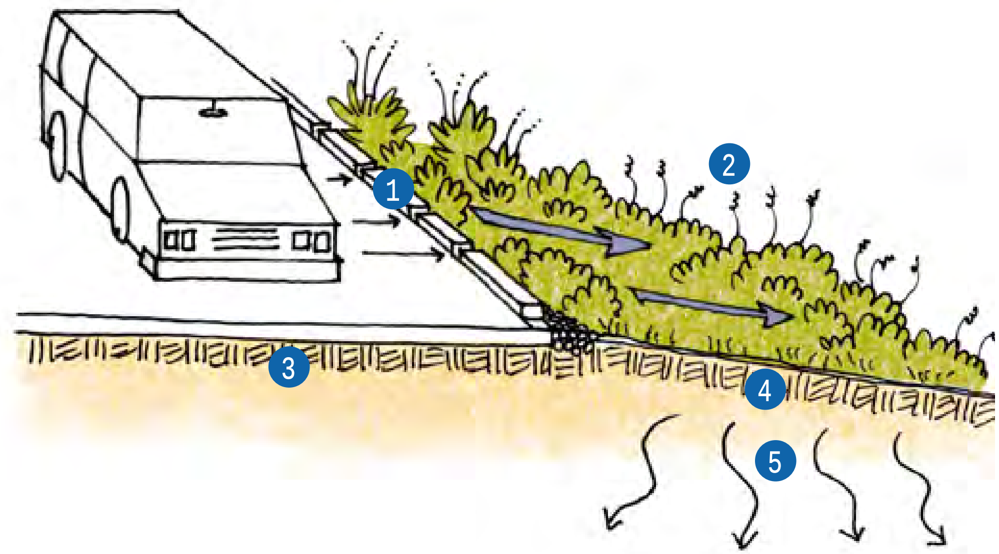
Optional curb cuts evenly disperse run-off inflow 1

Thick vegetation and 10% maximum slope 2

60-foot maximum road width 3

15-foot minimum buffer strip width (in the direction of flow) 4

Infiltration where feasible 5



DESCRIPTION

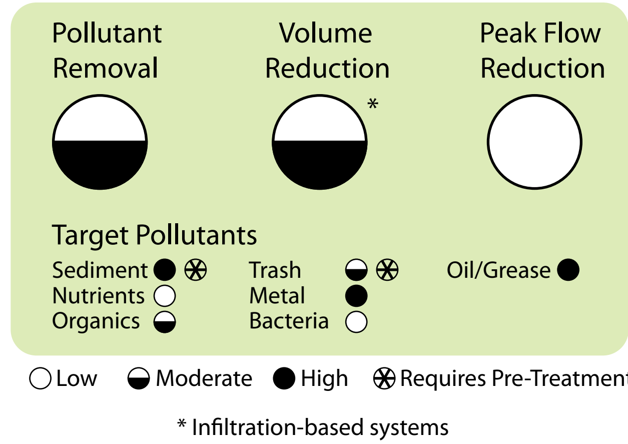
Vegetated buffer strips are sloping planted areas designed to treat and infiltrate sheet flow from adjacent impervious surfaces. They slope away from the impervious surface and are most often planted with grass, though other uniformly distributed plant species are also appropriate. Buffer strips function by slowing stormwater runoff and allowing sediment and other pollutants to settle and infiltrate. They ultimately discharge flows to the collection system or other BMPs.

Vegetated buffer strips are well-suited to treating runoff from roads and highways, roof downspouts, small parking lots, and pervious surfaces. They are also appropriate for the "outer zone" of a stream buffer, or as pretreatment for another stormwater BMP that provides detention or storage. In addition, they are generally attractive features that tend to be viewed as landscape amenities rather than as stormwater infrastructure.

BENEFITS

- Improves water quality.
- Attenuates peak flows, recharges groundwater.
- Good for roadside shoulders and landscape buffers.

- Attractive landscape feature.
- Minimal maintenance required.
- Easy to customize to varying site conditions.



LIMITATIONS

- Not appropriate for industrial or contaminated sites.
- Limited ability to treat large drainage areas.
- Limited stormwater volume reduction.
- May require irrigation in dry season, depending upon species.
- Persistent stormwater pollutants may accumulate in sediments, such as metals, oil, and grease.

SITING

Drainage area and slope: In general, buffer strips are thought to be effective at treating contributing road widths that are up to twice the width of the buffer strip. Because buffer strips cannot treat large amounts of runoff, the width of the road (or more generally the contributing drainage area) should be no greater than 60 feet. Additionally, buffer strips should be at least 15 feet wide (in the direction of flow) to provide water quality treatment. The upstream edge of the buffer strip should be contiguous to the roadway and the buffer strip should extend the full length of the contributing drainage area. The edge of the roadway should be flat and even to ensure sheet flow onto the buffer strip and prevent erosion. The top of the buffer strip should be set 2 to 5 inches below the adjacent pavement so that vegetation and sediment accumulation at the edge of the strip do not prevent runoff from exiting the road surface. Though once thought to help evenly distribute flow at the top of the buffer strip, level spreaders such as berms, sawtooth concrete borders, or rock trenches are no longer encouraged, because they tend to erode, wash out, and require more maintenance.

Buffer strips should be sited on gentle slopes between 1 and 10%. Steeper slopes may trigger erosion during heavy rain events, thus eliminating water quality benefits. On slopes greater than 5%, fiber rolls, check dams, or other means should be used to slow flows and reduce erosion potential. If the buffer strip slope is less than 0.5%, or if the underlying soil has infiltration rates of less than 0.5 inches per hour, an underdrain system should be installed to facilitate drainage. The underdrain would be sited at the toe of the buffer strip and connected to the collection system or another BMP.

Soils and infiltration rate: Planting soil should be at least six inches deep. Native soil can be used if approved by the project landscape architect. The surface of the buffer strip should be graded flat prior to placement of vegetation. If infiltration is desired, the native soil should drain at a rate of at least 0.5 inches per hour. Low-slope buffer strips will be more effective at infiltrating runoff.

DESIGN CONSIDERATIONS

Vegetation: The thicker and more uniform the plant cover, the greater the stormwater management benefits. In San Francisco's Mediterranean climate, native plants that can tolerate both inundation and drought should be used where possible, to minimize irrigation and fertilizer costs. 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 the maximum water quality performance.

Sizing: Vegetated buffer strips are sized using the flow-based calculations described in Step 7 of the Stormwater Control Plan chapter of the *Guidelines*. An electronic sizing tool is also provided with the *Guidelines* and is hosted on the SFPUC website at http://stormwater.sfwater.org in the Stormwater Design Guidelines section. The tool should be used for planning purposes only, such as determining the general footprint and preliminary dimensions. This calculator is not intended to provide final detailed calculations or dimensions.

OPERATIONS AND MAINTENANCE

The maintenance of vegetated buffer strips mainly consists of vegetation management. Recent research 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. Weed supression must be done much more frequently than mowing. Once a month is a typical weed supression schedule. The table on the following page provides more information on typical post-construction inspection and maintenance activities.

Typical Inspection Activities for Vegetated Buffer Strips

Activity	*Schedule*
· After first rain event, inspect for standing water and erosion.	Post-construction
· Inspect for standing water, trash accumulation, erosion, damage to vegetation, and sediment accumulation.	Annually

Typical Maintenance Activities for Vegetated Buffer Strips

Activity	*Schedule*
· Regularly water during first three months as vegetation estalblishes roots.	Post-construction
· Control invasive weeds.	Monthly
· Remove litter and mow or trim vegetation. · Regrade to eliminate standing water.	Annually or as needed

COST

The cost of a vegetated buffer strip depends upon the dimensions and location of the strip. One useful proxy estimate is the cost of sod, which is about $0.30 to $0.70 per square foot. This equates to $13,000 to $17,000 per acre. Once established, vegetated buffer strips require little maintenance. Typical maintenance costs are estimated at $350 per acre per year. Installation of underdrains at the toe of low-slope buffer strips will also increase installation and maintenance costs.

REFERENCES AND RESOURCES

Alameda Countywide Clean Water Program. 2006. "Vegetated Buffer Strips." *C.3 Stormwater Technical Guidance, v1.0.*

California Stormwater Quality Association. 2003. "TC-31 Vegetated Buffer Strip." *California Best Management Practice Handbook*.

Constructed Wetland

Also known as: stormwater wetland, treatment wetland, stormwater marsh

Inlet 1

Forebay (pretreatment and energy dissipation) 2

Irregular bottom surface 3

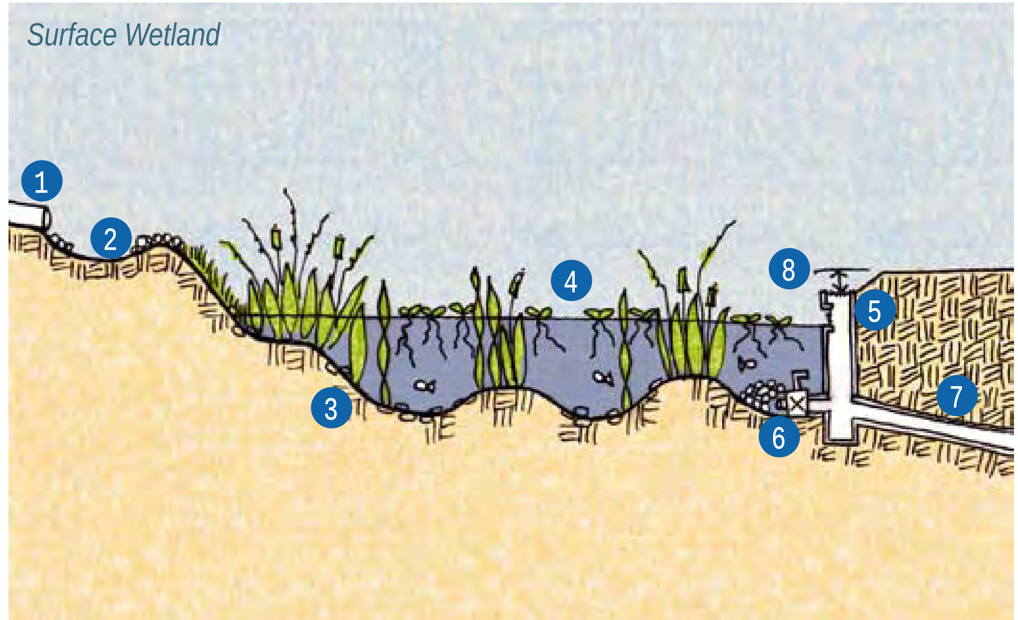
Open water surface 4

Overflow structure with screened inlets 5

Valve for drainage and maintenance 6

Outlet to collection system, catch basin, or receiving water 7

Minimum 1 foot freeboard 8



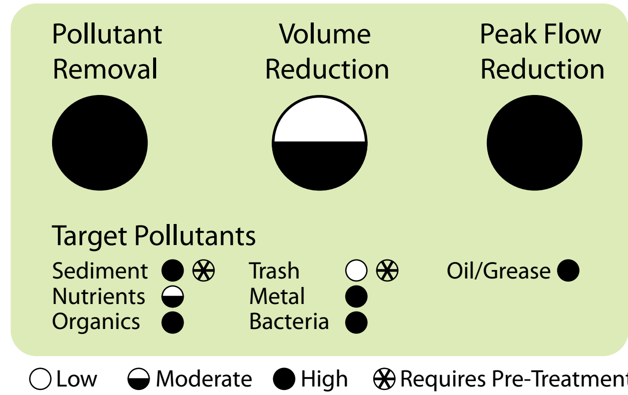
DESCRIPTION

Constructed wetlands are man-made wetlands designed to collect and purify stormwater through microbial transformation, plant uptake, settling and adsorption. Water is stored in shallow vegetated pools that are designed to support wetland plants. Constructed wetlands have some of the same ecological functions as natural wetlands and are beneficial for flood control and water quality improvement. Wetlands must be paired with other filtration or biofiltration BMPs that remove sediment and litter from stormwater prior to its entry into the wetland.

There are two main types of constructed wetlands: surface and subsurface flow wetlands.

- Surface flow wetlands maintain a shallow and relatively constant depth of standing or slow-flowing water year-round, and contain both emergent vegetation and open water. Vegetated areas foster microbial communities that transform and remove stormwater pollutants, while open water areas aid in pathogen removal, hydraulic circulation, and mosquito abatement if the wetland is stocked with mosquitofish.

- Subsurface flow wetlands are more commonly used in Europe and are sometimes called reed beds or vegetated rock filters (see the following fact sheet about Vegetated Rock Filters). Water in these systems flows below the ground surface through a planted substrate such as rock, gravel, or sand. Most of the treatment action occurs in the biofilm that grows on the substrate media. Compared to surface flow wetlands, subsurface flow wetlands generally require less land area and tend to have fewer mosquito management issues, but may be more expensive to construct and maintain. As a sub-category of vegetated rock filters, subsurface flow wetlands are planted with wetland vegetation; other types of vegetated rock filters may contain non-hydrophytic plants that do not require constant inundation.



Constructed wetlands have been shown to reduce total suspended solids, phosphorus, nitrogen, metals, and bacteria by 50 to 90%, depending on system design and influent water quality. Treatment occurs primarily in the root zone of wetland plants (for surface flow wetlands) or in the rock media (for subsurface flow wetlands) via microbial transformation, sedimentation, and plant uptake.

BENEFITS

- Effective at removing stormwater pollutants (sediment, nutrients, organic compounds, pathogens, heavy metals).
- Reduces stormwater peak flows, can reduce overall volume if runoff is stored and used.
- Attractive landscape feature and potential community park amenity.
- Provides valuable wetland habitat.
- Good in areas unsuitable for infiltration or with high groundwater table.
- Easily customizable to various sizes and dimensions, based on site, budget, and design intent.
- Can be designed to treat and store water for local non-potable use (e.g. for irrigation, toilet flushing, or fire protection) depending on site conditions and stormwater characteristics.

El Monte Sagrado - Living Resort and Spa in Taos, NM recycles almost all of its wastewater for landscape irrigation after treating the wastewater in a Tidal Wetland Living Machine. In addition, stormwater is captured and used to replenish ponds and waterfalls throughout the resort.

LIMITATIONS

- Requires relatively large land area.
- May require supplemental water source in dry season.
- Seasonal variation in water quality improvement as plants senesce in winter.
- Vegetation may appear dead or unkempt in winter and summer.

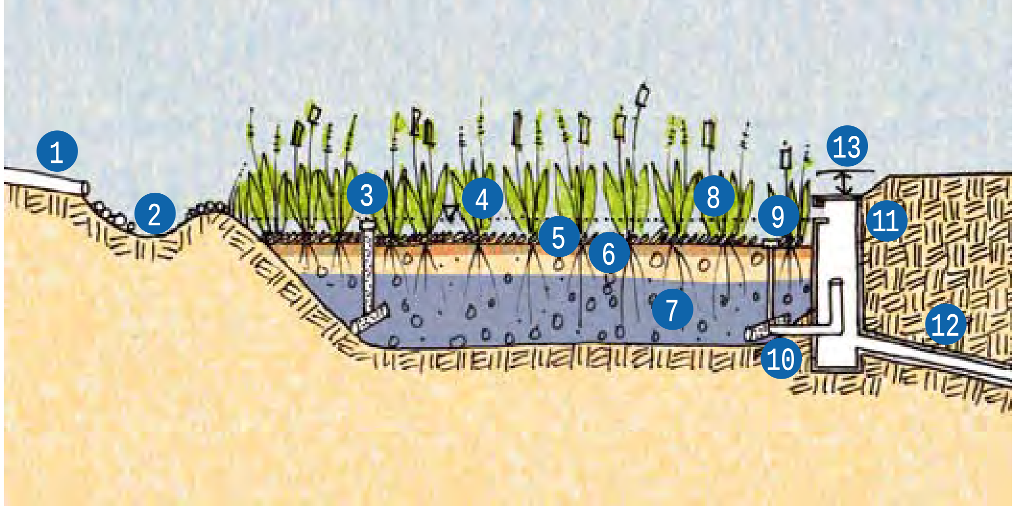
SITING

<u>Drainage area and slope</u>: Though they only occupy 3 to 5% of their contributing drainage area, stormwater wetlands require sufficient drainage to maintain a permanent pool, typically a minimum of 5 acres. Wetlands must be sited on a relatively flat area with less than 2% slope. While there is no minimum slope requirement, there must be enough elevation drop from inlet to outlet to ensure that water can flow through the system by gravity. The slope downstream of constructed wetlands should not exceed 15%.

<u>Soils and dry season water supply</u>: Because they are not designed to reduce runoff by infiltration, constructed wetlands can be used in almost all soil types. In Mediterranean climates like San Francisco, wetlands may either be allowed to evaporate in the dry season, or may be supplemented with an alternative source of influent water. Dry-weather alternative water sources could be street and irrigation runoff, groundwater, greywater, or other urban water applications. To treat greywater with wetlands, however, system design should follow wastewater treatment wetland guidelines rather than stormwater guidelines. Permitting and project review processes for greywater/wastewater treatment wetlands differ significantly from those applied to stormwater wetlands. The Regional Water Board will need to be informed of such design proposals early on in the process. For more information on using wetlands to treat greywater, see http://www.epa.gov/owow/wetlands/watersheds/cwetlands.html.

<u>Groundwater protection</u>: Wetlands may intersect the groundwater table, which will help support wetland vegetation. This should be avoided in areas where either the stormwater or the groundwater could be contaminated. In these areas, an impermeable liner can keep wetland and groundwater separate.

Subsurface Flow Wetland (volume-based inlet and outlet design)



1. Inlet
2. Forebay (pretreatment and energy dissipation)
3. Perforated riser and inlet pipe (riser conveys ponded water to gravel layer)
4. Water Quality Volume level
5. Mulch
6. Low permeability wetland soil
7. Medium and coarse gravel
8. Wetland vegetation
9. Observation well and cleanout
10. Primary outlet (perforated pipe with adjustable standpipe to control water level)
11. Overflow structure with screened inlets
12. Outflow to collection system, catch basin, or receiving water
13. Minimum 1 foot freeboard

DESIGN CONSIDERATIONS

Vegetation: The health of wetland vegetation is integral to the ability of stormwater wetlands to improve water quality. Wetlands should have zones of both very shallow (less than 6 inches) and moderately shallow (6 to 18 inches) standing water to maintain both vegetated and open water areas. Vegetated areas foster more microbial and plant treatment action, while open water areas can support mosquitofish (Gambusia spp.) to minimize mosquito breeding. Though native emergent plants should be used wherever possible, common stormwater wetland plant species include cattail (Typha latifolia), bulrush (Scirpus spp.), and reeds (Phragmites spp.). Cattails tend to require more maintenance because they can easily spread to nearby areas and become a nuisance.

Pretreatment: Pretreatment, which occurs via settling of coarse sediment and debris in a wetland forebay, is key to the function of constructed wetlands. Other BMPs may also be used upstream of a constructed wetland to enhance treatment effectiveness. Vegetated swales or buffer strips may help filter stormwater before it enters a stormwater wetland; alternatively or additionally, sediment removal devices such as a water quality inlet, a swirl separator, or a media filter can trap sediment prior to treatment by a wetland. This can reduce maintenance needs in the wetland itself.

Drainage and Overflow: Inlet and outlet configurations for surface and subsurface flow wetlands can vary, and should be designed by the project engineer to reflect site constraints and design goals. Subsurface flow wetland inlets can be located at the media surface or at depth. In the diagram on the previous page, stormwater overflows from the forebay and ponds on the surface of the main wetland pool. The ponded inflow moves down into the gravel media via the perforated standpipe; the wetland soil at the surface prevents the potential for short-circuiting by acting as an impermeable barrier. This type of inlet configuration is a volume-based design. In contrast, the inlet and outlet configuration shown for the Vegetated Rock Filter on page 66 is a flow-based design. The outlet configuration shown on the previous page consists of a reverse slope pipe leading to a stand pipe, which regulates the permanent pool water level. Either inlet and outlet design could be used for either BMP. All pipes should be at least 3 inches in diameter to prevent clogging.

Sizing: Wetlands must be designed and sized by a qualified engineer. To enhance pollutant removal, stormwater wetlands should have varied microtopography along the wetland bottom to create as long a flow path as possible at lower flows and a length to width ratio of between 2:1 and 4:1. Stormwater wetlands commonly occupy 3 to 5% of the drainage area. An electronic sizing tool using volume-based calculations is provided with the *Guidelines* and is hosted on the SFPUC website at http://stormwater.sfwater.org in the Stormwater Design Guidelines section. The tool should be used for planning purposes only, such as determining the general footprint and preliminary dimensions. This calculator is not intended to provide final detailed calculations or dimensions.

OPERATIONS AND MAINTENANCE

Wetlands should incorporate design features to make sediment cleanout of both the forebay and the main body of the wetland easier. Wetlands should have direct maintenance access to the forebay, to allow sediment cleanout every 3 to 5 years. In addition, the main body of the wetland should have a drain so it can be drawn down for more infrequent dredging. The table on the following page provides more information on typical post-construction inspection and maintenance activities.

COST

Though relatively expensive compared to other BMPs, constructed wetlands can achieve significant water quality improvement as well as volume reduction and peak flow attenuation for large drainage areas. Though costs vary widely based on system design, location, and desired treatment level, the California BMP Handbook estimates that a 1 acre-foot wetland might cost $57,000, or $2.62 per square foot for a half-acre two-foot deep wetland. Maintenance costs are estimated to be between 3 and 5% of construction costs; however, this will vary considerably from system to system.

REFERENCES AND RESOURCES

California Stormwater Quality Association. 2003. "TC-21: Constructed Wetlands." *California Best Management Practice Handbook- Municipal.*

Typical Inspection Activities for Constructed Wetlands

Activity	Schedule
• Check inlets and outlets for signs of clogging or erosion. • Monitor vegetation to ensure successful root establishment.	Post-construction
• Inspect for invasive vegetation and remove where possible. • Inspect for signs of mosquito breeding.	Semi-annually (beginning and end of rainy season)
• Monitor for sediment accumulation in the forebay and main wetland. • Check inlets and outlets for signs of clogging, erosion, or other damage.	Annually

Typical Maintenance Activities for Constructed Wetlands

Activity	Schedule
• Remove debris from and clean inlet and outlet structures. • Trim vegetation as needed.	Semi-annually (beginning and end of rainy season)
• Plant additional vegetation if at least 50% of the surface area has not established. • Harvest wetland plants that have been “choked out” by sediment build-up. • Repair undercut or eroded areas.	Annually or as needed
• Remove sediment from forebay when depth exceeds 6 inches or 50% of storage capacity.	As needed (Expected frequency every 3 to 5 years)
• Regrade or raise wetland berms as sediment and root mass accumulates.	As needed (Expected frequency every 20 to 50 years)

Center for Watershed Protection. 2001. "Stormwater Management Fact Sheet: Stormwater Wetland." 5 Jun 2008 <www.stormwatercenter.net>.

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Smith, Brooke Ray. 2008. *Re-Thinking Wastewater Landscapes: Constructed Wetlands for Urban-Ecological Mutualism in San Francisco*. Masters thesis, University of California, Berkeley.

United States Environmental Protection Agency. 1993. "Constructed Wetlands for Wastewater Treatment and Wildlife Habitat: 17 Case Studies." 17 Jun 2008 <http://epa.gov/owow/wetlands/construc/>.

Vegetated Rock Filter

Also known as: packed bed filter, rock-reed filter, subsurface flow constructed wetland, reed bed, vegetated submerged bed

Inlet 1

Forebay (pretreatment and energy dissipation) 2

Inlet pipe from forebay 3

Water surface elevation 4

Aerobic zone 5

Anaerobic zone 6

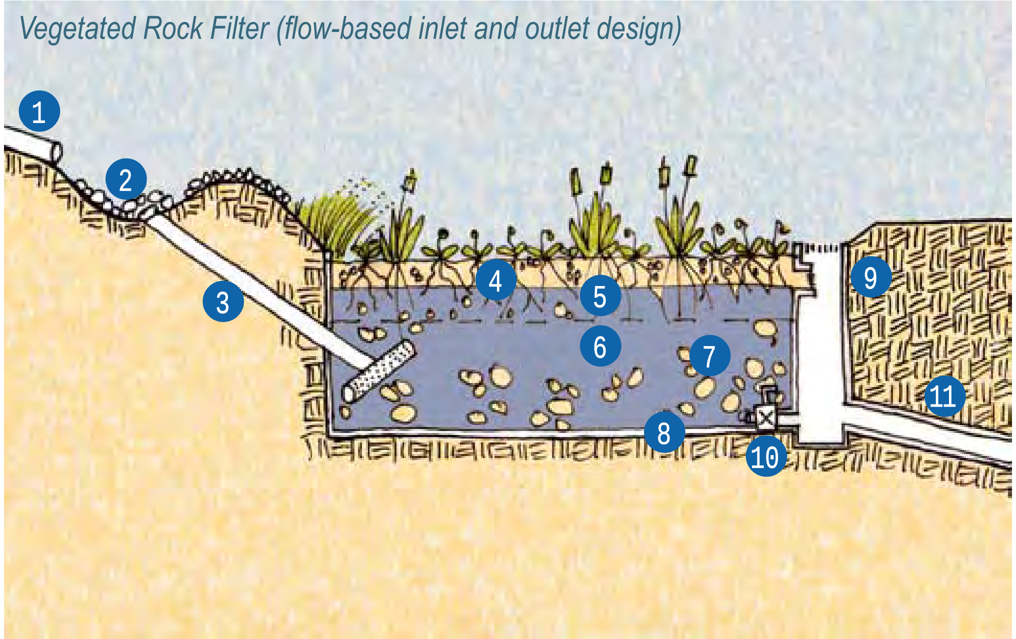
Coarse aggregate 7

Impermeable liner 8

Overflow structure with screened inlets 9

Maintenance drain with shut-off valve 10

Outflow to collection system, catch basin, or receiving water 11



DESCRIPTION

Vegetated rock filters (VRF) are basins or tanks filled with gravel or other similar media that support vegetation. Stormwater flows through the rock media just below the surface, thus eliminating surface water but maintaining a sufficient seasonal or perennial water level to sustain the vegetation. Water flows through the system by gravity, with the primary direction of movement either being horizontal, across the length of a treatment cell, or vertical, percolating down a deeper tank to an underdrain. Horizontal flow systems are more common and will be the focus of this fact sheet and the VRF sizing calculator. To maintain the appropriate subsurface water level, VRFs typically contain an impermeable liner.

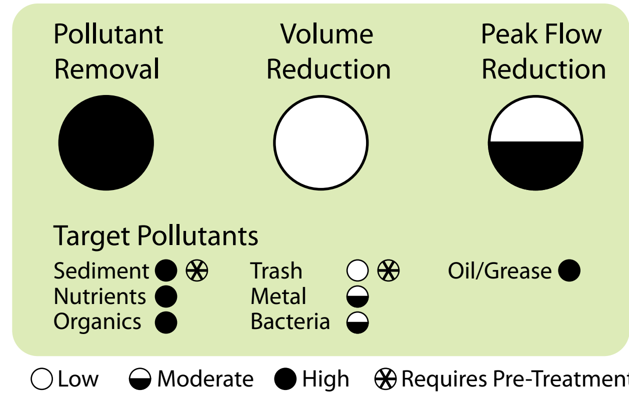
When planted with hydrophilic plants that can withstand root inundation, these systems are also called subsurface flow constructed wetlands. However, because the term "wetland" connotes a specific set of plant species, soils, and hydrology, "vegetated rock filter" describes a broader category of vegetated stormwater treatment facilities that may contain non-wetland plant species.

BENEFITS

- Effective stormwater pollutant removal.
- Attenuates peak flows.
- Creates wildlife habitat.
- Attractive landscape feature.
- Minimal risk of mosquito breeding if subsurface water level maintained.

LIMITATIONS

- Vegetation may appear unkempt in dry season.
- Treatment effectiveness decreases in winter as plants senesce.
- Nutrient removal is cyclical – vegetation must be harvested to permanently remove nitrogen and phosphorus from runoff.
- More expensive than surface flow constructed wetlands, and with fewer habitat benefits.



SITING

Drainage area and slope: Vegetated rock filters are a widely applicable stormwater management practice that can function in a broad range of scales, drainage areas, and land use types. They should be located on sites with less than 2% slope. The hydraulic head, however, should be great enough to ensure gravity flow; usually about 3 to 5 feet. Because they are not intended for infiltration and are typically lined, VRFs are appropriate BMPs in areas with low-permeability or contaminated soils.

DESIGN CONSIDERATIONS

Dimensions: Length to width ratios are typically between 2:1 and 4:1; however, some designs include multiple VRF cells in series with a length to width ratio of 1:2 each. VRFs are usually designed to treat the "first flush" of rainfall runoff at a filter loading rate of 1 to 4 inches per hour. Sizing based on this premise results in VRF footprints that are 2 to 5% of the contributing drainage area.

Materials: The typical filter media used are gravel, sand, or rocks at a depth ranging from 1 to 3 feet, which is the typical rooting depth for most wetland plants. In addition to pretreatment measures (discussed below) VRF cell design can help to prevent clogging by specifying larger gravel at the inlet and outlet (1.5 to 3 inches in diameter) and smaller pea gravel (0.5 inch diameter) in the main bed area.

Vegetation: In order to maximize performance and minimize maintenance, VRF vegetation should be adapted to local climatic conditions. Plant species should be tolerant of both drought conditions during the dry season, and inundated conditions in the winter. Common wetland plant species are Typha latifolia (cattail), Scirpus acutus or S. californica (bulrush), and Phragmites spp. (reeds), but many other hydrophytic species may also be used.

Pretreatment: Pretreatment is key to the function of vegetated rock filters. To prevent litter, sediment or debris from entering and clogging the gravel bed, it is recommended that VRFs include screens, a sediment forebay, or other equivalent pretreatment measures including pairing with other BMPs. Vegetated buffer strips or swales can also be used as part of a treatment train to remove gross solids upstream of the VRF, thereby extending the life of the filter media.

Treatment: VRFs perform a wide variety of chemical, physical and biological processes that remove pollutants from stormwater runoff. Filtration in the filter media is considered to be the primary removal mechanism. However, additional removal occurs through microbial biodegradation as well as pollutant uptake by the vegetation. VRFs have shown the ability to remove a high level of suspended solids (80% removal), nutrients (50%), organic compounds, bacteria (70%), and heavy metals (50%). In contrast to sand filters, the VRF includes a permanent body of sub-surface water, which creates an anaerobic zone for removing nitrate. With an adequate hydraulic residence time and sufficient supply of carbon in the anaerobic zone, VRFs have been able to remove 80 to 99% of nitrates from stormwater runoff.

Drainage and Overflow: Inlet and outlet configurations for vegetated rock filters and subsurface flow wetlands can vary, and should be designed by the project engineer to reflect site constraints and design goals. VRF inlets can be located at the media surface or at depth. In contrast to the volume-based design shown for the subsurface flow wetland on page 61, the VRF diagram shows a flow-based design for the inlet and outlet configuration.

The only outlet under typical operating conditions is at the surface of the downstream end of the filter, and it is the flow rate through the gravel media that determines treatment capacity. The maintenance drain would be kept closed unless full drainage of the VRF was necessary.

Sizing: Vegetated rock filters can be sized using the flow- or volume-based calculations described in Step 7 of the Stormwater Control Plan chapter of the *Guidelines*. VRFs with inlet and outlet configurations that incorporate storage above the filter bed are suited to volume-based sizing. Conversely, VRFs that do not incorporate storage above the filter bed are more suited to flow-based sizing. An electronic sizing tool is also provided with the *Guidelines* and is hosted on the SFPUC website at http://stormwater.sfwater.org in the Stormwater Design Guidelines section. The tool should be used for planning purposes only, such as determining the general footprint and preliminary dimensions. This calculator is not intended to provide final detailed calculations or dimensions.

OPERATIONS AND MAINTENANCE

VRFs can last over twenty years, but require regular inspection and maintenance to ensure proper operation. Treatment effectiveness is significantly reduced if the system becomes clogged with debris or sediment. Despite San Francisco's Mediterranean climate, supplemental watering during extended summer dry periods may not be required. Several studies indicate that it is possible to maintain VRF treatment function in dry weather because the filtration process is fairly independent of plant activity, and because the biofilm bacteria that provide biological treatment can often recuperate from desiccation within a day or two of hydric conditions. If wetland plants are used, such as meadow grasses that can grow in both wet and dry conditions, watering may not be required. However, if aquatic wetland species are desired, other non-potable irrigation sources such as groundwater, greywater, or recycled water may be used. The table on the following page provides more information on typical post-construction inspection and maintenance activities.

Typical Inspection Activities for Vegetated Rock Filters

Activity	Schedule
• Check inlets and outlets for clogging, erosion, and sediment build-up. • After first storm, check that desired drawdown time has been achieved. • Monitor vegetation to ensure successful root establishment.	Post-construction
• Inspect for sediment build-up in the forebay and gravel bed. • Inspect for invasive plants and remove them. • Check inlets and outlets for signs of clogging, erosion, or other damage.	Annually

Typical Maintenance Activities for Vegetated Rock Filters

Activity	Schedule
• Regularly water during the first three months as vegetation establishes roots.	Post-construction
• Remove debris from inlets and outlets to avoid clogging. • Replace vegetation if necessary to maintain at least 50% surface area coverage in plants after the second growing season.	Annually
• Remove sediment from forebay when depth exceeds 6 inches or 50% of storage capacity.	As needed (expected frequency every 3 to 5 years
• Major rehabilitation: if sediment build-up is preventing flow, remove gravel from VRF cell, replace with clean gravel, and replant.	Every 20 years

COST

Typical costs associated with VRFs include land costs, site investigation and clearing, earthwork, operations and maintenance, and materials: impermeable liner, gravel media, plants, inlet and outlet structures and pipes. Much of the capital cost derives from the liner and gravel items, which can be 50% or more of total cost. Without a liner, a prototypical VRF treating 100,000 gallons per day might have a $362,500 capital cost with $6,000 per year for operations and maintenance. With a plastic membrane liner, the same system might cost $466,700 up front, with the same maintenance costs. Maintenance costs are estimated at about 3 to 5% of construction costs.

REFERENCES AND RESOURCES

California Stormwater Quality Association. 2003. "TC-21: Constructed Wetlands." *California Stormwater BMP Handbook – New and Re-Development.*

Center for Watershed Protection. 2001. "Stormwater Management Fact Sheet: Stormwater Wetland." 18 June 2008 <www.stormwatercenter.net>.

Ellis, J.B., R.B.E. Shutes and D.M. Revitt. 2003. *Guidance Manual for Constructed Wetlands*. Bristol: Environment Agency.

Environmental Protection Agency. 2000. "Wastewater Technology Fact Sheet. Wetlands: Subsurface Flow (EPA 832-F-00-023)."

State of Georgia. 2001. *Georgia Stormwater Management Manual – Volume II*. August 2001.

University of New Hampshire Stormwater Center. 2006. "Gravel Wetland Fact Sheet." 18 June 2008 <http://www.unh.edu/erg/cstev/fact_sheets/gravel_wetland.pdf>.

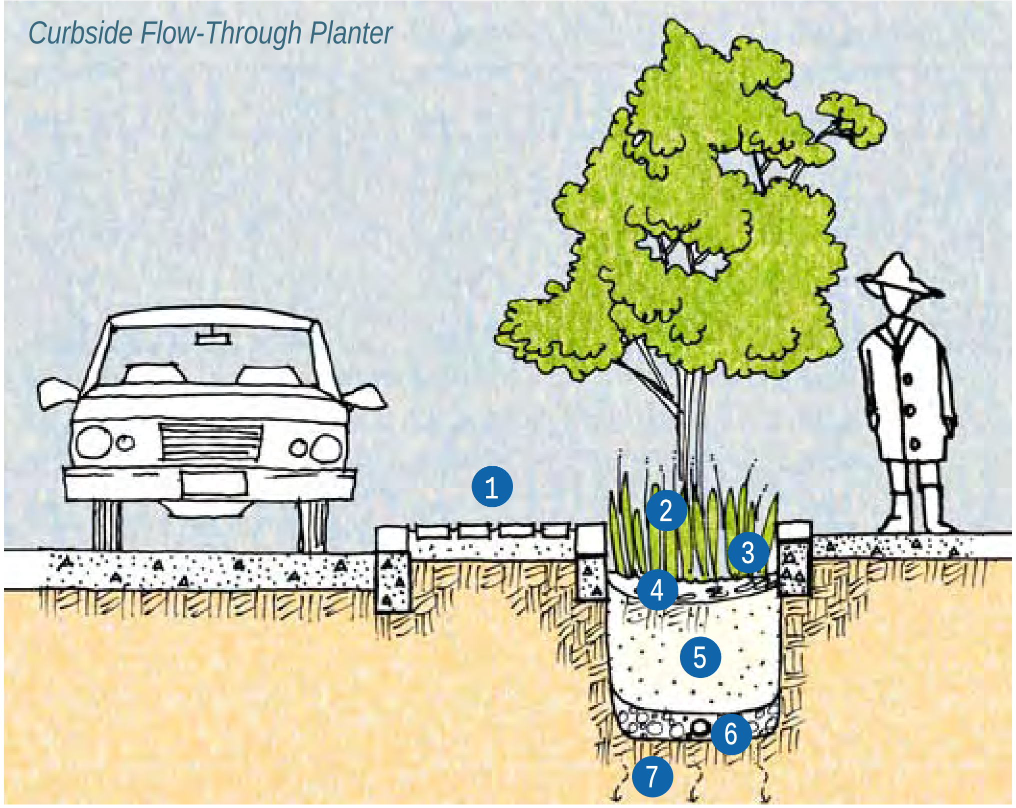
United States Department of Transportation, Federal Highway Administration. "Section 3.10.5 Vegetated Rock Filters." *Stormwater Best Management Practices in an Ultra-Urban Setting: Selection and Monitoring.* 4 Jun 2008 <http://www.fhwa.dot.gov/environment/ultraurb/uubmp3p9.htm>.

Winer, R. 2000. *National Pollutant Removal Performance Database for Stormwater Treatment Practices, 2nd Edition*.

Bioretention

Also known as: bioretention cell, bioretention planter, above-ground planter, flow-through planter, stormwater planter, and rain garden

1. Parking egress zone with curb cut
2. Dense wet- and dry-tolerant vegetation
3. 6-inch maximum ponding depth
4. 2- to 3-inch mulch depth
5. 18-inch bioretention planting soil
6. Perforated pipe in gravel jacket (if infiltration not feasible)
7. Infiltration where feasible



DESCRIPTION

Bioretention refers to the use of stormwater facilities that rely on vegetation and either native or engineered soils to capture, infiltrate, transpire, and remove pollutants from runoff, thereby reducing stormwater volume, attenuating peak flow, and improving stormwater quality. Bioretention BMPs feature vegetation that can tolerate periodic inundation and contain engineered soils with high organic content. If designed properly, they can be an aesthetic and habitat amenity as well as a stormwater treatment facility.

Bioretention systems can be designed as infiltration-based systems if the native soils beneath the facility are sufficiently permeable and there are no other constraints to infiltration such as soil or groundwater contamination. If infiltration is not feasible, they can be designed as flow-through systems that are contained within an impermeable liner and use an underdrain to direct treated runoff to the collection system. A note on terminology: bioretention facilities that are installed directly in the ground in a depressed area of the landscape where runoff collects are typically called "rain gardens;" those that are contained within a curb or hard-walled container are typically called "planters."

BENEFITS

- Easy and inexpensive to install.
- Wide range of scales and site applicability.
- Reduces runoff volume where infiltration is feasible and attenuates peak flows.
- Improves water quality and air quality.
- Increases effective permeable surfaces in highly urbanized areas.
- Creates habitat and increases biodiversity in the city.
- Provides aesthetic amenity.
- Facilitates groundwater reacharge (infiltration-based systems only).
- Facilitates evapotranspiration.

LIMITATIONS

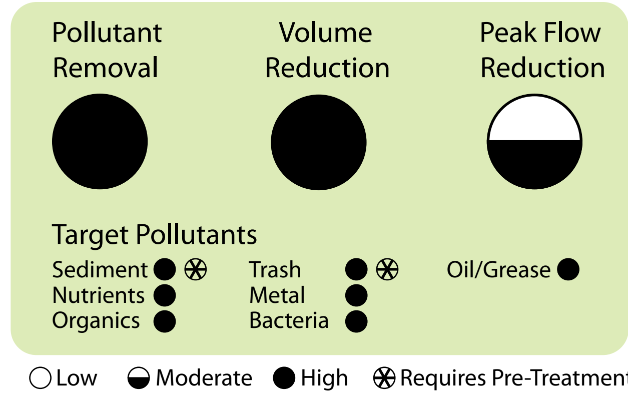
- Requires relatively flat site and sufficient hydraulic head for filtration.
- Vegetation requires maintenance and can look overgrown or weedy; seasonally it may appear dead.

SITING

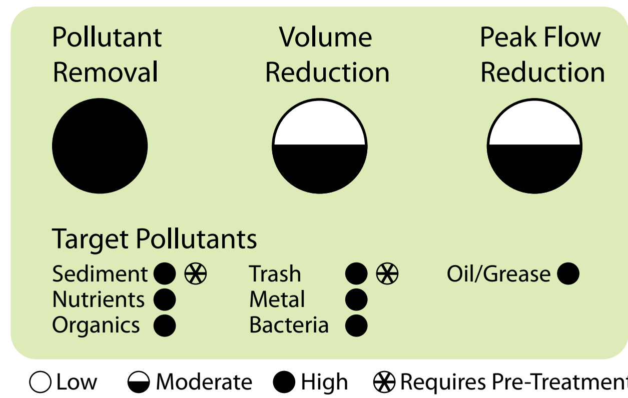
Because they tend to be small and versatile, bioretention systems can be used in a variety of contexts, including residential yards, office and commercial storefronts, parks, roadway median strips and right-of-ways, parking lots, and other landscaped areas. They are also easily integrated into highly urban retrofit projects.

<u>Drainage area</u>: A single rain garden or planter should not receive runoff from more than 1 acre of drainage area. Multiple bioretention cells (rain gardens or planters) with separate inlets can be used to treat stormwater from larger contributing areas.

Infiltration-based



Flow-through



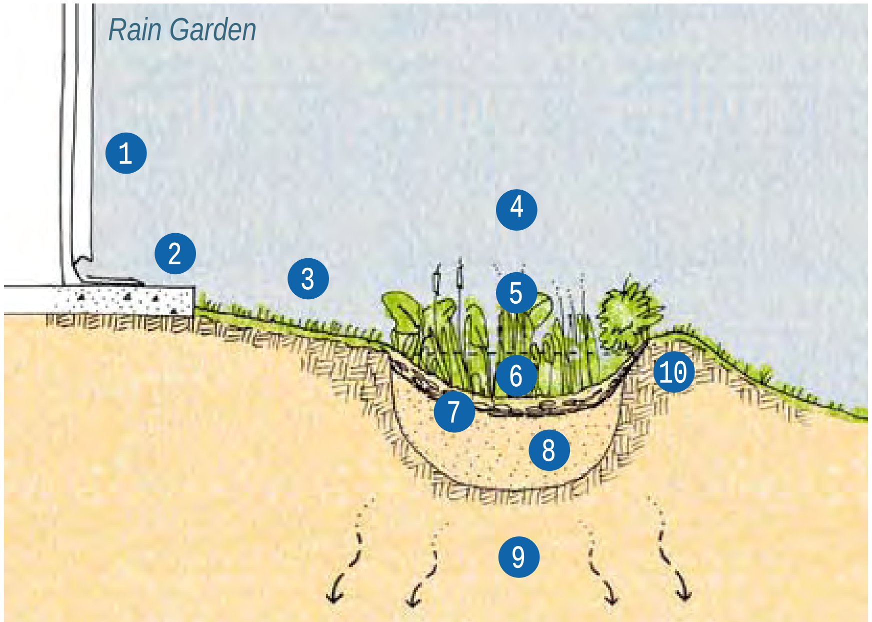
Rain garden captures and infiltrates stormwater from the paved surface in Mint Plaza, San Francisco.

Setbacks: To avoid damage to adjacent building foundations, infiltration-based bioretention systems should be placed a minimum of 10 feet downgradient or 100 feet upgradient of foundations. If the drainage area is less than 1,000 square feet or if the drainage area is less than 5,000 square feet and adjacent buildings do not have basements, City of San Francisco staff may approve reduced setbacks of 5 and 50 feet, respectively. In addition, infiltration-based BMPs must be at least 5 feet from any property line, 100 feet from any downgradient slope greater than 15%, and 150 feet from any drinking water well. There are no setback requirements for waterproof, lined, flow-through systems or systems with no run-on, provided a waterproof separation barrier is used between the BMP drain rock and adjacent foundations. Flow-through systems can be integrated into a building's foundation walls either at grade within a curb or above ground using a contained planter. They are typically placed where the building frontage meets the public right-of-way and can be designed to extend over the private property line.

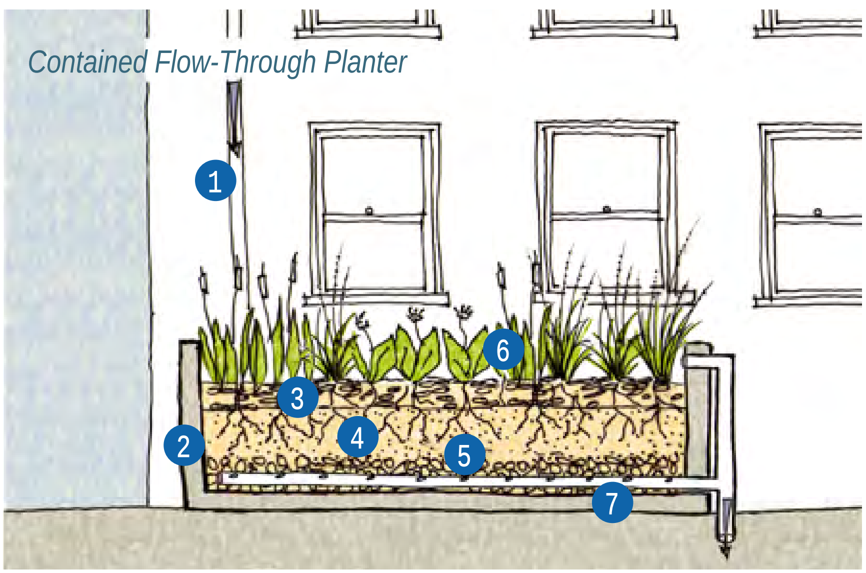
Slope and soils: Bioretention facilities are best suited to sites that have less than a 5% slope. For slopes greater than 5%, they can incorporate check dams or other flow control devices to retard flow. For infiltration-based systems, the drainage rate of the native soil should be at least 0.5 inches per hour. The bottom of the planting medium should be at least 4 feet above both the seasonally high groundwater elevation and bedrock elevation. There are no native soils requirements for lined, flow-through systems.

DESIGN CONSIDERATIONS

Materials: The surface of the bioretention facility is typically covered in a 2- to 3-inch layer of mulch or compost where some filtration occurs and microorganisms degrade hydrocarbons and organic material. In very urban settings, pea gravel or river rock may be a more appropriate surface material to reduce maintenance needs. This upper layer captures larger solids and can be replaced fairly easily; however, with the exception of systems capturing roof runoff, additional pretreatment is recommended for all bioretention systems. Typical pretreatment methods for bioretention include vegetated buffer strips, swales, and sediment forebays. Curbside bioretention systems capturing street runoff should have, at minimum, a shallow gravel area at the curb inlet to capture larger solids and protect the planted system from erosive flows.



1. Water from paved or landscaped surfaces and roof (maximum contributing area of 1 acre)
2. Splash block
3. Minimum 10 feet from foundation (see p. 70 for additional setback requirements)
4. Minimum 2-foot rain garden width
5. Dense, wet- and dry-tolerant vegetation
6. Ponding depth, 6 to 12 inches
7. Mulch, 2- to 3-inch depth
8. 18-inch bioretention planting soil
9. Native soils suitable for infiltration
10. Berm



1. Inlet from roof or other source
2. Water-tight container
3. Mulch
4. Bioretention planting soil
5. Gravel
6. Wet- and dry-tolerant plants
7. Underdrain to collection system

Alvarado Elementary School rain catcher planted with rain garden plantings. *Photo: Mara Seiling*

Residential rain garden in Maplewood, MN captures and infiltrates runoff from both residential yard and the street. *Photo: www.ci.maplewood.mn.us*

Beneath the surface layer is a layer of bioretention planting soil at least 18 inches deep. The planting soil is comprised of 60% sand and 40% compost or 50% sand, 30% compost, and 20% topsoil (by volume). The mixture should have an organic content between 4 to 10% (weight/weight), a clay content less than 5% (weight/weight), and a long-term design hydraulic conductivity of 4 in/hr. A recommended gradation for the planting soil is provided in the table below. Flow-through systems also require a 12-inch layer of gravel below the planting medium that houses the perforated underdrain. Other materials include splash blocks, flow spreaders, or other energy dissipation devices to prevent erosion at the flow inlet.

Recommended Gradation for Bioretention Planting Soils

US Sieve Number	*Percent Passing*
3/8"	100
No. 4	90-100
No. 8	70-100
No. 16	40-95
No. 30	15-70
No. 40	5-55
No. 100	0-15
No. 200	0-5

Vegetation: Where possible, use native vegetation and/or plants that provide habitat value for local insects, birds, and other species. The plant palette should be selected for viability in well-drained soil, as well as periods of inundation during the rainy season. Vegetation should be drought-tolerant, especially at the edges which remain primarily dry, but may require irrigation during initial establishment and during the dry season, depending on the application and species used. Trees planted in flow-through planters require more intensive maintenance, and often show limited growth and vigor. Therefore, containers should not be used for street tree plantings except in limited situations with underground constraints and where sidewalk widths are sufficient to accommodate large containers. Examples of vegetation appropriate for bioretention can be found in the Vegetation Palette, Appendix D of the *Guidelines*.

Drainage: During rain events, the bioretention system will fill with a few inches of water. If the underlying soils cannot infiltrate the collected water within the desired drain time (typically 48 hours), then a flow-through system with an underdrain is recommended. Drain times longer than 48 hours are not recommended as they can cause vector problems and impact plant growth.

Overflow: During larger storm events, ponding depths increase until collected runoff reaches the elevation of an overflow device, typically a weir or a riser. Excess flows are conveyed to the collection system or another BMP such as a vegetated swale, constructed wetland, detention pond, or detention vault.

Sizing: Bioretention facilities are sized using the volume-based calculations described in Step 7 of the Stormwater Control Plan chapter of the *Guidelines*. An electronic sizing tool is also provided with the *Guidelines* and is hosted on the SFPUC website at http://stormwater.sfwater.org in the Stormwater Design Guidelines section. The tool should be used for planning purposes only, such as determining the general footprint and preliminary dimensions. This calculator is not intended to provide final detailed calculations or dimensions. In general, rain gardens should be between 5 and 10% of the impervious area draining to them and should be at least 2 feet wide.

Some proprietary bioretention systems, such as Contech's UrbanGreen BioFilter and Americast's Filterra, are sized using flow-based calculations. Follow the manufacturer's instructions or contact the manufacturer to size these proprietary flow-based systems, and then verify with the sizing tool provided that the system meets required performance measures for the Port or SFPUC.

OPERATIONS AND MAINTENANCE

Like any landscape feature, bioretention facilities must be pruned, mulched and watered until the vegetation is established. Semi-annual plant maintenance is recommended, including weeding, mulching, and the replacement of diseased or dead plants. Mulch and compost improve the soil's ability to capture water. Because some of the sediment that enters the planters may form a crust on the soil surface, limiting the porosity of the soils, some raking of the mulch and soil surface may also be necessary to maintain high infiltration rates. Periodic trash removal may also be necessary. The table on the following page provides more information on typical post-construction inspection and maintenance activities.

Case Study: Portland, OR

Glencoe Elementary School in SE Portland installed a rain garden on their school grounds in 2003 to prevent neighborhood-wide sewer overflow problems while providing aesthetic and educational amenities to the schoolyard. The completed rain garden is a 2,000 square foot infiltration and detention system that manages runoff from 35,000 square feet of impermeable surfaces with a total cost of $98,000.

Rain Garden at Glencoe Elementary School in Portland, OR.

Formal rain garden in Portland, OR frames an outdoor patio area.

Typical Inspection Activities for Bioretention

Activity	Schedule
• After first storm event, inspect for proper drainage, erosion, and proper inlet and outlet functioning.	Post-construction
• Monitor vegetation to ensure successful root establishment. • Inspect for erosion, clogging, and vegetation damage.	Semi-annually (beginning and end of rainy season)

Typical Maintenance Activities for Bioretention

Activity	Schedule
• Regularly water during the first three months as vegetation establishes roots.	Post-construction
• Trim vegetation as needed to maintain desired appearance.	Monthly or as needed
• Remove debris from inlets and outlets to avoid clogging. • Add mulch to bare areas.	Semi-annually (beginning and end of rainy season)
• Replace dead or diseased plants. • Regrade soil surface if erosion or scouring has occurred.	Annually
• Till soil and replant if the system does not drain within the design drain time.	As needed (expected to be 3 to 5 years)

COST

Rain gardens can be a low cost way to manage small volumes of stormwater, such as on a residential property. Multiple rain garden cells can be used to manage stormwater from larger contributing areas. Beyond the cost of plant purchase and irrigation, capital costs are minimal since rain gardens do not typically require an underdrain, filter fabric, or other man-made devices. The more elaborate the garden, the more expensive installation becomes. Rain gardens are typically about 600 square feet and average $8 per square foot in construction cost.

The costs of installing and maintaining a bioretention planter vary depending on size, materials, and maintenance requirements of selected plantings. Installation cost for one 500 square foot concrete planter box with a 4-inch underdrain was estimated at $4,000;

maintenance costs for the same planter are estimated at $500 per year. Construction of another planter bed was estimated at a cost of $2.10 per square foot of impervious surface area, or $32.70 per square foot of planter bed.

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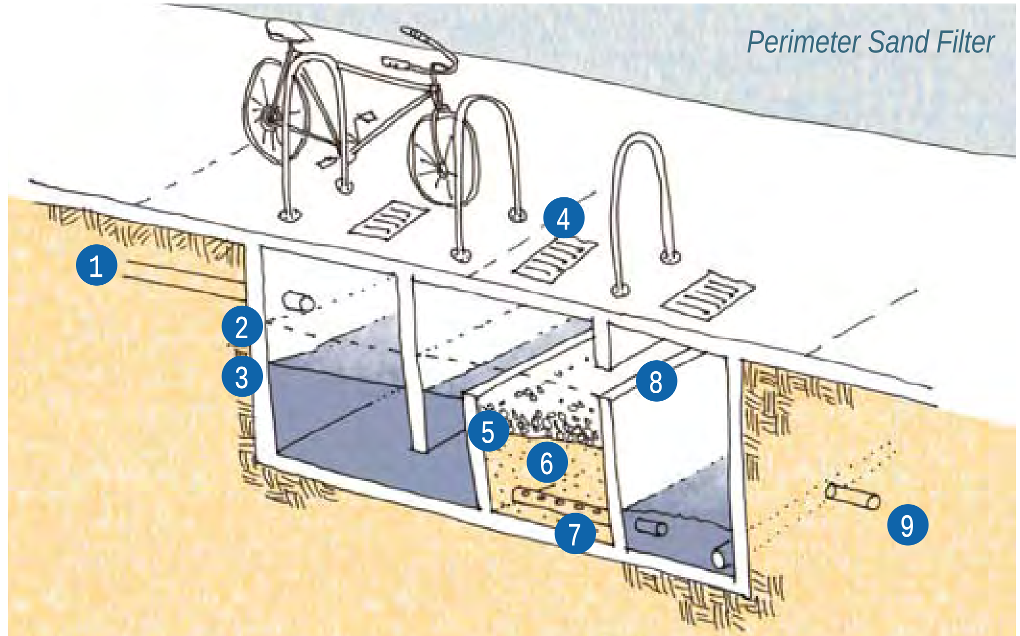
Media Filter

Sand filters also known as: inert media filter, filtration basin, Delaware sand filter, Austin sand filter, Washington D.C. sand filter

Other media filters also known as: organic media filter, sorptive media filter, compost stormwater filter, peat filter, biofilter, resin filter, perimeter filter



Inlet 1

Temporary ponding level 2

Permanent pool level 3

Access grates 4

Gravel bed 5

Sand bed 6

Perforated underdrain 7

Overflow 8

Outlet pipe 9

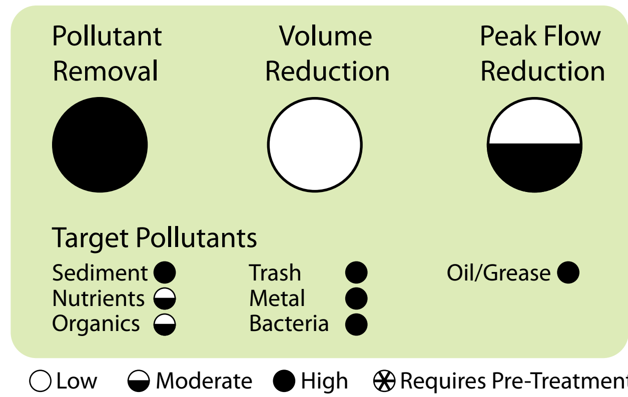
DESCRIPTION

Media filters detain and treat stormwater via filtration and adsorption of pollutants to the filter media. The most common filter media is sand. Filters utilizing sand as the filter medium will be referred to as "sand filters" in this fact sheet, whereas filters using other media, including organic materials such as compost and peat, and inorganic mineral materials such as iron-amended resin, activated carbon, and zeolite, will be referred to as "media filters."

Sand filters are generally two-chambered treatment devices consisting of a pretreatment sedimentation area to remove larger solids and a filtration area to remove fine solids, metals, organics, and some bacteria. They are estimated to remove 80% of total suspended solids, 50% of total phosphorus, 25% of total nitrogen, 40% of fecal coliform, and 50% of heavy metals from typical stormwater runoff. There are two general categories of sand filters:

- *Surface filters*, also known as Austin sand filters, consist of sedimentation and filter

Media Filter



chambers that are at ground-level and typically earthen. Because this filter type is flush with the ground plane, it is usually easier to maintain, but takes up more footprint area at a site.

- *Perimeter (subsurface) filters*, also known as Washington D.C. or Delaware sand filters, consist of two parallel trench chambers located in concrete vaults below an impervious surface, such as a parking lot. In this case, the pretreatment is built into the filter system as a sedimentation chamber that removes gross solids before stormwater passes to the filtration chamber.

The US EPA has more information about distinctions between types of sand filters. Commercially available sand filter products include the StormFilter and the VortFilter.

Media filters containing both organic and mineral filtration materials generally have greater ion exchange capacity than sand filters, and therefore can more effectively remove soluble metals and other dissolved pollutants. This renders media filters particularly effective for roadways and highly industrial sites that contribute higher concentrations of metals to stormwater runoff, particularly zinc and copper. These filters have been shown to consistently remove over 85% of oil and grease, 82% of heavy metals, and around 40% of total phosphorus. There are also two main types of non-sand media filters:

- *Flatbed (surface) filters* wherein stormwater percolates vertically through a bed of media material exposed to open air at the ground surface.
- *Subsurface (drop-in) filters* wherein cartridges containing filter media are placed in concrete vaults located below grade, with the number of cartridges a function of design flow rates. Stormwater flows horizontally through the cartridge, then downward to an underdrain system. They are considered easier to maintain than flatbed filters.

Additionally, a range of proprietary media filters are also available, such as the Aqua-Filter Stormwater Filtration System, Contech's StormFilter and BayFilter, and others.

Both sand and other types of media filters are designed as either flow-based or volume-based treatment devices. Volume-based filters are designed with storage to completely capture the treatment volume and then filter it through the media within a desired drawdown time (typically 48 hours). Flow-based filters are designed with filtration rates that are sufficient to pass the treatment flowrate without requiring storage. Flow-based designs require the use of specialized media with very high hydraulic conductivities, and therefore, flow-based designs are typically only used in proprietary media filters.

BENEFITS

- Effective removal of suspended solids, oil and grease, debris, and other attached pollutants.
- Effective removal of dissolved stormwater pollutants (media filters only); certain types of media may target specific pollutant removal if desired.
- Applicable in most soil types, appropriate in areas with poor infiltration.
- Easily customizable to varying site size and dimension constraints.
- Readily available materials (sand filters).

LIMITATIONS

- Minimal stormwater volume reduction, some peak flow attenuation.
- Requires flat site and sufficient hydraulic gradient to support gravity flow.
- Limited ability to remove dissolved pollutants such as soluble metals such as copper and zinc (sand filters).
- Provides low to moderate level of nitrogen removal and may increase nitrate levels.

SITING

Drainage area and slope: The maximum drainage area treated by sand filters is typically 5 acres. Both sand and media filters are best suited for relatively flat sites (less than 5% slope), but must have sufficient hydraulic head (3 to 5 feet) to allow runoff to flow through the filter. The scale of the filter may affect its functionality; large scale systems like playing field filters may be more appropriate for detention and infiltration, while smaller filters can be more easily integrated into a dense urban environment as flow-through treatment facilities.

Depth to groundwater and bedrock: For sand and media filters that allow infiltration, the groundwater and bedrock should both be at least 4 feet below the base of the filter to prevent filter damage and groundwater contamination.

DESIGN CONSIDERATIONS

Materials: All types of media filters typically include 18 to 24 inches of filter media above a 12-inch gravel underdrain layer. In peat or compost systems, the filter media generally includes an upper layer high in organic content, an intermediate layer of peat mixed with sand, and a lower layer composed primarily of sand. Compost filters typically consist of an18-inch layer of mixed compost material. These organic media have a high cation exchange capacity which helps capture dissolved constituents. For inorganic media filters other than sand, most products are proprietary and will have manufacturer instructions to guide design considerations. Both the open and underground units require 3 to 5 feet of head to operate properly and are designed with overflows. Media filters can be lined with concrete or can infiltrate if the underlying soil has an infiltration rate of at least 0.5 inches per hour.

Pretreatment: As with other filtration systems, sediment will accumulate on the media surface, thus slowing the filtration capacity of the filter over time. To minimize sediment loading, the filter chamber should be preceded by a forebay or sedimentation chamber where suspended particles, oil, and grease can settle. Complementary BMPs such as vegetated swales, vegetated buffer strips, water quality inlets, and swirl separators can also help screen large particulates and trash prior to entry into the media filter.

Drainage: Media filters can connect directly to the collection system, can provide pre-treatment for detention or storage BMPs, or can infiltrate into the underlying soil matrix.

Overflow: Media filters can be designed as online or offline devices. In the online configuration, all flows from the contributing drainage area are routed to the media filter. Flows greater than the water quality event are captured by an overflow device and conveyed back to the collection system. In the offline configuration, only the volume treatable by the filter is diverted into the device; all excess flows are directed to the collection system. This configuration limits exposure to large storm events and erosive flows, which can shorten the effective life of the filter media. In areas with flooding or flow control requirements, it may be preferable to design media filters as offline devices and direct larger flows to detention or infiltration BMPs such as detention vaults or ponds and constructed wetlands.

Sizing: Media filters are sized using the volume-based calculations described in Step 7 of the Stormwater Control Plan chapter of the *Guidelines*. An electronic sizing tool is also provided with the *Guidelines* and is hosted on the SFPUC website at http://stormwater.sfwater.org in the Stormwater Design Guidelines section. The tool should be used for planning purposes only, such as determining the general footprint and preliminary dimensions. This calculator is not intended to provide final detailed calculations or dimensions. Volume-based sand filters are designed to store the treatment volume within the sedimentation and filter chambers and to drain within a desired drawdown time, typically 24 to 48 hours. The available storage space includes the active sedimentation volume as well as the volume above the filter bed.

Some proprietary media filter systems are sized using flow-based calculations. The treatment capacity of the flow-based media filter should be greater than or equal to the treatment flowrate of the contributing drainage area. A simplified flow-based calculator has been provided on the SFPUC website (see above). However, it is highly recommended that the manufacturer be contacted directly and that their instructions be used to size these proprietary flow-based systems. As with volume-based filters, sedimentation pretreatment should be provided upstream of the filter.

OPERATIONS AND MAINTENANCE

While sand filters are an ancient form of water treatment, other types of media filters are a relatively new technology, and precise maintenance procedures are still being refined. Typical maintenance of media filters involves replacing the top 2 to 3 inches of media every few years and cleaning out the sediment from the sedimentation chamber. This sediment is removed and disposed of in a manner similar to street catch basin maintenance. The table on the following page provides more information on typical post-construction inspection and maintenance activities.

Typical Inspection Activities for Media Filters

Activity	Schedule
• Check that the filter surface is not clogged and that the filter is draining within the design drawdown time (typically 48 hours). • Check that the storage chamber does not leak when standing water is present.	Post-construction and semi-annually (beginning and end of rainy season)
• Check to ensure that filter bed is clean of debris and that sediment storage zone in sedimentation chamber is not more than 6 inches deep or 50% full. • Inspect grates, inlets, outlets, and overflow spillways for clogging, erosion, cracking, or water damage.	Annually

Typical Maintenance Activities for Media Filters

Activity	Schedule
• Remove trash and debris from inlet, outlet, sedimentation chamber, filter bed, and overflow devices to prevent clogging.	Semi-annually (beginning and end of rainy season)
• Remove sediment from sedimentation chamber when depth exceeds 6 inches or 50% of storage capacity.	Annually or as needed
• Repair or replace damaged or clogged parts of filter fabric.	As needed
• If water ponds at surface for more than 48 hours, clean or replace top 2 to 3 inches of saturated / clogged filter media. • Properly dispose of contaminated or saturated sediment after cleaning - may require special disposal if contains metals, pathogens, or trace organic compounds.	As needed (expected to be >3 years)

COST

Construction costs for a surface sand filter that treats a one acre drainage area are estimated at $18,500. Capital costs decrease with increasing drainage area. Perimeter sand filters tend to be less expensive, particularly if they are pre-cast rather than cast in place. Pre-cast perimeter media filters that treat a one acre drainage area range from $6,000 to $11,000. Annual maintenance costs average about 5% of the initial construction cost. The cost to replace the sand, filter fabric, and underlying gravel of a media filter is estimated at $1,700; however, a thorough and regular maintenance plan can significantly reduce these ongoing costs.

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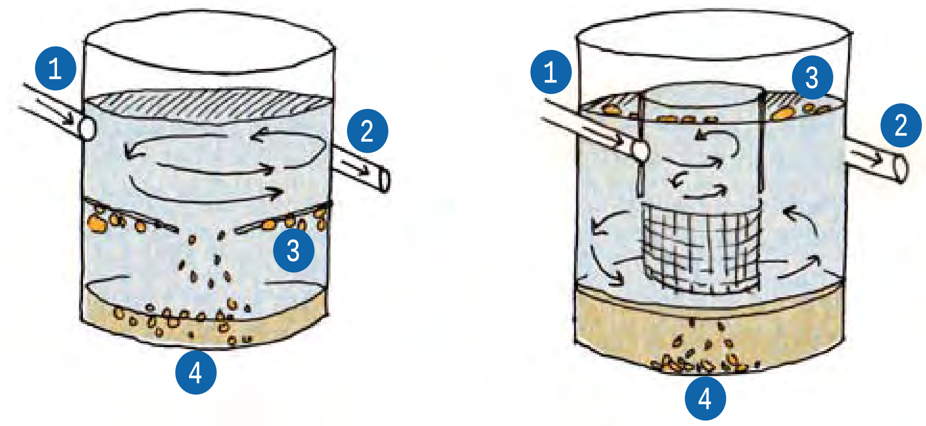
Media Filter

Swirl Separator *

Also known as: vortex separator, hydrodynamic separator, swirl concentrator

Inlet 1
Outflow 2
Floatables 3
Settleables 4



DESCRIPTION

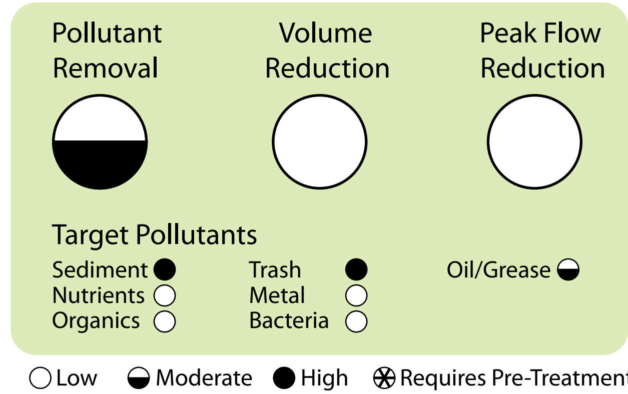
Swirl separators are circular flow-through structures that use a vortex action to separate coarse sediment and floatables (trash, debris, and, in some instances, oil) from stormwater. Manufacturers have developed several proprietary versions of swirl separators for stormwater treatment, all of which function differently and include different internal components. In all devices, stormwater is piped into a round chamber tangential to the side walls, creating centrifugal forces that spin stormwater around the outside of the chamber. In some devices, heavier sediment particles slide down a cone and settle into a collection chamber below. In others, the swirling inflow descends to a screened area where sediments are trapped and drop to a collection chamber and treated water passes through to the outside, eventually to the outlet. In either case, entraining the water in this circular motion provides significant removal of target pollutants within a relatively small footprint. Floatables are also removed by these devices; typically they are trapped by a baffle or inside the screened area either during the swirling motion or before the runoff discharges through an outlet pipe.

Swirl separators are not effective in removing soluble pollutants and smaller, less-settleable solids. They can provide effective pretreatment when paired with filtration devices, such as media filters or bioretention areas, to achieve higher removals of nutrients, metals, and organics.

** Swirl separators alone do not constitute compliance with San Francisco's stormwater requirements and are not considered treatment to the Maximum Extent Practicable (MEP) by the Regional Water Board. They are best used as part of a treatment train.*

Swirl Separator

Because swirl separators can be placed underground and come in a wide range of sizes, some small enough to fit within a standard manhole, they can be useful for removing settleables and floatables in areas where land availability is limited and tight retrofits are needed. The size of the drainage area that may be treated with swirl separators is limited by the maximum capacity of the units and by the available footprint.



BENEFITS

- Improves water quality by removing coarse sediment and floatables; some models remove oil and grease.
- Some models attenuate peak flows.
- Low space requirements.
- Good for sites where infiltration is not an option.
- Ideal as part of a treatment train.
- May be more cost-effective pre-treatment device than traditional wet or dry detention basin.
- May provide treatment in less space than wet vaults or detention basins.
- Due to sealed top and inlet configuration, mosquito control may be less of an issue than for wet detention basins.
- Low maintenance costs.

LIMITATIONS

- Swirl separators alone do not constitute compliance with San Francisco's stormwater requirements and are not considered treatment to the Maximum Extent Practicable (MEP) by the Regional Water Board.
- Is not effective for removal of dissolved pollutants, fine sediments, and pollutants that adhere to fine sediment.
- Some systems have standing water between storms that could raise mosquito breeding concerns.
- Drainage area is limited by capacity of largest models.
- Relatively high capital and installation costs.
- No aesthetic value.
- No habitat value.

SITING

Soil depth and stability, site slopes, and groundwater depth may affect the applicability of swirl separators to different sites.

DESIGN CONSIDERATIONS

Design variations in commercial units: Commercially available swirl separators for stormwater treatment vary in their geometry, radial baffle design, and internal circular chambers. Some manufacturers include baffles or other devices, thereby creating a "dampened vortex," to help particles settle out; others contend that free vortex creates less turbulence thereby increasing removal efficiency. Some include an inner chamber designed to enhance removal efficiency. Whether the inclusion of chambers and baffles gives better performance is unknown. Generally, a nonturbulent environment that allows particles to settle and floatables to rise, and protection against re-entrainment of settled particles, is considered an ideal condition for treatment. Depth of the units should also be considered; depth of units can extend from 3 feet below the inlet pipe up to 25 feet in depth for large units. Consult with manufacturers to determine the best product for the specific site conditions and treatment needs.

Treatment: Swirl separators are most effective where the pollutant load is primarily coarse sediment and floatables and where pretreatment of these pollutant types is desired to remove the treatment burden from downstream BMPs. Experience with swirl separators for treating Combined Sewer Overflows, the original use of the technology, suggests that the practical lower limit for removal is a particle diameter of 50-200 microns, depending on the specific gravity of the particle. For reference, it is generally believed that other treatment measures such as wet ponds and extended detention basins can remove smaller particles down to 10-20 microns. However, there is little data to support these numbers. Swirl separators may also be useful for pretreatment near stormwater "hotspots," such as gas stations, where high concentrations of pollutants are likely to occur.

Sizing: Depending on the manufacturer, swirl separators can treat design flows from 0.75 to 300 cfs, with units ranging from 4 feet in diameter for the smallest precast units to 40 feet in diameter for custom units and may extend up to 25 feet or more in depth.

Separators can be configured as online or offline devices. If configured as an offline facility, the device is designed to treat the full peak flow of the inlet pipe (hydraulic capacity equals treatment capacity). If the separator is an online facility, however, commercially available units typically have a peak flow through the inlet pipe about four times greater than the flow the device is designed to treat (hydraulic capacity equals four times treatment capacity). Flows that exceed the treatment capacity but not the hydraulic capacity can still pass through the device; however less pollutant removal is achieved. Designers should refer to the manufacturer's specifications to determine whether a product will be able to treat the desired flow.

OPERATIONS AND MAINTENANCE

Because there are no moving parts, swirl separators are generally not considered to be maintenance intensive when compared with land-based BMPs such as swales and treatment ponds. However, without regular maintenance, these devices are prone to the following:

- Accumulated sediment reducing available treatment volume;
- Sediment resuspension during high flow storm events;
- Accumulated floating material being released and discharged during high flow events; and
- Accumulation of pollutants to the point where contents are characterized as hazardous for petroleum hydrocarbons or soluble metals.

The rate at which each system accumulates pollutants is site-specific, and most manufacturers recommend at least one inspection per month during the first year after installation. Vactor or vacuum trucks are typically used for maintenance, so unobstructed access to the treatment chambers is important to facilitate removal of accumulated pollutants. The table on the following page outlines typical post-construction inspection and maintenance activities and schedules for swirl separators, but these will vary by manufacturer. Project sponsors should adhere to the maintenance plan specified by the manufacturer of the chosen product.

Typical Inspection Activities for Swirl Separators

Activity	Schedule
• Determine long-term maintenance schedule by visual inspection of floatables and sediment accumulation and by measurement of sediment deposition rate using a probe or "dipstick."	Monthly during first year of operation
• Check inlet and outlet pipes for obstructions. • Pump out unit and inspect for damage.	Annually

Typical Maintenance Activities for Swirl Separators

Activity	Schedule
• Remove accumulated sediment, debris, and floatables. Special disposal of floatables may be necessary if petroleum products are present.	Annually or as needed

COST

Capitol costs for pre-cast units range from $10,000 to $60,000 depending on the size, manufacturer, and model. Custom units are generally more expensive. Installation costs are site-specific depending on the need to relocate utilities, working space, and depth of installation, but are typically approximately one-half to one times the unit cost. Several sources cite operations and maintenance costs of approximately $1,000 per year, varying from year to year. Maintenance costs include removal (with a vactor truck) and disposal of sediment and debris.

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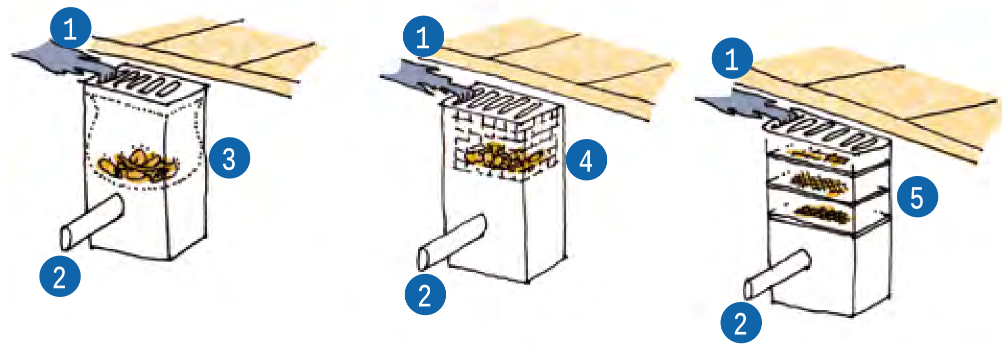
Drain Insert *

Also known as: storm drain inlet protection, catch basin insert, baffle box, litter insert, drainage basin protection



Stormwater enters drain 1

Treated outflow to collection system 2

Debris is caught in polypropylene sack 3

Debris is caught in plastic or metal mesh 4

Debris is caught in various filter trays 5

DESCRIPTION

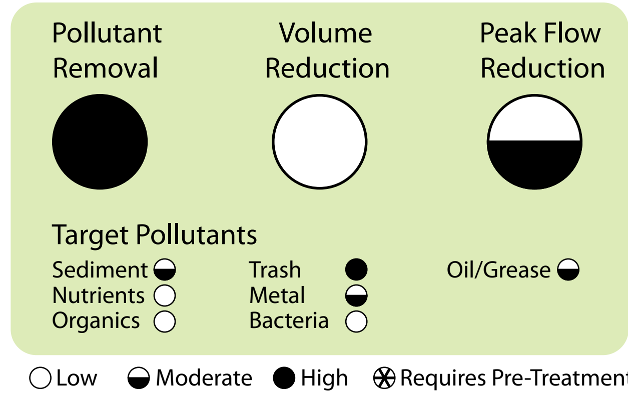
Drain inserts are manufactured filters, fabrics, or screens placed in a trench drain or catch basin to remove sediment and debris. Drain inserts are a flow-through separator technology, designed to provide treatment but not peak flow attenuation or volume reduction. There are three main types of drain insert: socks, boxes, and trays. A sock insert refers to fabric, usually polypropylene, that attaches either to the inlet frame or to the grate. Socks are meant for vertical (drop) inlets. Boxes are constructed of plastic or wire mesh filled with filtration media. Trays are rows of filtration media held in place by trays or mesh grates. The trays may hold different types of media, including: polypropylene, porous polymer, treated cellulose, and activated carbon.

BENEFITS

- Low installation and maintenance costs.
- Can be implemented at many types of locations and at many scales.
- Easy retrofit tool.
- Requires no additional space beyond standard drainage system.

** Drain inserts alone do not constitute compliance with San Francisco's stormwater requirements and are generally not considered treatment to the Maximum Extent Practicable (MEP) by the Regional Water Board. They are best used as part of a treatment train.*

- Easy access for inspection and maintenance.
- Minimal risk of mosquito breeding because no standing water.
- Captures sediment, metals, and oil and grease.
- Ideal as part of a treatment train.



LIMITATIONS

- Drain inserts alone do not constitute compliance with San Francisco's stormwater requirements and are generally not considered treatment to the Maximum Extent Practicable (MEP) by the Regional Water Board.
- Not suitable for large areas or areas with heavy sediment or litter loading.
- Requires more frequent maintenance than many other BMPs to avoid clogging.
- May require size modification to fit into drain inlets.
- If located on a road shoulder or median, maintenance may require traffic control.
- No aesthetic appeal.
- No habitat value.

SITING

Drain inserts are recommended primarily for retrofit situations or as pretreatment devices upstream of other BMPs. Drain inserts can be installed in nearly any storm drainage system because they require no additional space. Drain inserts are not suitable for large catchment areas or areas with heavy sediment or litter loading.

DESIGN CONSIDERATIONS

Treatment: Stormwater constituent removal varies by type of drain insert. Metal or plastic screens catch sediment, litter, and organic debris. Fabric inserts can trap oil/grease as well as sediment, litter, and debris. Filter inserts generally achieve the highest level of treatment, and can target other pollutants that sorb to the solids, such as metals and nutrients. Skimmers and absorbent pads can increase hydrocarbon removal. According to the California BMP Handbook, drain inserts can achieve total suspended solid (TSS) effluent concentrations ranging from 4-248 mg/L with a median value of 27 mg/L. Drain inserts are recommended for use as pretreatment upstream of other stormwater BMPs.

Overflow: Flows greater than the treatment event may bypass the drain insert through the catch basin's curb opening or may overflow from the insert into the catch basin. Clogged inserts can exacerbate flooding.

Installation and sizing: In general, drain inserts are designed to be installed beneath the inlet. They can attach to the inlet grate or to the catch basin frame. However, because most drain inlet products are proprietary technologies, sizing and installation should follow specifications provided by individual manufacturers. A high flow bypass should be included to allow stormwater into the collection system in the event that clogging occurs or flow rates exceed the water quality design flow rate.

OPERATIONS AND MAINTENANCE

Drain insert maintenance is relatively simple, since filter media can be easily removed and replaced. Drain inserts should be inspected frequently to prevent clogging. During installation, ensure that 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. The table on the following page provides more information on typical post-construction inspection and maintenance activities.

COST

Drain inserts tend to be less costly than other treatment BMPs, but also have a shorter structural life (individual inserts can last between 1 and 3 years) and offer less stormwater management benefit. Initial cost of individual inserts ranges from under $100 to about $2,000, but purchasing in bulk is more common and reduces purchase cost. As examples, Reusable Drain Guard (Dawg) costs $90-120 per insert and Ultra-Urban Filter (AbTech) costs $250-700 per unit.

Typical Inspection Activities for Drain Inserts

Activity	Schedule
• Ensure that stormwater directly enters drain insert without bypassing.	Post-construction
• Inspect for clogging or water damage. Ensure that device is free of debris and operational. • Monitor for sediment accumulation in, and upstream of, the insert.	Semi-annually

Typical Maintenance Activities for Drain Inserts

Activity	Schedule
• Clean insert and remove debris from upsteam side. • Modify insert placement if stormwater begins to bypass the drain insert.	Semi-annually or as needed
• Replace insert material, dispose of saturated insert properly - may require special disposal if it accumulates heavy metals, oil and grease, or trace organic compounds.	Every 1 to 3 years

REFERENCES AND RESOURCES

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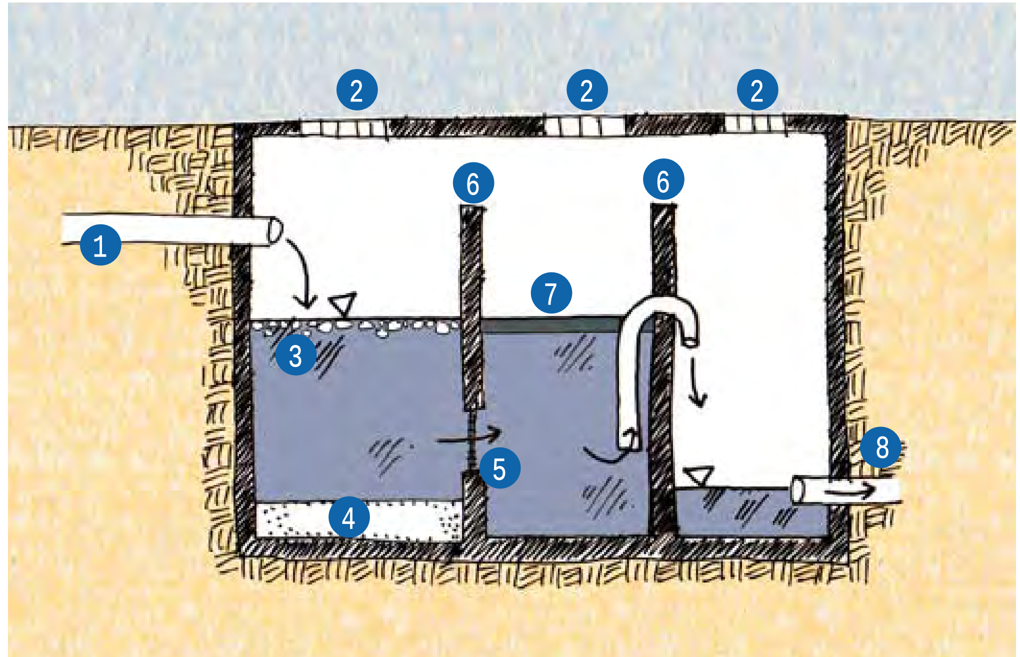
Water Quality Inlet *

Also known as: trapping catch basin, oil/grit separator, or oil/water separator



Inlet 1

Access manholes 2

Floatables 3

Settleables 4

Trash rack 5

Emergency overflow 6

Oil 7

Outflow 8

DESCRIPTION

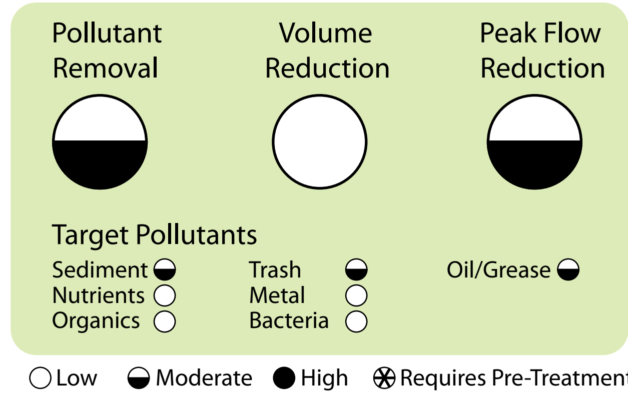
Water quality inlets (WQIs) consist of one or more chambers that promote settling of coarse materials and separation of oil from stormwater. Some WQIs also contain screens to help retain larger or floating debris, and some of the newer designs include a coalescing unit that helps promote oil/water separation. These devices are effective for capturing suspended solids and hydrocarbon spills, but are not very effective at removing other pollutants found in stormwater runoff such as bacteria, nutrients, metals, and organics. They are best used in conjunction with other BMPs that perform infiltration, detention, or bioretention of stormwater.

Most WQI designs include three vault chambers, with peak flow bypasses and baffles to improve retention of solids and floatables. In a three-chambered configuration, the first chamber captures larger solids, the middle chamber traps oil, grease, and other floatables, and the final chamber collects and discharges the treated runoff.

** Water quality inlets alone do not constitute compliance with San Francisco's stormwater requirements and are generally not considered treatment to the Maximum Extent Practicable (MEP) by the Regional Water Board. They are best used as part of a treatment train.*

The first chamber area may include plate settlers, screens, or other means of improving sedimentation. Similarly, the oil/grease chamber may include absorbent pillows, coalescing plates, and baffles to improve removal of hydrocarbons. As sediment levels increase in the vault, re-suspension can occur, which reduces the treatment efficiency of the BMP.

Water quality inlets are primarily designed to remove sediment from stormwater runoff by gravity settling. A WQI with a one-hour detention time can be expected to remove 20 to 40% of sediments, as well as some hydrocarbons. Only slight, if any, removal of nutrients, metals, and organic pollutants is typically achieved. To achieve higher levels of treatment, WQIs should be used along with other BMPs as part of a treatment train.



BENEFITS

- Effectively trap trash, debris, oil and grease, and other floatables.
- Can provide spill control for contaminated or heavily polluted runoff.
- Good for areas where land requirements and cost prohibit use of larger BMPs.
- Effective as part of a treatment train to reduce the burden on downstream BMPs.

LIMITATIONS

- Depending on their design, water quality inlets alone may not constitute compliance with San Francisco's stormwater requirements and are generally not considered treatment to the Maximum Extent Practicable (MEP) by the Regional Water Board.
- Minimal peak flow or volume reduction.
- Periodic standing water can foster mosquito breeding.
- Limited removal of dissolved pollutants (e.g. nutrients, emulsified oil).
- Pollutants trapped by inlet can re-enter stormwater during subsequent storms.
- Requires frequent cleaning.
- Not effective for large drainage areas.
- No aesthetic value.
- No habitat value.

SITING

Water quality inlets are most effective for drainage areas of 1 acre or less. WQIs are often used in industrial applications such as airport runways, equipment washdown areas, and gas station parking lots. WQIs should be constructed near a storm drain network so that flow can be easily diverted to the inlet for treatment. Inlets can be situated at the ground surface or underground, and they are available as pre-manufactured or cast-in-place units, typically constructed with reinforced concrete. A WQI should be water-tight to prevent possible groundwater contamination. WQIs should be sited such that vactor trucks can easily access and remove sediment and pollutants.

DESIGN CONSIDERATIONS

The WQI can be configured to receive runoff from a drain inlet grate or from a subsurface storm drain pipe. The piped configuration essentially seals off the permanent pool from the surrounding environment, which reduces the potential for mosquito breeding.

<u>Overflow</u>: In an offline configuration, only flows less than or equal to the design treatment capacity are directed to the water quality inlet. In an online configuration, all flows are routed to the device, but the vaults typically contain an internal bypass to redirect high flows around the sedimentation area. This helps prevent re-suspension of settled sediment.

<u>Sizing</u>: Typically, WQIs are offline, meaning only diverted flows enter the system as opposed to all stormwater flows. These offline units generally are sized to handle the first 0.5 to 1 inch of runoff from drainage areas, known as the "first flush." Upstream flow splitting structures divert runoff to the offline structure. If designed as an online device, the WQI should be sized for the entire hydraulic capacity of the inlet pipe and should include a high flow bypass to prevent turbulent flow from re-suspending settled pollutants. Outlet configurations should be sized to drain the first flush volume within the desired time.

OPERATIONS AND MAINTENANCE

Water quality inlets must be regularly inspected and accumulated sediment, floatables, and hydrocarbons must be removed. A lack of regular clean-outs can lead to re-suspension of settled stormwater pollutants and washout of trapped floatables and hydrocarbons, rendering the WQI ineffective. Because WQIs can accumulate potentially toxic sediments (metals, hydrocarbons, and trace organic compounds adsorb to soil particles), proper disposal in a hazardous waste landfill by trained personnel may be required. The table below provides more information on typical post-construction inspection and maintenance activities.

Typical Inspection Activities for Water Quality Inlets

Activity	Schedule
• Inspect for clogging, erosion, and sediment build-up. • Ensure that system does not cause back-ups or flooding.	Post-construction
• Determine long-term maintenance schedule by visual inspection of floatables and sediment accumulation and by measurement of sediment deposition rate using a probe or "dipstick."	Monthly during first year of operation
• Keep a log of the amount of sediment collected and date removed. • Health inspectors should perform routine inspections to prevent mosquito breeding.	As needed

Typical Maintenance Activities for Water Quality Inlets

Activity	Schedule
• Remove surface debris and sediment from inlets to avoid clogging. • At least twice during each wet season, settled sediment, floatables, and hydrocarbons should be removed by trained operators. • Dispose of settled sediment properly - may require special disposal if contaminated with metals or trace organic compounds. • Apply vector control treatment to open systems with standing water as needed.	Semi-annually or as needed

COST

Water quality inlet costs vary widely depending on size and depth. Pre-manufactured units are generally less expensive than cast-in-place units. A typical pre-cast catch basin costs between $2,000 and $3,000, but oil/water separators can be more expensive. For a cast-in-place WQI, construction costs range from $5,000 to $16,000 with an average cost of $8,500. Maintenance costs can be expensive if residuals are toxic and require special disposal. Vactor trucks, the most common means of cleaning catch basins, cost between $125,000 and $150,000. It may be possible to hire a vactor truck or share one between communities. Cleaning usually takes place semi-annually and each truck can typically hold 10 to 15 cubic yards of material (enough storage for 3 to 5 catch basins).

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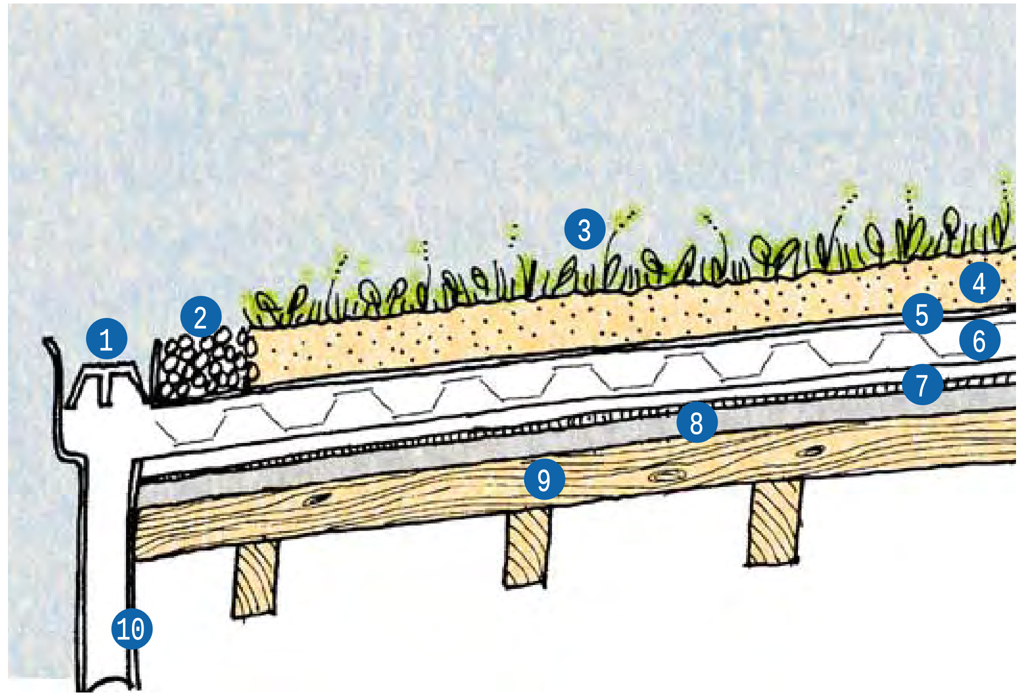
Water Quality Inlet

Vegetated Roof

Also known as: eco-roof, green roof

- Leaf screen 1
- Gravel 2
- Drought-tolerant plants 3
- Growing medium 4
- Filter membrane 5
- Drainage and storage 6
- Root barrier and waterproof membrane 7
- Insulation 8
- Roof structure 9
- Gutter system for overflow 10



DESCRIPTION

Vegetated roofs are roofs that are entirely or partially covered with vegetation and soils. Vegetated roofs have been popular in Europe for decades and are now gaining popularity in the U.S. because they provide multiple environmental benefits. Vegetated roofs improve water quality by filtering contaminants as the runoff flows through the growing medium or through direct plant uptake. Studies have shown reduced concentrations of suspended solids, copper, zinc, and PAHs (polycyclic aromatic hydrocarbons) from vegetated roof runoff. The engineered soils absorb rainfall and release it slowly, thereby reducing the runoff volumes and delaying peak flows. Rainfall retention and detention volumes are influenced by the storage capacity of the engineered soils, antecedent moisture conditions, rainfall intensity, and duration. A typical vegetated roof has been found to retain 50 to 65% of annual rainfall and reduce peak flows for large rain events (those exceeding 1.5 inches) by approximately 50%. Additionally, vegetated roofs generally provide greatly enhanced insulation of roofs.

Vegetated roofs fall under two categories: intensive or extensive. Intensive roofs, or rooftop gardens, are heavier, support larger vegetation and can usually be designed for use by people. Extensive vegetated roofs are lightweight, use smaller plants, and are not intended for use by people. Vegetated roofs can be installed on most types of commercial, multi-family, and industrial structures, as well as on single-family homes, garages, and sheds. Vegetated roofs can be used for new construction or to re-roof an existing building. Candidate roofs for a "green" retrofit must have sufficient structural support to hold the additional weight of the vegetated roof, which is generally 15 to 30 pounds per square foot saturated for extensive roofs and more for intensive roofs.

The Academy of Sciences building has a nearly 2.5-acre vegetated roof.
Photo: Rana Creek-Living Architecture

Intensive vegetated roofs provide usable open space in addition to their stormwater management function.

BENEFITS

- Provides insulation and can lower heating and cooling costs for the building.
- Extends the life of the roof – a green roof can last twice as long as a conventional roof, saving replacement costs and materials.
- Provides noise reduction.
- Reduces the urban heat island effect.
- Lowers the temperature of stormwater runoff, which maintains cool stream and lake temperatures for fish and other aquatic life.
- Creates habitat and increases biodiversity in the city.
- Provides aesthetic and recreational amenities.

LIMITATIONS

- Generally limited to roof slopes less than 20 degrees (5-in-12 pitch).
- May require additional structural support to bear the added weight.
- Potentially increases seismic hazards with increased roof weight.
- Long payback time for installation costs, based on energy savings.
- May attract unwanted wildlife.
- Irrigation may be necessary to establish plants and maintain them during extended dry periods.
- Vegetation requires maintenance without which can look overgrown or weedy; seasonally it can appear dead.

DESIGN CONSIDERATIONS

An intensive vegetated roof may consist of shrubs and small trees planted in deep soil (more than 6 inches) arranged with walking paths and seating areas. In contrast, an extensive vegetated roof includes a shallow layer of soil (less than 6 inches) with low-growing vegetation and is more appropriate for roofs with structural limitations. Both categories of vegetated roofs include engineered soils as a growing medium, subsurface drainage piping, and a waterproof membrane to protect the roof structure. Ideal vegetation for vegetated roofs has the following characteristics: drought tolerance, self-sustainability, heartiness over a range of temperatures and moisture conditions, minimal maintenance requirements, fire resistance, and perennial life cycle.

Based on findings from the City of Portland (2006) and the Puget Sound Action Team (2005), roofs with slopes up to 40 degrees are appropriate for extensive vegetated roofs, though slopes between 2 and 20 degrees are most suitable. All vegetated roofs are assembled in layers. The top layer includes the engineered soils and the plants. The soil is a lightweight mix that includes some organic material. Under the soil is a drainage layer that includes filter fabric to keep the soil in place and a core material that stores water and allows it to drain off the roof surface. Next is the root barrier, which prevents roots from puncturing the waterproof membrane that lies below it, then a layer of insulation, and finally there is the roof structure.

OPERATIONS AND MAINTENANCE

Each vegetated roof installation will have specific operation and maintenance guidelines provided by the manufacturer or installer. Intensive vegetated roofs generally require more continued maintenance than extensive roofing systems. In the first few years watering, light weeding, and occasional plant feeding will ensure that the roof vegetation becomes established. Routine inspection of the waterproof membrane and the drainage systems is important to the roof longevity. The table on the following page provides more information on typical post-construction inspection and maintenance activities.

COST

A typical roof size of a single-family home in San Francisco is estimated at 1,500 square feet, while commercial buildings are closer to 10,000 square feet. The costs of vegetated roofs vary widely depending on the size and the type of roof. In Portland, OR, the cost of installing a vegetated roof ranges from $10 to $20 per square foot for a new roof, and $6 to $40 for a re-roof compared with conventional roof costs of $3 to $15 and $10 to $35 per square foot for a new roof and re-roof, respectively.

Annual maintenance costs are estimated at $1.25 to $5.49 per square foot, which includes aeration, plant and soil inspection, flow monitoring and reporting. Maintenance costs can come down even lower once plantings are established if low-maintenance plant species are used.

Vegetated Roof Examples

In San Francisco, CA...

San Francisco has several completed vegetated roof projects including: the new Academy of Sciences vegetated roof which is 2.5 acres or approximately 100,000 square feet, the Environmental Living Center in Hunter's Point, a 2-acre intensive vegetated roof on North Beach Place, the Yerba Buena Gardens located above a parking garage, Portsmouth Square located above a garage in Chinatown, and the Griffith Pump Station.

In Chicago, IL...

Chicago's first green roof was a 20,000 square foot roof on the City Hall that was constructed in 2000. In 2005, the city launched its Green Roof Grant Program, awarding $5,000 each to 20 selected residential and small commercial green roof projects (each with a footprint of less than 10,000 square feet). As of October 2006, more than 250 public and private green roofs were under design and construction in Chicago, totaling more than 1 million square feet of green roofs. The city also developed policies that encourage green roof development in Chicago. For example, all new and retrofit roofs in the city must meet a 0.25 solar reflectance, which green roofs are effective in meeting but traditional roofs are not. Also, the city offers a density bonus for roofs that have a minimum of 50% vegetative cover.

Wildflowers grow among other plants on the Griffith Pump Station vegetated roof in San Francisco.

Vegetated roofs can be designed to be visible from the street to add unique textures and colors to building design.

Typical Inspection Activities for Vegetated Roofs

Activity	Schedule
• Periodically inspect vegetation and irrigation (if present). Water as-needed to ensure vegetation establishes itself.	First year or until vegetation is established
• Inspect visible drainage features to ensure drainage is free-flowing and not clogged with sediment	Semi-annually and/or following large storm events

Typical Maintenance Activities for Vegetated Roofs

Activity	Schedule
• Clean visible drainage features • Maintenance of permanent irrigation (if present), including monitoring of irrigation schedule	Semi-annually or as needed
• Replace dead vegetation and remove weeds or excessive leaf litter or trash • Repair eroded areas	Annually or as needed

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Vegetated Roof Examples (cont.)

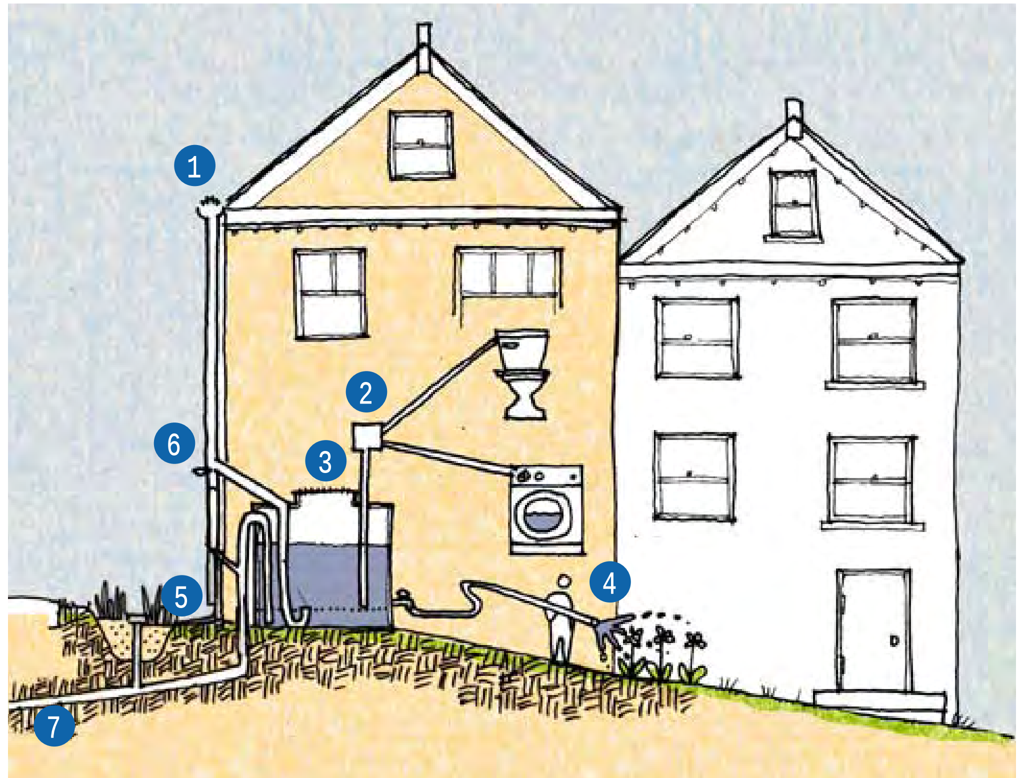
In Toronto, Ontario...

The City of Toronto initiated a green roof demonstration project in 2000 to “find solutions to overcome technical, financial and information barriers to the widespread adoption of green roof infrastructure in the marketplace.” In February 2006, the Toronto City Council approved the Green Roof Pilot Program, allocating $200,000 from Toronto Water’s budget to encourage green roof construction. Subsidies of $10 per square meter ($0.93 per square foot) and up to a maximum of $20,000 were made available to private property owners for new and retrofit green roof projects. Additionally, the Green Roof Strategy recommended the following actions: use green roofs for all new and replacement roofs on city-owned buildings; use zoning and financial incentives to make green roofs more economically desirable; initiate an education and publicity program for green roofs; provide technical and design assistance to those interested in green roof building; identify a ‘green roofs resource person’ for each city division; develop a database of green roofs in the city; conduct and support ongoing monitoring and research on green roofs; add a green roof category to the Green Toronto Awards; and establish partnerships with other institutions.

Rainwater Harvesting

Also known as: rain barrel, cistern, rainwater collection

- Leaf screen 1
- Pump 2
- Screened maintenance opening 3
- Water reused for non-potable uses 4
- Splash block 5
- First flush diverter 6
- Overflow to collection system 7



DESCRIPTION

Rainwater harvesting is the practice of collecting and using rainwater from impervious surfaces such as roofs and patios. It is an age-old technology; communities in ancient Rome were designed with individual cisterns and paved courtyards, which captured rainwater to augment supply from the city's aqueducts. Today, rainwater harvesting is growing in popularity as people look for ways to use water resources more wisely.

Many rural areas around the world rely on rainwater as their primary water source, but areas served by municipal water have tended to overlook rainwater as a water resource. San Francisco would like to change that by promoting rainwater harvesting in our urban setting.

It is now legal to divert stormwater from San Francisco's combined sewer system. In 2005, city staff amended the plumbing code via Ordinance 137-05, making it possible to direct rainwater to alternative locations such as rain gardens, rain barrels, and cisterns.

The relevant Plumbing Code is Section 306.2., which reads: "Roofs, inner courts, vent shafts, light wells or similar areas having rainwater drains, shall discharge directly into a building drain or building sewer, **or to an approved alternate location** based on approved geotechnical and engineering designs."

There are currently two rainwater harvesting strategies being promoted for San Francisco: rain barrels and cisterns. Rain barrels are small containers, typically ranging from 50 to 100 gallons, designed to capture rainwater runoff from roofs that can be used for irrigation, vehicle washing, or other non-potable applications. Rain barrels are inexpensive, easy to install and maintain, and well suited to small-scale residential sites. Cisterns are larger than rain barrels, ranging from 100 gallons on a small residential site to millions of gallons beneath schools and parks. They can be installed above or below ground, or even on the roof, depending upon site conditions. In addition to irrigation and vehicle washing, water from cisterns can be used for heating and cooling and toilet flushing—if properly connected to indoor plumbing. The table on the following page lists the required components for cistern systems.

The Public Utilities Commission, the Department of Public Health, and the Department of Building Inspection have partnered to encourage the safe use of rainwater for irrigation and toilet flushing without requiring treatment to potable standards. No permit is required to install a rain barrel that does not connect to an indoor plumbing system. However, all cisterns require a permit from the Department of Building Inspection. Systems designed to collect and treat rainwater for potable uses will be inspected and permitted on a case-by-case basis. The following permits are needed for the installation of rainwater harvesting systems:

- Plumbing permits are required for all rainwater harvesting systems servicing indoor fixtures, regardless of cistern size
- Electrical permits are required for all systems using pumps or other electrical equipment or controls
- Building permits are required for cistern footings, foundations, enclosures, and roof structures

A disconnected downspout and rain barrel.
Photo: Clean Air Gardening

Installation of a cistern in Sausalito, CA.
Photo: Sherwood Engineers

Cambria Elementary School's cistern in Cambria, CA captures runoff water from its 12-acre campus for storage in a 2-million-gallon cistern beneath the school's athletic fields. *Photo: Rehbein Environmental Solutions, Inc. www.rehbeinsolutions.com/projects/cambria.html*

- Rain barrels with downspout connected to collection system
- Grading and erosion control permits may be required for underground facilities

All systems must comply with the City of San Francisco Planning Code, the City of San Francisco and Building Code, and the 2007 City of San Francisco Plumbing Code, which consists of the 2007 California Plumbing Code, the 2006 Uniform Plumbing Code, and the 2007 City of San Francisco Plumbing Code Amendments.

Required System Components for Cisterns

1. Roof surfaces serving as catchments for watering shall not include copper or materials treated with fungicides or herbicides.
2. Gutters must be fully screened, continuous grade.
3. Storage containers, tank liners, and tank coatings must be listed as food grade, or be approved for potable water storage. Containers must be opaque, water tight, vented, completely covered and screened.
4. All openings must be screened.
5. For above-ground systems, spigot and/or hose bibb for drawing water must be at least 2 inches from the bottom and must be labeled "NONPOTABLE".
6. Overflow device must be equal in size to the total of all inlets and must lead to an approved discharge location with approved air gap.
7. First flush diverter must be automatic self-draining with clean out.
8. Safety labels (non-potable, vector hazard, drowning hazard icons).
9. Installation of gutters, leaders, downspouts, piping, fittings, valves, and screens must comply with California Plumbing Code. *
10. All plumbing materials must be listed with a recognized testing agency such as NSF or ANSI. *
11. University of Southern California approved backflow prevention device located at the service connection with no fixtures between it and the water meter. *
12. Outdoor spigots must have an atmospheric vacuum breaker attached.

* Only if connected to indoor plumbing

BENEFITS

- Offsets the volume of potable water used for non-potable applications, such as irrigation and toilet flushing.
- Keeps relatively clean water out of the City's collection systems, thereby enhancing the performance of the City's combined sewer infrastructure and protecting water quality.
- Reduces the volume and peak flows of stormwater entering the sewer, helping to reduce flooding and combined sewer discharges.
- Reduces the energy and chemicals needed to treat stormwater in the City's sewage treatment plants.
- Reduces the energy expended transporting potable water from distant sources.
- Low maintenance requirements (for above ground cisterns).
- Good for sites where infiltration is not an option.

LIMITATIONS

- Limited storage capacity.
- Provides no water quality improvements.
- Requires infrastructure (pumps or valves) to use stored water.

SITING

Both rain barrels and above-ground cisterns must be sited in a stable, flat area. Rain barrels and cisterns may not block the path of travel for fire safety access. Overflow locations, which can include rain gardens, additional rain barrels or cisterns, or a discharge point to the collection system, must be designed to both direct outflow away from building foundations and prevent nuisance flows to adjacent properties. Overflow may not discharge water across a public right-of-way. Tanks should be placed in a cool or shaded area to avoid algal growth.

Rainwater Harvesting Examples

In Cambria, CA...

The elementary school in Cambia captures all of the stormwater from the 12-acre campus and stores it in large pipes under 130,000 square feet of new athletic fields. Up to 2 million gallons of water can be stored. The stored water is used to irrigate the fields year round.

In Seattle, WA...

The Seattle Public Utilities (SPU) RainCatcher Pilot Program includes cisterns that are used for rainwater collection for stormwater runoff flow and volume control and to offset potable water needs. Cisterns include an operable valve that can be opened during the wet season, discharging a small amount of water onto an adjacent permeable surface such as a lawn or rain garden to slow down flow, or closed to store up to 500 gallons of roof runoff, which can be used later for irrigation.

Each cistern costs the SPU a total of $1000, with $325 of that sum going to the wholesale purchase of the cistern and $675 to installation and the SPU overhead. SPU installs the cisterns at no cost to the participant, provides maintenance and support, and evaluates the performance over time. SPU is currently analyzing the impact of cisterns on the combined sewer system as part of a grant. SPU also sells rain barrels to households in the SPU's direct service areas. The rain barrels cost $59 each for the SPU customers and $69 for non-customers.

Mills College in Oakland, CA employs a rain catchment system that includes cascading bronze sculptural elements that direct rainwater into cisterns for storage and reuse. Photo: Rumsey Engineers

DESIGN CONSIDERATIONS

Proper design and sizing of the rainwater harvesting system are critical to ensure full peak flow benefits. Prior to harvesting rainwater from the roof, the roof must be cleaned, and the downspout must be disconnected from the sewer and connected to the rainwater harvesting system. Regardless of the size, all rainwater harvesting systems include the following basic components: conveyance, storage, and distribution. Stormwater from roof downspouts is conveyed through pipes from the roof or drainage management area to a storage area. Water is stored in the system until it is distributed either by gravity through a spigot or by a pump. Some pretreatment is required to prevent clogging (e.g., leaf screens and first-flush diverters) before the stormwater enters storage. Rain barrels and cisterns should be made of dark material to prevent light from entering the container. This will avoid algal growth. All openings should be screened to prevent litter and mosquitoes or other vectors from entering. Generally, cisterns have an operable manhole opening on the top that allows access for maintenance and monitoring. Pipes conveying rainwater to indoor fixtures must be yellow. Label all rainwater harvesting system pipes and fixtures, including toilet tanks: NON-POTABLE WATER, DO NOT DRINK. Label your rain barrel and cistern with safety stickers provided by the SFPUC at 1155 Market Street.

Rainwater harvesting systems are sized according to non-potable water demand. An electronic sizing tool is also provided with the *Guidelines* and is hosted on the SFPUC website at http://stormwater.sfwater.org in the Stormwater Design Guidelines section. The tool should be used for planning purposes only, such as determining the general footprint and preliminary dimensions. This calculator is not intended to provide final detailed calculations or dimensions.

OPERATIONS AND MAINTENANCE

Semi-annual inspection is advisable to confirm that all the parts are operable and not leaking. Rainwater harvesting systems, including drainage management area and gutters, must be kept clear of debris, and all screens must be properly maintained to prevent mosquitoes and other vectors from breeding. Rain barrels and cisterns should be cleaned annually with a non-toxic cleaner, such as vinegar. All backflow prevention assemblies must be tested annually by the system owner using a certified tester approved by the City and County of San Francisco (see approved testers at: http://www.sfdph.org/dph/files/EHSdocs/ehsCrossflowdocs/cbpat0108.pdf). Regular use of the water stored in systems between rain events is critical to ensure that storage is available for the next storm event. During the rainy season, it can be difficult to use the stored water because irrigation is generally not necessary. The stored water can be used during the rainy season for other non-potable uses such as toilet flushing or fire suppression. The table below provides more information on typical post-construction inspection and maintenance activities.

Typical Inspection Activities for Rainwater Harvesting

Activity	Schedule
• Check that all parts are operational and not leaking.	Post-construction and semi-annually (beginning and end of rainy season)
• Check backflow prevention assemblies using a certified tester approved by the City and County of San Francisco (see approved testers at: http://www.sfdph.org/dph/files/EHSdocs/ehsCrossflowdocs/cbpat0108.pdf).	Annually

Typical Maintenance Activities for Rainwater Harvesting

Activity	Schedule
• Clean with a non-toxic cleaner, such as vinegar.	Annually
• Clear litter and debris from drainage management area, gutters, system, and screens. • Use stored water periodically during the rainy season to ensure that storage is available for the next rain event.	As needed

COST

The cost of rainwater harvesting systems typically varies between $1 to $2 per gallon of capacity, depending on the size and type. Generally, According to the Low Impact Development Center (2007), small residential rain barrels that connect to the existing gutters can be as inexpensive as $225-$300 for 200-300 gallons of roof storage. A large-scale surface cistern costs approximately $40,000 for storage of 20,000 gallons of stormwater. Cisterns installed underground tend to have higher installation and maintenance costs.

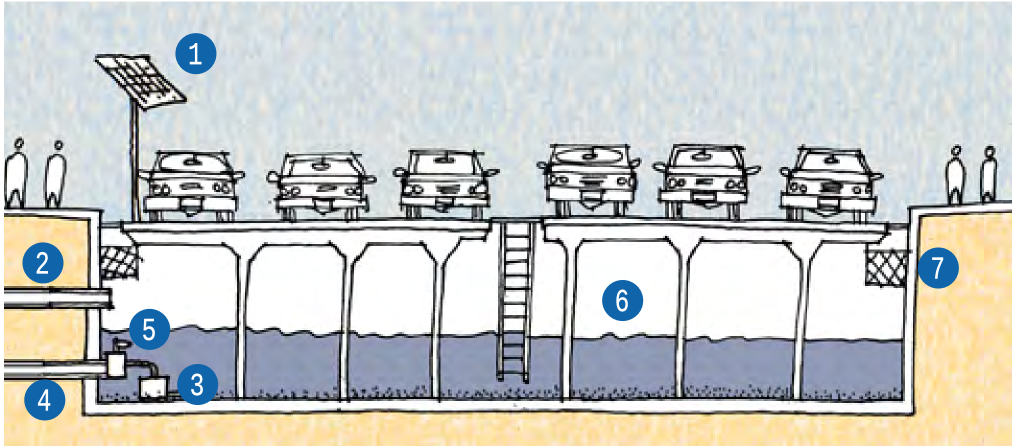
Rainwater Harvesting Examples (cont.)

In Oakland, CA...

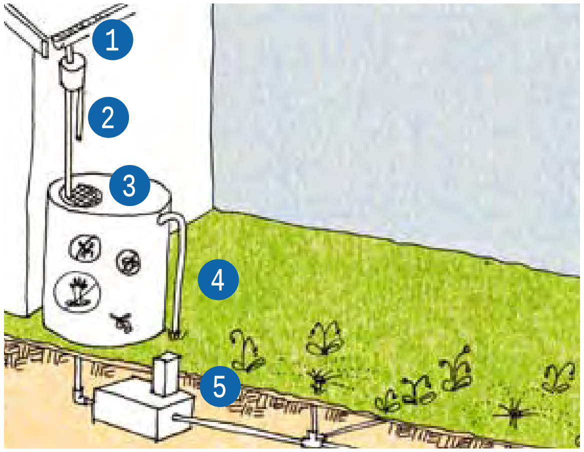
The Natural Science Building on the campus of Mills College in Oakland, CA has been designed with a rainwater collection system that will reduce water use and serve as an important educational opportunity for students occupying and learning in the building. Laboratories are notorious for their use of large volumes of water, due to equipment washing requirements. If designed with traditional water efficiency standards, this building would have used more water in one year than 20-40 homes in the surrounding area. The Natural Science Building's rainwater harvesting system, in combination with other water efficient strategies incorporated in the design of the laboratories, will reduce domestic water use by approximately 60%, capturing and using an estimated 50,000- to 60,000-gallons of water annually.

The system is designed as an attractive sculptural element serving as a teaching tool for faculty and students. The roof, which also hosts an array of photovoltaic panels, directs rainwater to a functioning, water-collecting sculpture. A header box at the parapet of the roof sends the water cascading down a series of bronze sculptural elements to a 2000-gallon stainless steel storage tank—created from a recycled mayonnaise container.

Before the water is supplied to the building, it is filtered with sub-micron and UV light filters and then directed to toilets and trap primers. The simple system uses readily available water purification components. When rainwater is not available, the system is backed up by the city's water system.



*In urban areas, **underground cisterns** can store stormwater runoff from paved surfaces.*



***Above-ground cisterns** can be attached to irrigation systems in residential settings*

1. Solar panel to power pump
2. Overflow drains to collection system
3. Pump
4. Outflow to nonpotable use
5. Valve to drain for maintenance
6. Design storm elevation
7. Trash rack

1. Screen on gutter prevents large debris from entering cistern
2. First flush diverter
3. Screened access prevents mosquite breeding
4. Overflow to collection system
5. Pump with maintenance access

REFERENCES AND RESOURCES

Kinkade-Levario, Heather, 2007. *Design For Water: Rainwater Harvesting, Stormwater Catchment, and Alternate Water Reuse*. Gabriola Island, BC: New Society Publishers.

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Los Angeles County. 2002. "Development Planning for Stormwater Management: A Manual For the Standard Urban Stormwater Mitigation Plan (SUSMP)." Los Angeles: Department of Public Works. 18 June 2008 <http://ladpw.org/wmd/NPDES/SUSMP_MANUAL.pdf>.

Low Impact Development Center, Inc. 2007. "Cost of Rain Barrels and Cisterns, Sizing of Rain Barrels and Cisterns." 18 June 2008 <http://www.lid-stormwater.net/raincist/raincist_cost.htm and http://www.lid-stormwater.net/raincist/raincist_sizing.htm>.

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Tom Richmond and Associates. 1999. "Start at the Source: Design Guidance Manual for Stormwater Protection." San Francisco: Bay Area Stormwater Management Agencies Association. 18 June 2008 <http://scvurppp-w2k.com/pdfs/0203/c3_related_info/startatthesource/Start_At_The_Source_Full.pdf>.

TreeHugger. 2007. "Seattle RainCatcher Pilot Program." 18 June 2008 <http://www.treehugger.com/files/2005/03/seattle_raincat_1.php>.

Assembling a rainwater harvesting system at Cesar Chavez Elementary School, San Francisco, CA.

Source Control Resources

The following references and resources provide guidance on source control measures. Specific land uses and activities that require source control measures as specified in Attachment 4 of the Phase II General Permit include:

- 100,000 sq. ft. commercial developments: loading/unloading dock areas, repair/maintenance bays, vehicle/equipment wash areas
- Restaurants: equipment/accessory wash areas
- Retail gasoline outlets: fueling area
- Automotive repair shops: fueling area, repair/maintenance bays, vehicle/equipment wash areas, loading/unloading dock areas
- Parking lots: parking area, oil contamination and performance maintenance

REFERENCES AND RESOURCES

City of San Diego. 2002. "Model Standard Urban Storm Water Mitigation Plan (SUSMP) for San Diego County."

City of Ventura. 2002. "Ventura Countywide Technical Guidance Manual for Stormwater Quality Control Measures."

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

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

"State Water Resources Control Board Order Number 2003-0005-DWQ." 17 November 2008 <http://www.waterboards.ca.gov/water_issues/programs/stormwater/docs/final_attachment4.pdf>.

Offsite Conveyance Requirements

In addition to treating the water quality volume or flow rate for a given contributing area, designers must ensure that larger flows are accommodated safely by the project. Regulations differ for public right-of-way versus private parcels.

For developments in which the developer is building a city street that will be deeded back to the City (i.e., in Mission Bay or Hunters Point), San Francisco Subdivision Regulations (Section XII Streets: j.3) require designers to ensure that the 5-year storm is safely conveyed into the collection system and that the 100-year storm is safely passed off the site. These regulations apply only to streets.

For private parcels, designers are responsible for ensuring that stormwater is safely conveyed from the site for the 60-minute, 100-year storm in compliance with the California Plumbing Code Section 1101.11.

REFERENCES AND RESOURCES

City and County of San Francisco, 1982. "Subdivision Regulations – Department of Public Works Order No.124,677." Approved January 6, 1982.

"California Plumbing Code," 2007.