Chapter 5. Hydromodification Management, Low Impact Development, and Treatment Control Measures

Introduction

Hydromodification management, LID, and treatment control measures are designed to meet distinctly different regulatory requirements. Those different regulatory requirements can be summarized as follows:

- Hydromodification Management Requirements – Address changes to runoff characteristics from urbanization and other sources that would otherwise result in the artificially altered rate of erosion or sedimentation within downstream natural channels.
- Low Impact Development Requirements – Address more holistic environmental objectives associated with restoration of the natural hydrologic regime and reduce pollution in runoff.
- Treatment Requirements – Address impacts to stormwater pollutant concentration and/or pollutant load that would otherwise result from urbanization.

Each of these requirements and the corresponding design approach necessary to demonstrate compliance is discussed in greater detail within this chapter. The design practitioner has a number of optional control measures at his/her disposal that can satisfy these requirements on an individual or collective basis. The suitability of each control measure to address one or more of the requirements discussed above varies based on its functionality. A summary of the allowable application of each control measure to address hydromodification, LID, and/or treatment control requirements is shown in Table 5-1. Notice the high correlation between the ability of LID measures to simultaneously address hydromodification management and treatment control requirements. In order for proprietary devices to be counted as LID, project specific calculations must be provided to demonstrate volume reduction to the satisfaction of the reviewing agency.

Table 5-1 Summary of Control Measure Functionality

✓ Acceptable Option **"RR" Runoff Reduction, used in combination with other measures**

Control Measure	Appropriate for Compliance With: Hydromodification Management Standards	Low Impact Development Implementation	Treatment Control
Alternative Driveways	RR	✓	RR
Capture and Re-Use	RR	✓	RR
Compost-Amended Soil	RR	✓	RR
Constructed Wetland Basin	✓		✓
Disconnected Pavement	RR	✓	RR
Disconnected Roof Drains	RR	✓	RR
Green Roof	RR	✓	✓
Infiltration Basin	✓		✓
Infiltration Trench	✓	✓	✓
Interceptor Trees	RR	✓	RR
Porous Pavement	RR	✓	RR
Sand Filter (Austin Sand Filter)	✓		✓
Bioretention Planter (Flow-Through)	✓	✓	✓
Bioretention Planter (Infiltration)	✓	✓	✓
Underground Storage (Tanks, Vaults, etc.)	✓		
Vegetated Filter Strip		✓	
Vegetated Swale		✓	✓
Water Quality Detention Basin	✓		✓
Proprietary Devices			✓

Note: Runoff Reduction (RR) measures contribute to the overall required mitigation, but are not standalone measures and need to be combined with appropriate treatment controls or hydromodification management controls as needed.

Hydromodification Control Principles and Applicability

As development occurs, much of the natural vegetated areas are replaced by impervious surfaces such as roofs, streets, and parking lots. This increase in impervious area typically results in a corresponding increase in the volume, velocity, and peak flow rate of runoff discharged from the site, as well as a reduction in bed material to downstream channels and streams. Such artificially created changes to runoff characteristics are known as hydromodification and can result in accelerated erosion or sediment deposition within downstream natural channels.

Hydrologic characteristics can also be impacted as a result of improvements to stormwater conveyance or detention facilities. Although stormwater detention facilities can lessen peak rates to those of natural conditions, they are not effective in significant reduction of stormwater volume. As such, stormwater detention facilities require proper design procedures to ensure that they successfully mitigate impacts to the duration of geomorphically significant flow. Forthcoming sections within this chapter are devoted to discussion of proper design procedures. Hydromodification management can be assessed using continuous simulation hydrologic modeling (as opposed to a single event as typically used for flood control design). Hydromodification management requirements are based on the Sacramento Stormwater Quality Partnership (SSQP) Hydromodification Management Plan (HMP) originally developed in 2011 and revised in February 2013.

Figure 5-1 is a flowchart that illustrates the process to determine the applicability of the hydromodification management requirements for a project. The exemptions are summarized below and shown graphically on Figure 5-2, Applicability Map[1] (additional background information for the exemptions is available within the Sacramento Stormwater Quality Partnership HMP).

Projects Located in an Exempted Area

Some projects may be exempt from hydromodification mitigation requirements based on the conditions in the watershed or the receiving waters. Projects are exempt from hydromodification mitigation requirements if the project:

- Drains directly to the Sacramento or Lower American River:
  Projects discharging directly, or through exempted drainage channels, or through underground drainage conveyance system and pump stations, to the Lower American River or Sacramento River will not be subject to hydromodification management requirements.
- Area is within a highly developed watershed:
  The threshold for a "highly developed" watershed in Sacramento County is a watershed with 5% or less developable area.
- Drains to an exempted Special drainage area:
  Three drainage areas in Sacramento County have been investigated and determined not to be subject to hydromodification requirements: City of Sacramento North Natomas Basin, Metro Air Park in unincorporated Sacramento County, and the Franklin Creek (formerly known as Shed B) watershed in the City of Elk Grove. Additional information about why these three areas are exempt can be found in Section 3.2.4 of the HMP.

[1] Full size map available at: http://www.beriverfriendly.net/docs/files/File/HMP/HMP%20Map%20Fig%203-7_FULLSIZE.pdf

Municipal Agency Projects

The following municipal agency projects may be exempted from implementation of hydromodification controls:

"Projects that are replacement, maintenance, or repair of the Permittees' existing flood control facilities, storm drains, public utilities, or transportation network." [2016 MS4 Permit, Attachment J, Provision F.2.i.ii.(1)]

Existing flood control facilities includes debris basins, retention/detention basins, levees, and flood control channels. Existing storm drains include storm drain pipes and associated facilities, such as catch basins, inlets, curbs, gutters, ditches, man-made channels, water quality features, and structural BMPs. Existing public utilities includes electricity, natural gas, sewage treatment, waste collection/management, telecommunications, water, and other services provided to municipal residents. Transportation network includes structures that permit vehicular or other movement of people or goods, including roads and streets, sidewalks, pedestrian ramps, bike lanes, railways, and transit lines.

Replacement, maintenance, or repair includes:

- cleaning,
- trenching and resurfacing associated with utility work,
- grinding or resurfacing of impervious surfaces that does not result in exposing underlying subgrade material (dirt),
- pothole repair, and
- similar activities with the purpose of ensuring proper operation of flood control facilities, storm drains, public utilities, or transportation network elements.

Prior Approved Projects – Revised July 19, 2021

A project shall qualify as a Prior Approved Project if it meets the criteria of one of the following Categories:

Category 1. A project will be exempt from HMP and LID requirements if the project's site design is approved or established by one of the following methods no later than July 1, 2018:

a. The site has a complete application submitted for a tentative map to construct a single-family subdivision; or

b. The site has an approved Plan Review, Special Permit or Conditional Use Permit, Design Review/Preservation Review entitlement; or

c. The project has a complete building permit application submitted; or

d. The project has a set of improvement plans submitted; or

e. A project being issued a new building permit to complete work commenced under a prior permit may be considered exempt from HMP requirements at the discretion of the local Permitting Agency; or

f. A Project in a large specific or community plan area that has a drainage master plan approved on or after July 1, 2017 but prior to July 1, 2018.

Category 2. A project will be exempt only from HMP requirements if:

- Discharging directly to a segment of a channel or creek with permitted improvements under a 404 permit or 401 certification from the relevant Federal or State regulatory agencies; and
- The applicant's 404 permit and 401 certification must be currently valid and obtained no later than July 1, 2018.

The Category 2 exemption does not apply for projects with 404 permits or 401 certifications that require hydromodification management, and does not provide exemption from LID requirements.

Category 3. A public agency project will be exempt from HMP and LID requirements if the project's design has been completed (final bid documents submitted) and/or a contract has been advertised no later than July 1, 2018.

Priority Projects

Priority projects listed in Table 1-2 will be subject to hydromodification management requirements. Refer also to Table 3-3 of this manual.

Discharges Directly to Exempted Channels

Projects discharging to creeks or channels meeting one or more of the following characteristics will not be subject to HMP requirements:

- All surfaces of the channel (bed and both banks) have a continuous erosion resistant lining of concrete, stone (rip-rap), permanent synthetic turf reinforcement fabrics, or other permanent material.
- The channel was constructed for the sole purpose of flood and stormwater conveyance in an area where natural stream channels did not historically exist.
- The drainage channel was designed and constructed with permissible velocity according to the City of Sacramento's Storm Drainage Design Standards (City of Sacramento, 2009).
- The channel was designed and constructed in accordance with the National Resource Conservation Service (NRCS) Part 654 Stream Restoration Design National Engineering Handbook, Chapter 8 Threshold Channel Design 654.0803 Allowable Velocity Method (NRCS, 2007), which provides guidance on stable channel design.

Potential exemption from the hydromodification management requirements, to be determined on a case-by-case basis, will be considered for projects discharging to creeks or channels where Federal or local levee projects have been constructed, including the construction of new concrete floodwalls on banks, excavation and reshaping of the creeks and associated improvements. Federal project levees or structures currently identified by the Sacramento Area Flood Control Agency (SAFCA) that meet this exemption criteria include the South Sacramento Streams (Morrison Creek Stream Group). The

South Sacramento Streams Group includes Morrison Creek, Florin Creek, Elder Creek and Unionhouse Creek located in the southern portion of the Sacramento urbanized area, which has historically been vulnerable to flooding. The U.S. Army Corps of Engineers, the Central Valley Flood Protection Board, and SAFCA were authorized to improve these creeks and channels in the South Sacramento Streams Group and the project consists of levee improvements starting south of the town of Freeport and running easterly along the southern edge of the urbanized area. The upgrades to the channels and creeks in this area intend to significantly improve the flood protection to the community by construction of new concrete floodwalls on banks, excavation and reshaping of the creeks and associated improvements. These in-stream alternations have prepared the creeks for the potential hydromodification impact, i.e. erosion from additional runoff.

These exemption criteria do not apply to channels that the local flood control authority may deem undersized or incised for flood control purposes. Refer to the local flood control authority for more information.

Redevelopment Projects

The HMP exemption will be provided to redevelopment projects (e.g., infill) that do not increase the effective impervious area or decrease the infiltration capacity of pervious areas compared to the pre-project conditions.

Infill projects are those that meet all the following criteria as defined below, as determined by the permitting authority:

1. The project is consistent with the applicable general plan designation and all applicable general plan policies as well as with applicable zoning designation and regulations.
2. The proposed development occurs on a project site of no more than eight acres in size and is substantially surrounded by urban uses.
3. The project site has no value as habitat for endangered, rare or threatened species.
4. Project site is located within 1/2 mile of a major transit stop identified by Sacramento Area Council of Governments (SACOG) Metropolitan Transportation Plan (MTP 2035).

Figure 5-1 Hydromodification Mitigation Applicability Flow Chart

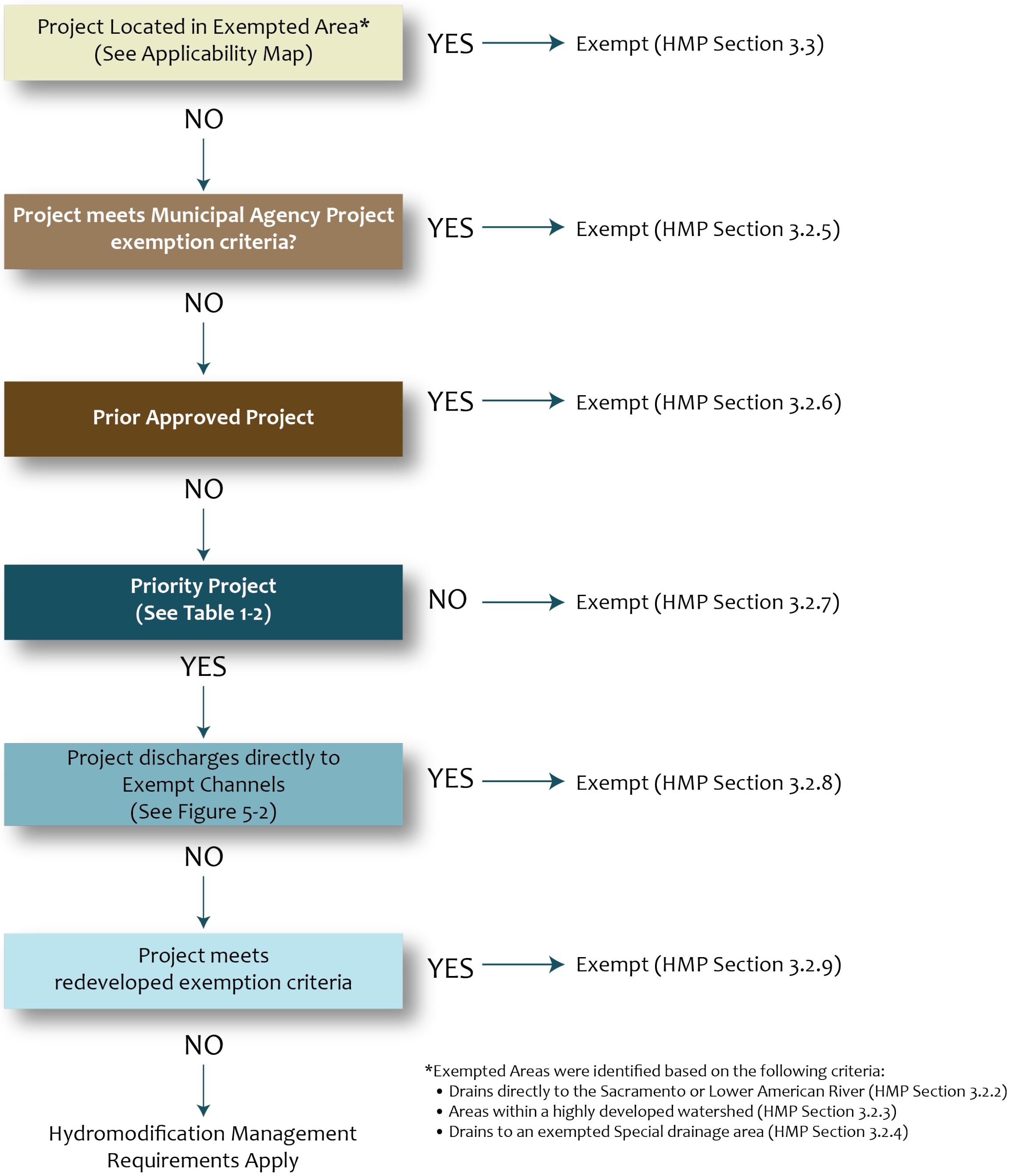
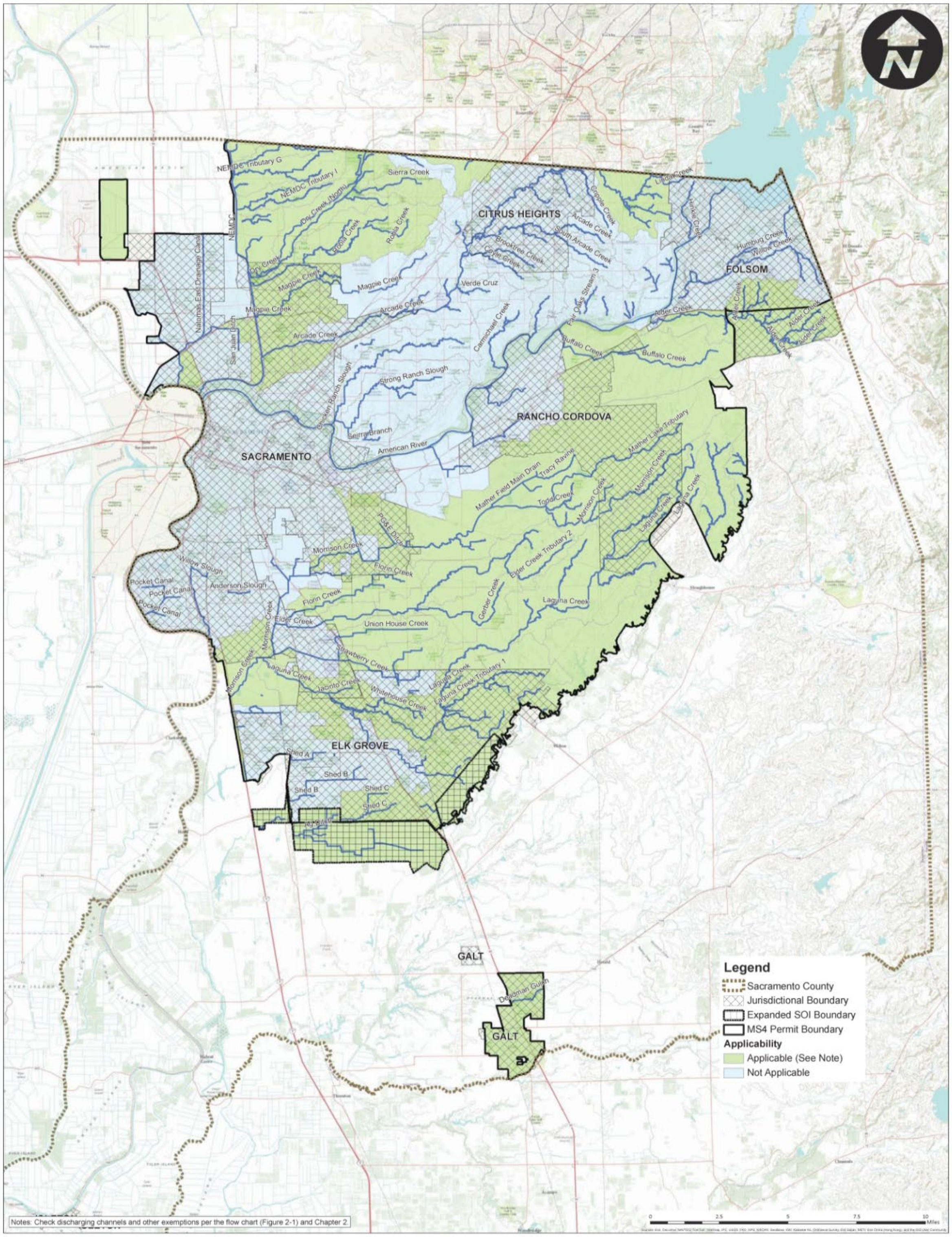


Figure 5-2 Applicability Map



[Click here to link to Figure 3-1, Identifying Stormwater Quality Requirements for New Development and Redevelopment Projects.]

Click on this link for a higher resolution copy of the Applicability Map:
http://www.beriverfriendly.net/Newdevelopment/

Selecting Hydromodification Controls for Your Project

If hydromodification control measures are required for your project, the answers to the following questions will help you determine the appropriate control measure(s) for your unique conditions:

- **How much space is available** on the project site for a hydromodification control facility?
  Refer to the fact sheets at the end of this chapter to determine the space requirements for the various types of hydromodification control measures. Consider that some facilities can be integrated into the landscaping planned for the site. Also, although underground facilities do not take up as much space, they can be more costly to construct and maintain.

- What are the **site conditions and associated limitations** on use of stormwater quality hydromodification control measures for this property?
  As described in the fact sheets at the end of this chapter, the selection and design of stormwater hydromodification control measures is largely dependent on soils, topography/slope and other natural site features.

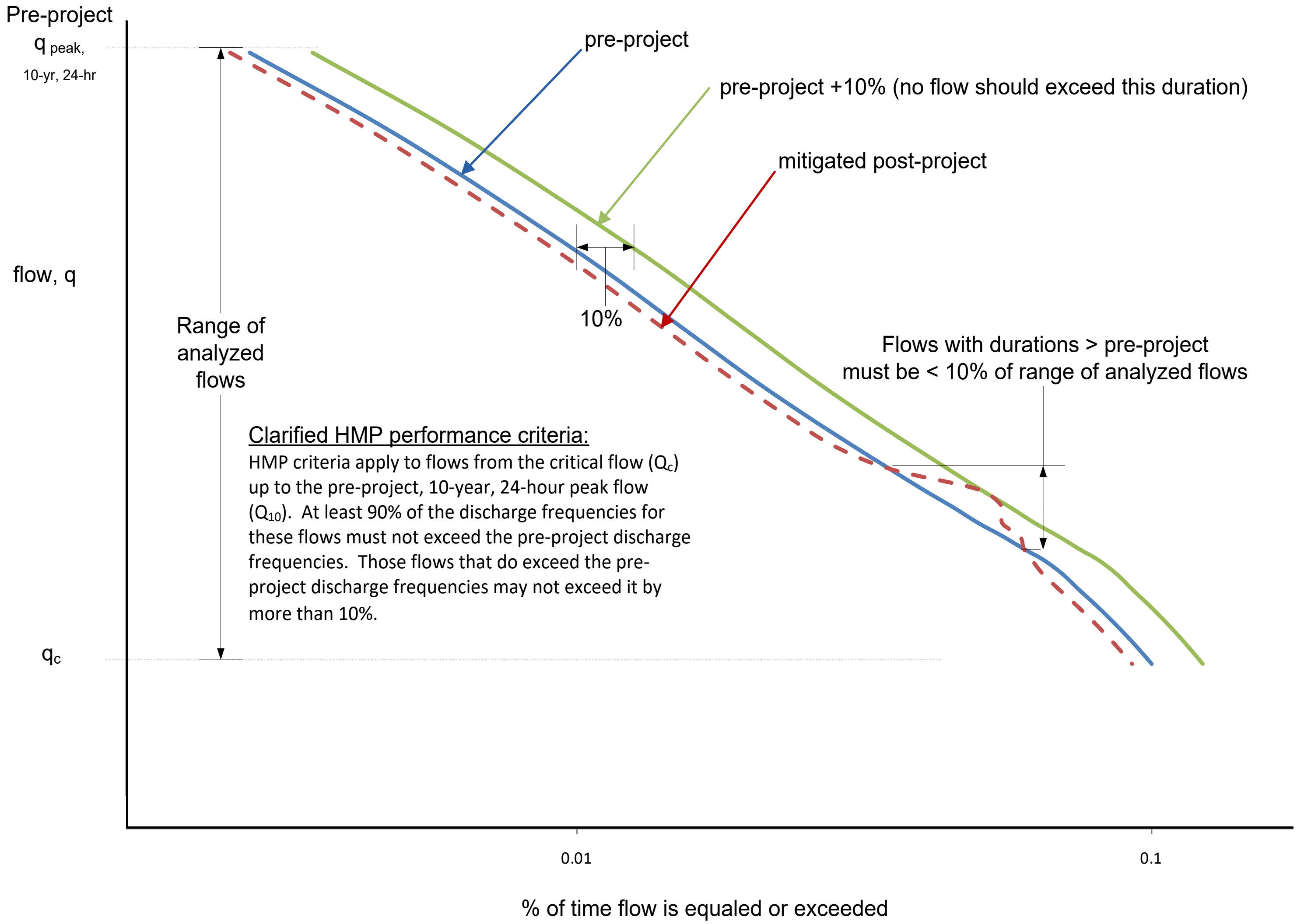
- What **level of maintenance** will the property owner be capable and willing to conduct as long as he/she owns the property?
  Consider the short and long-term maintenance needs of the hydromodification control measures (as described on the fact sheets at the end of this chapter) and whether or not the property owner can agree to those requirements. The permitting agencies in the Sacramento Region require that the property owner sign a maintenance agreement or obtain a permit to ensure long-term maintenance. Such maintenance agreements require reconstruction or replacement of the feature when it fails to function properly. For informational purposes, projected lifespan information is provided for the various control measures in Appendix B.

Designing Hydromodification Controls

The performance criteria from the Sacramento HMP are as follows:

Flow duration control - For flow rates ranging from 25% or 45% of the pre-project 2-year recurrence interval event (0.25Q2 or 0.45Q2) to the pre-project 10-year runoff event (Q10), the post-project discharge rates and durations shall not deviate above the pre-project rates and durations by more than 10% over more than 10% of the length of the flow duration curve (see Figure 5-3). The specific lower flow threshold will depend on results from the channel susceptibility assessment.

Figure 5-3 Visual Demonstration of the HMP Performance Criteria



Projects that discharge to channels with high or very high susceptibility are required to design for a larger range of flows (0.25Q2 – Q10) than projects that discharge to channels with low or medium susceptibility (0.45Q2 – Q10). The larger range of flows will result in larger required hydromodification controls. The channel susceptibility is determined based on the susceptibility assessment tool in Chapter 4 of the SSQP HMP (http://www.beriverfriendly.net/Newdevelopment/). For project applicants that choose not to assess the susceptibility of the receiving waters, the lower flow rate (0.25 Q2) must be used.

Alternative Design Approaches for Hydromodification Management

There may be some projects for which on-site hydromodification management is not feasible or desirable. In those cases, that applicant may choose to implement in-stream measures to address project hydromodification impacts (see Chapter 7 of the HMP). This alternative option requires continuous simulation modeling and field data collection. The results of the analysis will be subject to review by the permitting agencies and approval is not guaranteed. Additional information for in-stream hydromodification mitigation can be found in Chapter 8 of NRCS Part 654 Stream Restoration Design National Engineering Handbook. Other sources of information are available from the U.S. Army Corps of Engineers, the US EPA, and the California State Water Resources Control Board. Refer to the following:

http://www.spk.usace.army.mil/Missions/Regulatory/Mitigation/

https://www.epa.gov/cwa-404/stream-assessment-and-mitigation-protocols-review-commonalities-and-differences

Low Impact Development Principles

The goal of low impact development measures is to mimic a site's predevelopment balance of runoff and infiltration by using design techniques that infiltrate, store, evaporate, and detain runoff close to its source. Low impact development controls are integrated into site design and can be distributed throughout the site in a series of small-scale (or micro-scale) measures. As explained in Chapter 1, this approach is one of the key elements in low impact development (LID) design.

For the purposes of this manual, LID is defined as follows: "Low impact development is a stormwater management strategy that emphasizes conservation and use of existing natural site features integrated with distributed, small-scale stormwater controls to more closely mimic natural hydrologic patterns in residential, commercial, and industrial settings." *(Puget Sound Action Team 2005)*

The goal of low impact development measures is to mimic a site's predevelopment balance of runoff and infiltration by using design techniques that infiltrate, filter, store, evaporate, and detain runoff close to its source.

LID measures are typically integrated into site landscaping (including open space, yards, streetscapes, road medians, and parking lot and sidewalk planters) or into the design of paved and other impervious areas, such as the building roof. Small-scale runoff controls integrated into the project design and located close to the source of the water and pollutants can help reduce the need to convey water and treat it in large, often more costly end-of-pipe facilities located at the bottom of drainage sheds. By reducing the total runoff volume, these measures can also help alleviate potential downstream habitat degradation and erosion problems.

Although LID measures can reduce the size/need for stormwater quality treatment and hydromodification facilities, other drainage and flood control design requirements for the project still apply, as specified by the local permitting agency. References for drainage and flood control requirements are listed in Appendix F. This chapter addresses the following basic low impact development strategies:

- Open Space Preservation
- Runoff Reduction
- Runoff Management

In order to allow flexible LID implementation that is both quantifiable and beneficial, a point system has been developed that permits a wide range of options that can be selected based upon the discretion of the practitioner given the unique characteristics of each project. Each priority new development or redevelopment project is required to earn a minimum of 100 points based upon the LID measures selected and implemented. The computational procedure for residential projects differs somewhat from commercial projects. A discussion of these methods as well as the method for tabulating points earned is also presented within this chapter. Examples of tabulating points for both residential and commercial sites can be found within Appendix A. Compliance with LID principles is required at all stages of approval, including master planning and final improvement or grading plans for individual projects.

Open Space Preservation

Open space is defined as "non-impervious area within the project that is subtracted from the total project area to reduce the area used in sizing treatment BMPs". Because of this benefit, open space is awarded LID credit points. The percentage of open space is translated directly into LID points on a 1:1 ratio (1 LID point for each 1% of open space in relation to the total project area).

For LID implementation, open space includes, but is not limited to, natural storage reservoirs, drainage corridors, buffer zones for natural water bodies, stream setbacks and buffers, and flood control detention basins.

There are two types of open space credits available, on-project and off-project. On-project open space is credited at a 1:1 ratio within the project area, and it also reduces the treatment area requirement. Off-project open space credit allows individual projects within a master planned community to also receive credit at a 1:1 ratio for the open space preserve (1 LID point for each 1% of open space in relation to the total master planning area), including parks, drainage corridors, and floodplains, etc. However, unlike the on-project open space, because this open space is not located within the project area it does not provide a reduction in the treatment area requirement. An example of tabulating open space LID points is presented within Appendix D.

Runoff Reduction

This manual describes a range of methods to reduce runoff by replacing, strategically locating, and/or minimizing conventional impervious surfaces. The covered approaches are:

- Disconnection of Impervious Surfaces, such as Pavement Areas and Roof Drains
- Interceptor Trees

The LID point system uses the "Effective Area Managed" credit system for runoff reduction. Separate residential and commercial worksheets for determining "effective area managed" by runoff reduction measures can be found within Appendix D. For all projects, the LID point system assigns 1 point for every 1 percent of project area effectively managed (i.e. 1:1 ratio).

Use of runoff reduction controls can reduce the amount of water requiring treatment on a site.

Disconnection of Impervious Surfaces

In conventional designs, runoff and associated pollutants from impervious surfaces (such as parking lots and roof tops) flow directly to a storm drain system. In other words, the impervious areas are "directly connected" to the storm drains. Impervious areas can be "disconnected" when the runoff from the area is redirected to flow over landscaping, into bioretention planters, or through pervious pavement. Criteria are provided in Appendix D to define how dimensional variation in impervious surface disconnection translates to "Effective Area Managed" credits.

This chapter introduces several measures that involve disconnecting impervious surfaces from the storm drain system:

- Disconnected Pavement
- Disconnected Roof Drains - including disconnection through infiltration systems

Refer to Disconnected Pavement and Disconnected Roof Drain BMP Fact Sheets for additional information.

Interceptor Trees

Trees intercept stormwater and can retain a significant amount of the captured water on their leaves and branches, allowing for evaporation and dissipation of the energy of runoff. Their root structures absorb and uptake runoff and associated pollutants. The shade provided by trees keeps the ground under the trees cooler, thereby reducing the amount of heat gained in runoff as it flows over the surface and into the storm drain. In turn, this helps keep stream temperatures cool and healthy for fish and other aquatic life.

Developers and designers who use trees as part of an integrated post-construction stormwater quality plan can receive interceptor tree credits as described in Appendix D. Appendix D also describes how interceptor tree credits are translated to "Effective Area Managed" credits for runoff reduction as a function of tree type (i.e. evergreen, deciduous, etc.).

Refer to the Interceptor Trees BMP Fact Sheet for additional information.

Runoff Management

This manual describes a range of methods to manage runoff by replacing, strategically locating, and/or minimizing conventional impervious surfaces. The covered approaches are:

- Porous Pavement
- Alternative Driveways
- Green Roof
- Capture and Re-Use
- Compost-Amended Soil

The LID point system also uses the "Effective Area Managed" credit system for runoff management. Separate residential and commercial worksheets for determining "effective area managed" by runoff management measures can be found within Appendix D. For all projects, the LID point system assigns 2 points for every 1 percent of project runoff from area effectively managed (i.e. 2:1 ratio).

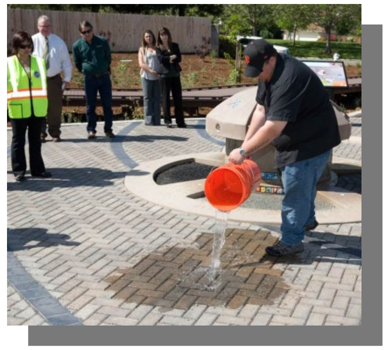
SAHM can also be used to demonstrate LID compliance through volume reduction. For all projects, the LID point system assigns 2 points for every 1 percent of volume reduction (i.e. 2:1 ratio). Volume reduction is calculated as follows:

$$\%\text{ Volume Reduction} = \frac{(Un{-}Mitigated\ Post\ Development\ Volume - Mitigated\ Post\ Development\ Volume)}{(Un{-}Mitigated\ Post\ Development\ Volume - Pre\ Development\ Volume)} \times 100$$

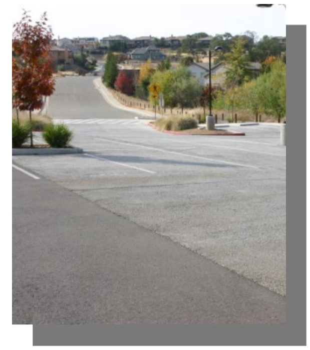
Porous Pavement

Traditional asphalt and concrete pavement can be substituted with one of several different types of porous pavements, such as pervious concrete and pavers. The degree of permeability varies by type of material (for example, reinforced grass pavement is more pervious than cobblestone pavers), and the appropriate type to use depends on anticipated traffic loads and uses. There are various examples of pervious concrete, and many examples of pavers installed throughout the Sacramento area. Refer to the Porous Pavement BMP Fact Sheet for additional information.

Porous Pavement at
Fair Oaks Promenade,
City of Folsom



Porous Pavement at
Elk Grove-Rain Garden Plaza



Porous Pavement at
Nisenan Community Park,
City of Folsom

Alternative Driveway

Alternative driveways are one design application which involves replacing all or a portion of a standard impervious driveway with pervious materials such as grass or pavers. Check with the local permitting agency for any restrictions associated with the use of porous pavements or alternative driveway designs. Refer to the Alternative Driveway BMP Fact Sheet for additional information.

Green Roof

Instead of using conventional roofs, which generate runoff during a rain storm, consider installing a "green roof", also known as an "ecoroof." The roof functions like a sponge, using several inches of soil and a top layer of vegetation to capture and slow rainwater as it flows from the rooftop to the ground. The concept has been popular in Europe for centuries, has become more common in the Pacific Northwest and Midwest (e.g., Chicago), and is gaining popularity in California. Various green roof installations have been completed since the late 1990s in the San Francisco Bay Area and more recently in southern California. See the references at the end of this chapter for more information. Also refer to the Green Roof BMP Fact Sheet for additional information.

Capture and Re-Use

Excess stormwater volume resulting from project impervious surfaces can be captured and re-used on site to mitigate impacts to receiving waters. The most typical application of the capture and re-use approach is store excess stormwater as a supplement for irrigation supply, although additional re-use options may be available for commercial development. Residential development can incorporate measures such as rain barrels, cisterns, or ponds to effectively capture and re-use stormwater runoff from roof areas.

Compost-Amended Soil

The compost-amended soil BMP is an option in the BMP toolbox that has a smaller footprint than impervious surface disconnection. This BMP option is intended to be a less complex alternative compared to bioretention and engineered infiltration BMPs. Compost-amended soil is also ideal as a design feature in landscape and open space areas. The volume of water to be infiltrated is assumed to be captured within pore spaces of a simple, depressed bed of mulch and compost-amended soil that overlies the native soil (with no underdrain). The mulch and amended soil provide short-term storage for the water until it can infiltrate the native underlying soil. Refer to the Compost-Amended Soil BMP Fact Sheet for additional information.

Selecting Low Impact Development Measures for Your Project

Refer to Table 3-3 to determine which LID control measures may be used in your project. Work with your civil/geotechnical engineer and planner to study the infiltration capacity of the soils and the future use of the site when making this determination. The local permitting agency may require permeability tests, depending on the type of control measure and site conditions. For pervious pavement, identify parking areas, walkways and patios that will not experience high traffic loadings. Involve your landscape architect in the initial site layout to locate and slope paved areas toward vegetated areas whenever possible. Once you've selected the measures most appropriate for the site, refer to the LID credit worksheets (Appendix D) to prepare the site design.

Low Impact Development Points Worksheets

Appendix D includes worksheets for calculating LID points for residential and commercial priority new development and redevelopment projects and background information documenting the process used to derive the score. Use the worksheets to determine to what extent you can reduce project runoff by incorporating one or more of the LID control measures described in this chapter. Use the worksheets also to determine the remaining required treatment water quality volume or flow (if any) adjusted for low impact development use, and then use Chapter 5, **Hydromodification Management, Low Impact Development, and Treatment Control Measures**, and Appendix E to guide you through the process of selecting and sizing your treatment measures.

Treatment Control Principles

The stormwater quality treatment control measures profiled in this chapter are the more common ones being implemented throughout the state and the rest of the country. Studies have shown these measures to be effective if properly installed and maintained. Alternative technologies that provide equivalent treatment may be proposed and will be considered by the permitting agencies, but may result in additional time for agency review and approval unless coordinated well in advance with the appropriate agency staff.

Stormwater quality treatment control measures are engineered technologies designed to remove pollutants from site runoff. They can have a higher cost and require more space than the LID measures discussed elsewhere in this chapter. All development and redevelopment projects meeting the size thresholds on Table 3-3 require treatment control measures, but the required treatment volume or flow can be reduced (potentially to zero) through the use of LID measures. The treatment control methods suitable for a given project depend on a number of factors including: type of pollutants to remove, amount of stormwater runoff to be treated, site conditions, and state general industrial NPDES permit requirements, when applicable. Land requirements, and costs to design, construct and maintain treatment control measures vary by measure and locale.

Unlike flood control measures that are designed to handle peak flows from large storm events, stormwater quality treatment control measures are designed to treat the more frequent, lower flow storm events. Small frequent storm events (0.5 inches of rain and less) on the average represent over 80% of the total average annual rainfall for the Sacramento area. The water quality flow (WQF) and water quality volume (WQV) are targeted for treatment in order to reduce pollutants to the "maximum extent practicable" standard.

Selecting Treatment Control Measures

If stormwater quality treatment control measures are required for your project, the answers to the following questions will help you determine the appropriate control measure(s) for your unique conditions:

- What are **pollutants of concern** for the future land use of the development?
  See Table 3-1 in Chapter 3, which correlates project types with likely pollutants of concern. When you have identified the pollutants, you can use the pollutant removal effectiveness information on the fact sheets at the end of this chapter to find control measures that would be most appropriate for treating those pollutants.

- What **amount of stormwater runoff** will need to be treated?
  The amount of stormwater runoff that needs to be treated for a site is defined by the local permitting agencies as the water quality volume (WQV) or water quality flow (WQF), described later in this chapter. In the Sacramento region, treating this amount of runoff is presumed to remove pollutants in urban runoff to the maximum extent practicable. Using LID measures will decrease the amount of runoff needing to be treated, which in turn will likely reduce costs and space requirements for the treatment control measures.

  Appendix D will lead you through the process of credits for "effective area managed" and then determining the remaining water quality volume or flow remaining to be treated.

- **How much space is available** on the project site for a stormwater quality treatment facility?
  Refer to the fact sheets at the end of this chapter to determine the space requirements for the various types of stormwater quality control measures. Consider that vegetated facilities can typically be integrated into the landscaping already required by the permitting agency for the site. Also, although underground facilities do not take up as much space, they can be more costly to construct and maintain.

- What are the **site conditions and associated limitations** on use of stormwater quality treatment control measures for this property?
  As described in the fact sheets at the end of this chapter, the selection and design of stormwater quality control measures is largely dependent on soils, topography/slope and other natural site features.

- What **level of maintenance** will the property owner be capable and willing to conduct as long as he/she owns the property?
  Consider the short and long-term maintenance needs of the treatment control measures (as described on the fact sheets at the end of this chapter) and whether or not the property owner can agree to those requirements. The permitting agencies in the Sacramento Region require that the property owner sign a maintenance agreement or obtain a permit to ensure long-term maintenance. Such maintenance agreements require reconstruction or replacement of the feature when it fails to function properly. For informational purposes, projected lifespan information is provided for the various control measures in Appendix B.

Designing Treatment Control Measures

The treatment control measures presented in this manual are sized and configured using either a volume-based or flow-based design approach, as explained in more detail in Appendix E:

Volume-Based Design (WQV)

Treatment control measures that depend on storage and gravitational settling for pollutant removal (e.g. detention basins, vaults) are designed for the water quality volume. Volume-based design criteria call for the capture and infiltration or treatment the runoff from the project site from the 85th percentile runoff event.

Flow-Based Design (WQF)

Flow-through treatment control measures that do not require long detention times for pollutant removal (e.g. vegetated swales) are designed for the water quality flow. Flow-based design criteria call for the capture and treatment of the flow produced by rain events of a specified magnitude, usually the 85th percentile hourly rainfall intensity multiplied by a factor of 2. This equate to an intensity of 0.20 inches/hour for projects in the City of Folsom and 0.18 inches/hour for projects located in other cities in Sacramento County and unincorporated Sacramento County.

Appendix E includes instructions for calculating the expected water quality volume (WQV) or water quality flow (WQF) for your project. The procedure requires you to determine the amount of impervious surfaces that will contribute runoff to the treatment control measures. In addition, site run-on that is not diverted around the site and combines with other runoff will need to be treated.

Proprietary Treatment Control Measures

Proprietary stormwater quality treatment measures are manufactured devices intended to capture and treat post-construction site runoff to remove pollutants. The permitting agencies in Sacramento County allow certain proprietary devices for treatment of runoff, under certain conditions, as described below.

Agencies in Sacramento: Since the late 1990's, the Sacramento Stormwater Quality Partnership has been conducting a study to investigate and verify the field performance of proprietary stormwater quality devices. In November 1999, the Partnership published a report that describes the protocol that must be followed in order for a particular device to be accepted for use in the Sacramento area. The protocol is based on a comparison of the performance of the proprietary device to that of widely- accepted public domain measures, such as vegetated swales. Manufacturers are invited to submit data that can be reviewed for conformance with the protocol. In addition to devices accepted using the Sacramento area protocol, the Partnership will consider technologies with the Washington State Department of Ecology's General Use Level Designation for Basic (TSS) Treatment on a case by case basis.

For an updated list of accepted devices and more details on the Sacramento proprietary study, see *www.beriverfriendly.net* (new development). In select cases, the local permitting agency may allow the use of other proprietary treatment measures as a "pilot study." In such cases, the property owner and/or manufacturer will be required to fund and complete a monitoring study to verify the device's performance. Since approval is not guaranteed, site designers proposing to use an alternative technique should coordinate with the permitting agency early in the site design process.

Site designers proposing to use accepted proprietary device(s) on their project need to include the following items in the submittal and on the (to scale) improvement plans:

- Plan view of device & appurtenances on the civil site plans
- Section view of device & appurtenances in reference to other utilities
- Detail drawings of device & appurtenances
- Specifications and installation notes.

Operation and Maintenance

The property owner is ultimately responsible for the operation, maintenance, and long-term continued performance of the hydromodification management, low impact development, and treatment control measure(s). Failure to properly operate and maintain the measures could result in no mitigation of stormwater impacts. Inadequate stormwater management is a violation of the local permitting agencies' municipal codes, as well as state and federal water quality regulations.

For projects using these control measures, verification of long-term maintenance provisions is required. This is mandated by the agencies' State-issued stormwater permits. The local permitting agencies in the Sacramento area require execution of a maintenance agreement, covenant or permit with the property owner. Typically, maintenance agreements and covenants are recorded with the deed for the property and follow property ownership. Such maintenance agreements require reconstruction or replacement of the feature when it fails to function properly. For informational purposes, Appendix B presents projected lifespan information for the various control measures.

Check with the local permitting agency about the maintenance submittal requirements and timing for execution of the agreement. See Appendix B for additional information and a sample maintenance agreement.

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Fact Sheets

This chapter includes fact sheets for all of the hydromodification management, low impact development, and treatment control measures listed in Table 3-3. Each fact sheet describes the purpose of the control measure, applicability, design requirements, and any operation and maintenance issues that may affect its design.

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Alternative Driveways

Description

Photo source: City of Folsom

Alternative driveways are designed to reduce the volume and rate of runoff and increase localized infiltration. These driveways exhibit one or more of these features: permeable surfaces, drain to landscaping, provide access to more than one house, and/or limit concrete use to narrow driving strips. It is recommended that you read the Porous Pavement and Disconnected Pavement fact sheets before using this one, since this technique employs principles from those fact sheets.

Siting Considerations

- Land use: Single-family residential development and redevelopment.
- Driveway slope: 10% maximum.
- Soils: Appropriate for all soil types but porous pavement requires an underdrain for soil types C and D.

Vector Considerations

- Potential for mosquitoes in vegetated features of alternative driveways due to standing water (at or near the surface) will be greatly reduced or eliminated if the driveway is properly designed, constructed, and operated to maintain its infiltration capacity.

Advantages

- Replaces regular pavement, so does not require additional land on the site.
- Can reduce size of downstream stormwater quality treatment measures by reducing the volume required to treat.
- Sometimes more attractive than traditional pavement.
- Potential LEED Credits
    - Credit 6.1 – Stormwater Design – Quantity Control

Limitations

- If driveway includes a public right-of-way or utility easement, contact local permitting agency to determine if alternative driveway design is acceptable and if so, any special requirements.
- See Siting Considerations.

Maintenance Recommendations

- Driveways with disconnected pavement require no additional maintenance over traditional driveways, but accumulations of sediment adjacent to driveway need to be removed periodically to keep surface water flowing evenly into the adjacent porous area.
- Refer to Porous Pavement fact sheet for maintenance requirements related to pavers, modular block and other porous materials.

How Do Alternative Driveways Work?

Driveways can comprise a significant portion of the total transportation network in a conventional suburban residential development. Alternative driveways reduce a development's total directly connected impervious surface by using permeable materials, reducing the amount of pavement, paving area and/or by draining to landscaped areas. This, in turn, reduces the runoff and may provide incidental pollutant removal. Alternative driveway designs are easily adopted into most residential construction projects, can improve the aesthetics, and, if incorporated early in project design, may reduce the size and associated cost of treatment controls.

Planning and Siting Considerations

- Consult a geotechnical engineer as to the suitability of each type of Alternative Driveway for specific load requirements.
- For Alternative Driveways using porous pavement, see planning and siting considerations on the Porous Pavement Fact Sheet elsewhere in this chapter
- Specific design considerations apply to each type of Alternative Driveway (see variations discussed below).

Variations

Four types of Alternative Driveways are discussed in this fact sheet: 1) pervious driveway, 2) "Hollywood" driveway, 3) disconnected driveway, and 4) shared driveway. Alternative designs may be acceptable on a case-by-case basis; check with the local permitting agency for verification before proceeding with design.

Pervious Driveway.
Photo: Carrera Construction

Pervious Driveway

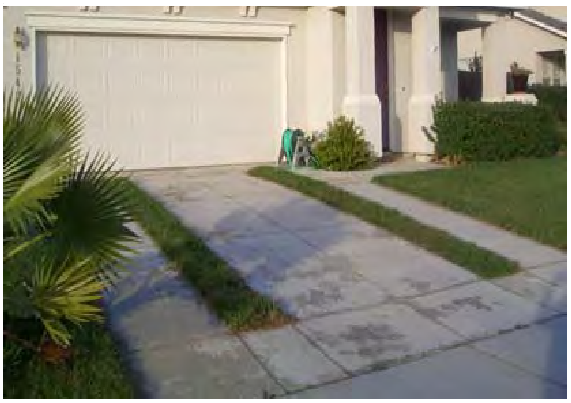
Pervious driveways allow water to pass through the driveway surface via void spaces in the material and/or between units. Various types of pavement may be used to make the driveway surface permeable: pervious concrete or asphalt, modular block, cobblestone block or porous gravel (see Porous Pavement Fact Sheet elsewhere in this chapter for details). Design Criteria: See Table AD-1 for design criteria. Also, refer to the Porous Pavement fact Sheet.

"Hollywood" Driveway

A Hollywood Driveway, where only the wheel tracks are paved with concrete, is a viable, inexpensive design if the driveway is straight. The center strip can be left open to be planted with grass or groundcover, or filled with a permeable material such as gravel, modular block pavement, or pervious pavement if water conservation/ irrigation is a concern.

Design Criteria: See Table AD-1 for design criteria.

Other names: ribbon driveway, paving-under-wheels driveway



"Hollywood" Driveway in Natomas area, Sacramento. Photo: ECORP Consulting

"Hollywood" Driveway in Southland Park area, Sacramento. Photo: ECORP Consulting

Disconnected Driveway

Conventional driveways are considered "directly connected" to the storm drain system because stormwater runoff from the driveway enters the storm drain system directly. Driveways disconnected from the storm drain system reduce runoff and provide incidental pollutant removal by passing runoff over an adjacent vegetated or otherwise porous surface that intercepts, infiltrates and filters the runoff. There are various design approaches: 1) slope the driveway to drain onto adjacent turf or groundcover, 2) install a slotted drain near the lower third of the driveway and discharge the drain to a landscaped area (if this is not considered a safety/tripping hazard), and 3) install grooves in the driveway pavement to help direct flow to the vegetated area. Some agencies may also allow an under sidewalk drain which connects the depressed landscape area adjacent to the driveway with the gutter/storm drain.

Design Criteria: See Table AD-1 for design criteria.

Shared Driveway

Driveways can be configured to provide access to two or more garages. Consult the local permitting agency to determine if this practice will be allowed for your project.

Design Criteria

Design criteria for alternative driveways are listed in Table AD-1.

Table AD-1. Alternative Driveways Design Criteria

Also see Appendix D for information on calculating runoff reduction credits.

Variation/ Design Parameter	Requirement
Pervious Driveway	
General	▪ See Porous Pavement Fact Sheet for specifications. ▪ Surface sloped to provide positive drainage away from building foundations.
Subgrade drain	▪ Required in C and D soils. Use a gravel trench or perforated pipe embedded in a 8-12-inch layer of crushed rock. Connect to another LID element or the storm drain system (not sanitary sewer).
Hollywood Driveway	
General	▪ Tracks 2.5 to 3.5 feet wide, separated by a porous center strip at least three feet wide. ▪ Slope driveway toward center strip to promote drainage or install grooves to help direct flow into porous strip. ▪ Porous center strip groundcover, grass, or drain rock.
Porous center strip	▪ Groundcover, grass, drain rock, or porous pavement.
Irrigation	▪ Consider irrigation for center strip vegetation.
Disconnected Driveway	
General	▪ Design the driveway cross slope greater than the longitudinal slope so that runoff is directed across landscape. ▪ Size the adjacent landscape area to accommodate flow from the driveway. Water from driveway surface should flow an average of 8 feet over landscaping prior to reaching the right of way. ▪ If a slotted drain is used, install it perpendicular to the flow path to direct flow into vegetation, and provide removable grates for cleaning. ▪ If runoff flows across sidewalk, it must sheet flow and spread at least two feet wide to avoid concentrated flows.
Edge of driveway	▪ Must be approximately 3 inches above the vegetated area.
Shared Driveway	
General	▪ Configurations vary, consult local permitting agency.

Construction Considerations

- Disconnected driveway: Properly slope the grade of the driveway and adjacent porous area to allow for even sheet flow over the porous material. Level of turf should be below top of pavement.

- Porous Pavement: See Porous Pavement BMP Fact Sheet Construction Considerations, elsewhere in this chapter.

Long-term Maintenance Recommendations

Refer to the inspection and maintenance recommendations in the Porous Pavement Fact Sheet.

Resources for More Information

- California Nevada Cement Promotion Council (CNCPC), www.cnccp.org
- National Ready Mixed Concrete Association (NRMCA), www.nrmca.org
- Pacific Southwest Concrete Alliance, www.concreteresources.net
- Asphalt Pavement Association, www.apaca.org
- National Precast Concrete Association, www.precast.org
- Portland Cement Association, www.portcement.org
- National Asphalt Pavement Association, www.hotmix.org
- Asphalt Emulsion Manufacturers Association, www.aema.org
- Western States Chapter of the American Concrete Pavement Association, www.wscacpa.com
- Association of Asphalt Paving Technologists, www.asphalttechnology.org
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Bioretention Planter

Description

A bioretention planter is a low-lying vegetated planter that receives runoff from roof drains or adjoining paved areas. A shallow surcharge zone above the vegetated surface temporarily stores stormwater (the water quality volume, WQV). The accumulated runoff gradually infiltrates into an underlying sand/peat bed and then into a gravel layer. If the planter is a flowthrough bioretention planter, it has an impermeable bottom liner and an underdrain pipe to collect the treated water and discharge it to the municipal storm drain. Planters without an impermeable bottom liner (infiltration planters) may also require an underdrain when the underlying soils are less permeable than the planter's sand/peat layer.

Photo Credit: City of Portland

Siting Considerations

- Contributing Drainage area: Typically ≤ 1 acre.
- Depth to Groundwater: > 10 ft from planter soil surface (only applies to infiltration planter without underdrain).
- Slope: Relatively flat.
- Planters can be used with any soil type, although depending on the recommendations of the project geotechnical engineer, a liner and/or underdrain may be needed.
- Setback: Flow-through planter is required if within 10 ft. of building foundation unless otherwise specified by local permitting agency.

Pollutant Removal Effectiveness	
Sediment	High
Nutrients	Low
Trash	Medium
Metals	High
Bacteria	Medium
Oil and Grease	High
Organics	High

The following is a partial list of the most common target pollutants for the Sacramento area: copper, lead, mercury, pathogens, diazinon, and chlorpyrifos. For more complete information refer to:

http://www.waterboards.ca.gov/water_issues/programs/tmdl/integrated2010.shtml

Source: CASQA California Stormwater BMP Handbook, January 2003

Vector Considerations

- Potential for mosquitoes due to standing water will be greatly reduced or eliminated if the planter is properly designed, constructed, and maintained.

Advantages

- Relatively inexpensive when integrated into site landscaping.
- Suitable for parking lots and sites with limited space.

- Reduces peak flows during small storm events.
- Attractive and relatively easy to maintain.
- Potential LEED Credits
    - Credit 6.1 – Stormwater Design – Quantity Control
    - Credit 6.2 – Stormwater Design – Quality Control

Limitations

- Not appropriate for industrial sites or locations where spills may occur, unless infiltration is prevented.
- Not suitable for steeply sloping areas.

General Maintenance Recommendations (Low to Moderate)

- Periodically remove debris and sediment from planter.
- Repair/replace vegetation as necessary to maintain full cover.
- See Table BP-2 for additional vegetation maintenance recommendation.

How Does a Bioretention Planter Work?

A bioretention planter is designed to receive runoff from downspouts, piped inlets or sheet flow from adjoining paved areas. A shallow surcharge zone above the vegetated surface temporarily stores runoff (the water quality volume or WQV). The runoff gradually infiltrates through the root zone of the vegetation and into the underlying sand/peat bed where it fills the pore spaces. A variety of natural mechanisms remove pollutants from the runoff as it infiltrates through the root zone and is detained in the sand/peat bed before reaching a base layer of gravel.

Kindred Hospital, City of Folsom

If infiltration to the underlying soil is not possible or desired, a flow-through bioretention planter with an impermeable bottom liner and underdrain should be used. The underdrain gradually dewaters the sand/peat bed over the drawdown period and discharges the runoff to the downstream storm drain system. If an infiltration planter is used, there is no impermeable bottom liner, and runoff percolates into the ground. An underdrain may still be needed if the permeability of the underlying soils is lower than the sand/peat layer (based on the recommendations of the project geotechnical engineer), but at least a portion of the treated runoff will infiltrate into the underlying soil. See Figures BP-1 and BP-2 for typical bioretention planter configurations.

Other Names: Stormwater Planter, Infiltration Planter, Flow-through Planter, Biofilter, Porous Landscape Detention, Rain Garden

Planning and Siting Considerations

> ***Early Design is Critical!***
> *Bioretention planters must be located on the site plan at the earliest possible design phase when laying out the building and parking footprints and before the site grading plan is prepared.*

- For infiltration type planters, consult a geotechnical engineer about site suitability.
- Select location where site topography is relatively flat and allows runoff drainage to the bioretention planter.
- Integrate bioretention planters into other landscape areas when possible.
- Bioretention planters may be located within landscape areas as "rain gardens" and may have a non-rectangular footprint to fit the site landscape design.
- In expansive (C, D) soils, locate bioretention planters far enough from structures to avoid damage to foundations (as determined by a structural or geotechnical engineer). 10 feet is given as a rule-of-thumb on the first page of this fact sheet. Alternatively, use a flow-through bioretention planter.

Dixieanne Ave Bioretention Planter, City of Sacramento

2500 River Plaza Drive, City of Sacramento

Design Criteria

Design criteria for bioretention planters are listed in Table BP-1. Use the Design Data Summary Sheet provided at the end of this fact sheet (Table BP-3) to record design information for the permitting agency's review.

Details on bioretention specifications shall be included on improvement plans to aide in proper construction and implementation of the bioretention planter.

Table BP-1. Bioretention Planter Design Criteria

Design Parameter	Criteria	Notes
Contributing drainage area	$\leq$ 1 acre	Ideally suited for small areas such as parking lot islands, perimeter building planters, street medians, roadside swale features, and site entrance or buffer features. Can be implemented on a larger scale, provided the WQV and average depth requirements are met.
Design volume	WQV or as dictated greater by SAHM modeling (for projects with hydromodification requirement)	See Appendix E in this Design Manual
Side slopes / sidewalls	Vertical sidewalls or side slopes of 3:1 or shallower	Bioretention planters typically have vertical sidewalls. Larger bioretention planters should have side slopes of 3:1 or shallower.
Design drawdown time	12 hrs	Period of time over which WQV drains from planter.
Design average surcharge depth (d_s)	6-12 in	
Containment curb (if applicable)	Height > 6 in	Design to deter skateboarding and satisfy ADA requirements.
Inlet curb cuts (if applicable)	$\geq$ 12 in wide	To prevent clogging and promote flow spreading. Pavement should be slightly higher than swale. Include energy dissipaters.
Top layer[1]	6 in (minimum)	Sandy loam topsoil. Deeper layer recommended for better vegetation establishment.
Bioretention soil media layer[1]	18 in (minimum)	Design mix to achieve approximately 5 in/hr infiltration rate and provide 12-hour drawdown; check with permitting agency for verification. See more detailed bioretention soil media specifications in Appendix I of this Design Manual.
Gravel layer	9 in	AASHTO #8 Coarse Aggregate
Filter fabric		Per project geotechnical engineer.
Minimum width	30 in	
Underdrain (as required)	3-4 inch perforated pipe	Typically for all flow-through planters, planters within 10 ft. of a building foundation, and infiltration planters where underlying soils have lower permeability than the planter's sand/peat media layer
Overflow device	Varies	Connect to storm drain system. See Figures BP-1 and BP-2 for recommended designs. Alternative designs may be allowed; check with permitting agency.

[1] See Construction Considerations below for recommendations regarding compaction

Design Parameter	Criteria	Notes
Waterproofing membrane		Per recommendations from project geotechnical engineer.
Vegetation		Appropriate for well-drained soil but will also withstand being inundated for periods of time.

Design Procedure

Step 1a – Calculate Water Quality Volume (WQV)

Using the calculations given in Appendix E, determine the contributing area and stormwater quality design volume, WQV, based on a 12-hour drawdown period.

Step 1b – SAHM Modeling for Hydromodification Management (If applicable)

Upsize the bioretention planter volume as necessary based upon modeling results if implementing as a hydromodification control. Maintain depth so as to adhere with 12–hour maximum drawdown for WQV.

Step 2 – Design average surcharge depth (ds)

Select the average WQV depth between six (6) and twelve (12) inches. Average depth is defined as water volume divided by the water surface area of the planter. Use a maximum depth of six (6) inches if planters are located in the public right of way.

Step 3 – Calculate planter surface area (A_S)

The design surface area of the planter is determined from the design WQV and depth (d_s) as follows:

$$\mathbf{A_S = WQV/d_s}$$ **(see Figures BP-1 and BP-2)**

Step 4 – Design base courses

Bottom Gravel layer – Provide a 9-inch gravel layer (AASHTO #8 Coarse Aggregate)

Bioretention Soil Media layer – Provide an 18-inch (minimum) bioretention soil media layer over the gravel layer as shown in Figures BP-1 and BP-2. Place filter fabric between bioretention soil media and gravel layer.

Top layer – Provide a sandy loam top layer above the bioretention soil media layer. This layer should be a minimum of six (6) inches deep, but a deeper layer is recommended to promote healthy vegetation.

Step 5 – Select subbase liner

If expansive soils are a concern, chemical or petroleum products are handled or stored within the contributing drainage area, or infiltration is not desired for any reason, use a flow-through bioretention planter with an impermeable liner (see Figure BP-2). Otherwise, use an infiltration planter and install a non-woven geotextile membrane below the gravel layer to allow infiltration.

Step 6 – Provide underdrain if needed

Provide a perforated underdrain pipe if the planter has an impermeable bottom liner or as required by the project geotechnical engineer. Size the underdrain to ensure a 12-hour drawdown and connect it to the downstream storm drain system. Place underdrain at the top of the gravel layer as shown in Figures BP-1 and BP-2.

Historical District, The City of Folsom

Step 7 – Select vegetation

Select vegetation that:

- Is suited to well-drained soil but will withstand being inundated for periods of time;
- Will be dense and strong enough to stay upright, even in flowing water;
- Considers root systems and canopy (for trees, if any);
- Has minimum need for fertilizers;
- Is not prone to pests and is consistent with integrated pest management practices which promote less use of chemical pesticides; and
- Is consistent with local water conservation requirements.

The Alameda Countywide C.3 Stormwater Technical Guidance handbook contains a detailed plant list for consideration, although vegetation selection must be approved by the permitting agency. Potential options include: Juncus balitcus (Baltic rush), Eleocharis macrostachya (creeping spikerush), Hordeum brachyantherum (meadow barley), and Muhlenbergia rigens (deergrass), although other vegetation may also be appropriate. See Appendix J for additional plant selection guidance. Avoid the use of bark or similar buoyant material that will tend to float when the vegetated area is inundated. Check with the local agency's Ordinance if the planter will be used to satisfy landscaping requirements.

https://cleanwaterprogram.org/index.php/resources/recources/development.html

Step 8 – Design overflow device

Provide an overflow device with an inlet to the storm drain system. Set the overflow inlet elevation above the WQV surcharge water level. A drop inlet or an overflow standpipe with an inverted opening are appropriate overflow devices (see Figures BP-1 and BP-2).

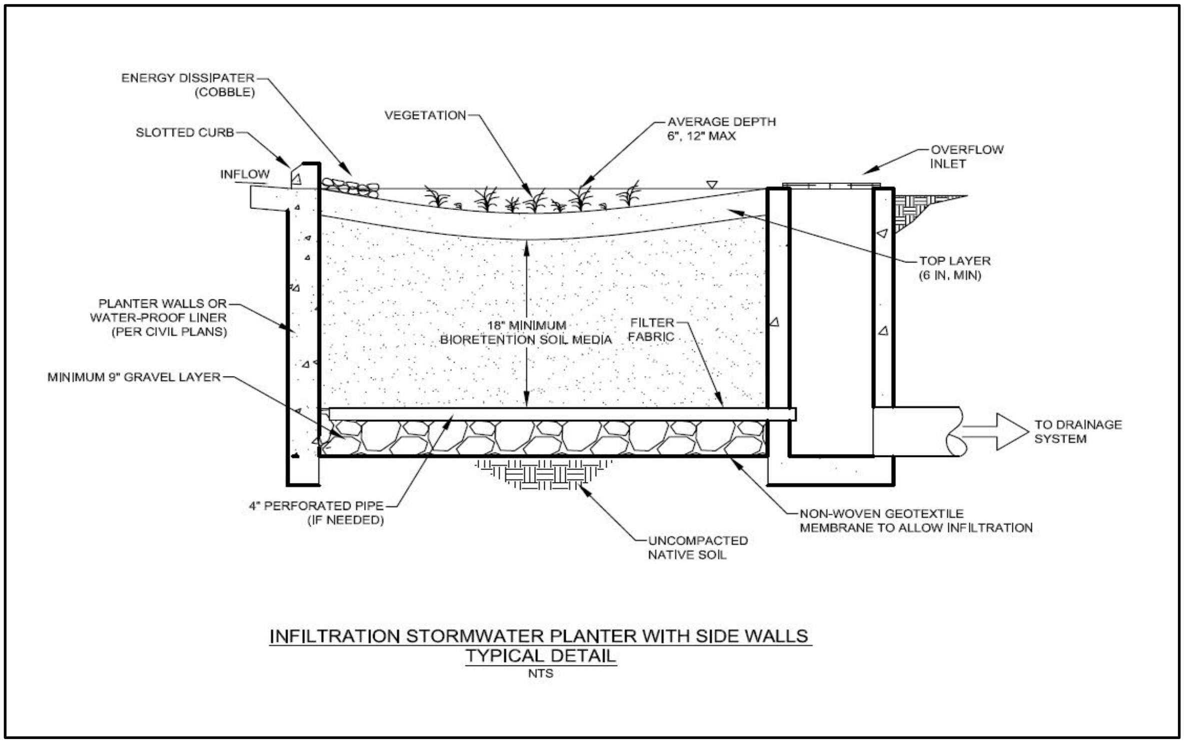

Figure BP-1.

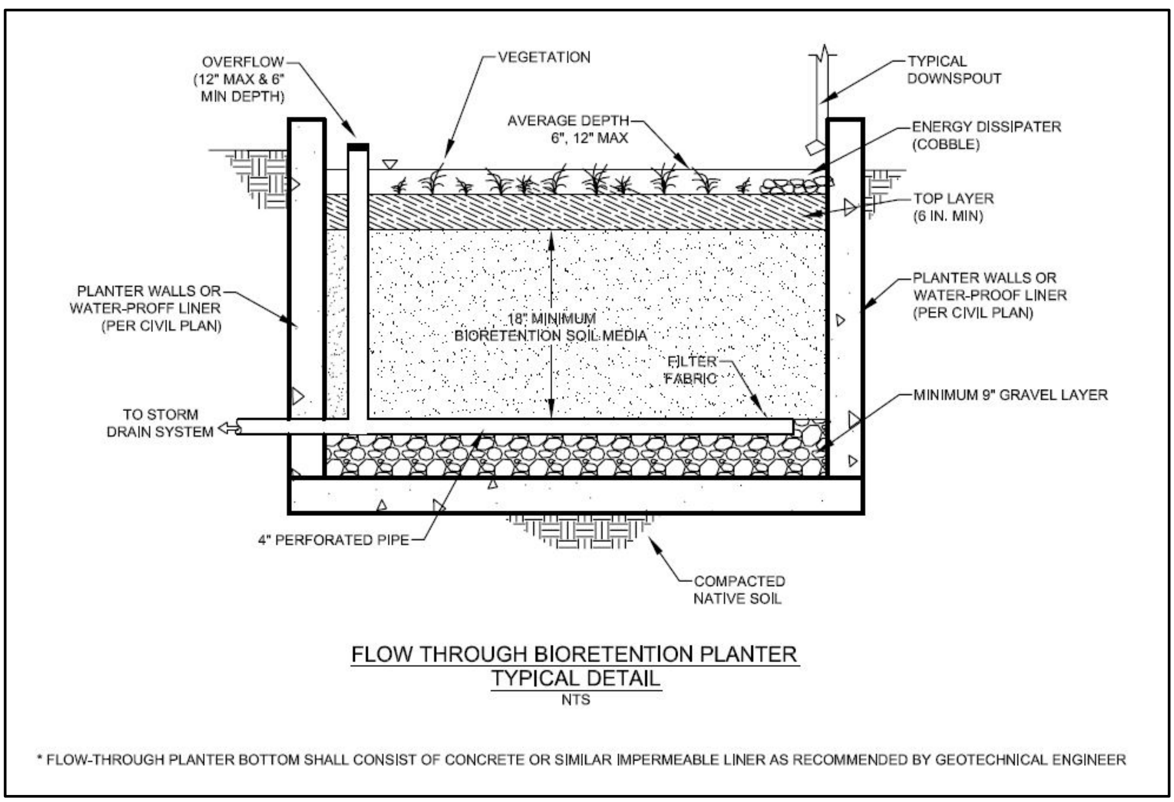

Figure BP-2.

(other media mix and overflow design options may be allowed; check with permitting agency for verification)

Construction Considerations

- Divert runoff (other than necessary irrigation) during the period of vegetation establishment. Where runoff diversion is not possible, cover graded, seeded, and/or planted areas with suitable erosion control materials.
- For planters that are flush with the surrounding landscape, install sediment controls (e.g., staked straw wattles) around the planter to prevent high sediment loads from entering the planter during construction activities.
- Repair, seed, or re-plant damaged areas immediately.
- Place top layer and bioretention soil media layer each in 12" max lifts. Allow soil to settle naturally and boot compact after the final lift has been placed to achieve 80% to 85% relative compaction. No mechanical equipment shall be used to compact planters including vibratory plates.

Long-term Maintenance

The local permitting agencies in the Sacramento area will require execution of a maintenance agreement or permit with the property owner for projects including a bioretention planter. Check with the local permitting agency about the timing for execution of the agreement. Such agreements will typically include requirements such as those outlined in Table BP-2. The property owner or his/her designee will be responsible for compliance. See Appendix B for additional information about maintenance requirements and sample agreement language.

Table BP-2. Inspection and Maintenance Recommendations for Bioretention Planters

Activity	Schedule
Trim vegetation (as applicable) and remove weeds to limit unwanted vegetation.	As needed
Remove litter and debris from landscape area.	As needed
Use integrated pest management (IPM) techniques to reduce use of chemical pesticides and herbicides.	Monitor for pests regularly and take other action as needed.
Inspect the planter to determine if runoff is infiltrating properly (i.e., perform a drawdown test).	At least twice per year during storm events. Additional inspections after periods of heavy runoff are desirable.
If infiltration is significantly reduced, remove and replace top layer and sand/peat layer.	May be required every 5 to 10 years or more frequently, depending on sediment loads.
Reconstruct or replace the control measure when it is no longer functioning properly.	See projected lifespan in Appendix B for informational purposes.
Prune trees and shrubs	Every 1-2 years

Table BP-3. Design Data Summary Sheet for Bioretention Planter

Designer: ______________________ **Date:** __________

Company: ______________________

Project: ______________________

Location: ______________________

1a. Determine Design Water Quality Volume

a. Contributing drainage area	Area =		ft^2
b. Water Quality Volume	WQV =		ft^3

1b. Adjust Volume Up for Hydromodification Management
(If Applicable) Based upon SAHM Modeling

a. Water Quality Volume based on SAHM modeling	V =		ft^3
b. SAHM Model Demonstrates Compliance with Flow Duration Standards	(Yes or No)		

2. Design average surcharge depth (d_s)

d_s = 6-12 inches (0.5-1 foot) d_s = ft

3. Design Planter Surface Area (A_s)

$A_s = WQV/d_s$ A_s = ft^2

4. Base Course Layers

a. Top Layer (6 in. minimum)		in
b. Bioretention Soil Media (18 in. minimum, See App I)		in
c. Gravel Layer (9 in. minimum)		in

5. Planter Type (check type used)

☐ Infiltration without underdrain ☐ Infiltration with underdrain

☐ Flow-through with impermeable liner

6. Vegetation (describe) ______________________

7. Overflow Device (check type used or describe "Other")

☐ Drop inlet ☐ Standpipe

☐ Other ______________________

Notes: ______________________

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Compost-Amended Soil

Description

Photo source: RBF Consulting

The compost-amended soil BMP is an option that has a smaller footprint than impervious surface disconnection. This BMP option is less complex than both planter boxes and engineered infiltration BMPs. Compost refers to decomposed organic matter. A wide variety of compost products are available in bagged and bulk assortments. These may be a combination of plant-based compost, manure-based compost, bio-solids, and other agriculture by-products (such as chicken feathers). Compost made solely from plant-based products (such as wood chips and yard waste) are low in salts and preferred over manure-based composts, which are higher in salts. However, plant-based compost is generally more expensive (refer to the Limitations section below for more information on high-salt compost).

Siting Considerations

- Compost-amended soil is a cost-efficient alternative that can be used in residential or commercial settings seeking a spatially more efficient alternative to disconnection across permeable areas of unmodified "native" soils.
- Site compost-amended soil areas similar to other typical infiltration BMPs.

Vector Considerations

- The potential for ponding water is limited based upon inherently shallow design depth. Although possible, the potential for vector breeding is generally low in a scenario involving a malfunctioning system.

Advantages

- Compost-amended soil areas area a particularly strategic approach for sites with hydrologic soil groups "C" and "D".
- Useful for street projects, roadways, and parking lot areas (with concurrence from the project geotechnical engineer).

- Potential LEED Credits
    - Credit 6.1 – Stormwater Design – Quantity Control
    - Credit 6.2 – Stormwater Design – Quality Control

Limitations

- Compost-amended soil areas are not intended to incorporate sub-drain systems. As such they are not suitable for use in situations where infiltrated water, or water with excessive ponding poses an elevated risk of adverse consequence.
    - Not allowable for auto repair or retail gasoline sites.
    - May not be suitable for hillside development on slopes greater than 25%, and highly discouraged on slopes greater than 3:1 (only allowable with concurrence from the project geotechnical engineer).
- Compost-amended soil is not allowable in areas where the water table or bedrock is less and 10 feet from the surface.
- Most plants do not tolerate soils that are high in salts. Many forms of compost made with manure and bio-solids can be high in salts. Avoid using these amendments in soils that are naturally or have become high in salts (above 3 mmhos/cm[1]) and when plant establishment is desired. In such cases, choose a plant-based compost for soil amendment.
- Caution should be used in implementing compost-amended soils in watersheds impaired for nutrients or part of a nutrient TMDL.

General Maintenance

- Routine inspection of compost-amended soils should evaluate factors that may decrease the soil's infiltration capacity, aeration, organic content, or cause diseased vegetation.
- Typical post-construction concerns include areas subject to compaction, hydric or waterlogged soils, poor cover conditions, unanticipated further development, and a decrease in organic content.
- Corrective actions for amended soils include restoring infiltration capacity of the soil by extensive mechanical aeration, deep tilling, and additional amendments. Any diseased vegetation should be removed and replaced.

[1] measurement of electrical conductivity in *milliohms per centimeter*

Design Criteria

- Required surface area of amended soil is equal to 25% of the contributing impervious area.
- Required depth of amended soil can be determined from the equation below:

$$D_{BMP} = \frac{D_{DR} * R_V}{\varnothing * \frac{A_{BMP}}{A_{BMP} + A_I}}$$

Where D_{BMP} is the depth of the amended soil, D_{DR} is the design rainfall depth (synonymous with treatment requirement depth, P_o, see Appendix E), Ø is the amended soil porosity, R_V is the volumetric runoff coefficient of the total contributing area (see table below), A_{BMP} is the area of the amended soil, and A_I is the contributing impervious area. Soil porosity can generally be estimated at about 0.35. Other soil specific information regarding porosity and other physical characteristics can be obtained from textbooks or the NRCS Web Soil Survey. Refer to:

http://websoilsurvey.sc.egov.usda.gov/App/HomePage.htm

Percent Impervious	Volumetric Runoff Coefficient, Rv
20	0.17
40	0.28
60	0.41
80	0.60
100	0.89

- Provide suitably sized overflow and scour protection measures at the facility inlet. For projects using compost-amended soils for hydromodification management, the bypass design rate should be based upon events greater than Q10. Refer to the local agency to confirm no additional requirements for bypass capacity.
- The amended soil bed should consist of approximately 12% to 15% compost by volume.
- The amended soil bed should be covered with 3" of mulch (4"-6" layer installed will typically settle down to a 3" layer). The finished grade of the mulch layer should be constructed as a shallow depressed area (2" typically). Do not use redwood or cedar mulch.
- Inclusion of a relief drain is optional at the designer's discretion to drain the facility in the event of a failure. This is highly recommended in high density residential and commercial settings. However, use of relief drains is not permissible in watersheds impaired for nutrients or part of a nutrient TMDL.

Design Procedure

General Design

Design criteria for compost-amended soil are listed in Table CAS-1. Use the Design Data Summary Sheet provided at the end of this fact sheet (Table CAS-3) to record design information for the permitting agency's review.

Table CAS-1 Compost-Amended Soil Design Criteria

Design Parameter	Criteria	Notes
Compost-amended soil area to contributing impervious surface area ratio	0.25 minimum	
Design volume	WQV or as dictated greater by SAHM modeling (for projects with hydromodification requirement)	See Appendix E in this Design Manual for WQV. Volume provided should consider a 2" graded surface depression.
Design Depth	$D_{BMP} = \dfrac{D_{DR} * R_V}{\varnothing * \dfrac{A_{BMP}}{A_{BMP} + A_I}}$	Increase depth (if necessary)
Design drawdown time	48 hrs.	Period of time over which WQV drains from compost-amended soil area.
Amended soil compost content	12% to 15% by volume	
Mulch layer	3" minimum	Not redwood or cedar bark.
Relief drain (optional)	3 inch perforated pipe (minimum)	Not permissible in watersheds with nutrient impairment or TMDL.
Overflow device	WQR, or Q10 (for projects complying with hydromodification standards)	
Waterproofing membrane	Not permissible	

Step 1 – Calculate amended compost surface area (A_S)

The design surface area is to be a minimum of 0.25*contributing impervious area.

Step 2a – Calculate Water Quality Volume (WQV)

Using the calculations given in Appendix E, determine the contributing area and stormwater quality design volume, WQV, based on a 48-hour drawdown period.

Step 2b – Adjust Design Volume (If necessary for hydromodification compliance)

For projects using compost-amended soil area to comply with hydromodification compliance provide additional area or compost-amended depth as necessary such that flow duration standards are satisfied based upon SAHM modeling.

Step 2c – Adjust Design Depth (if necessary)

Adjust/increase depth if necessary to comply with the following equation described in previous sections within this fact sheet:

$$D_{BMP} = \frac{D_{DR} * R_V}{\varnothing * \dfrac{A_{BMP}}{A_{BMP} + A_I}}$$

Step 3 – Design relief drain (optional)

Provide a 3" diameter perforated pipe and relief drain if desired by owner. Increase size and number of drains if necessary to accommodate actual size of compost-amended soil area. Not for use in nutrient impaired watersheds, or watersheds with a nutrient TMDL.

Step 4 – Design overflow device

Size inflowing curb cuts or overflow risers based upon the water quality flow rate for the 85th percentile storm. Projects using compost-amended soil to comply with hydromodification management standards should size overflows for at least Q10, or as dictated greater by local agency standards.

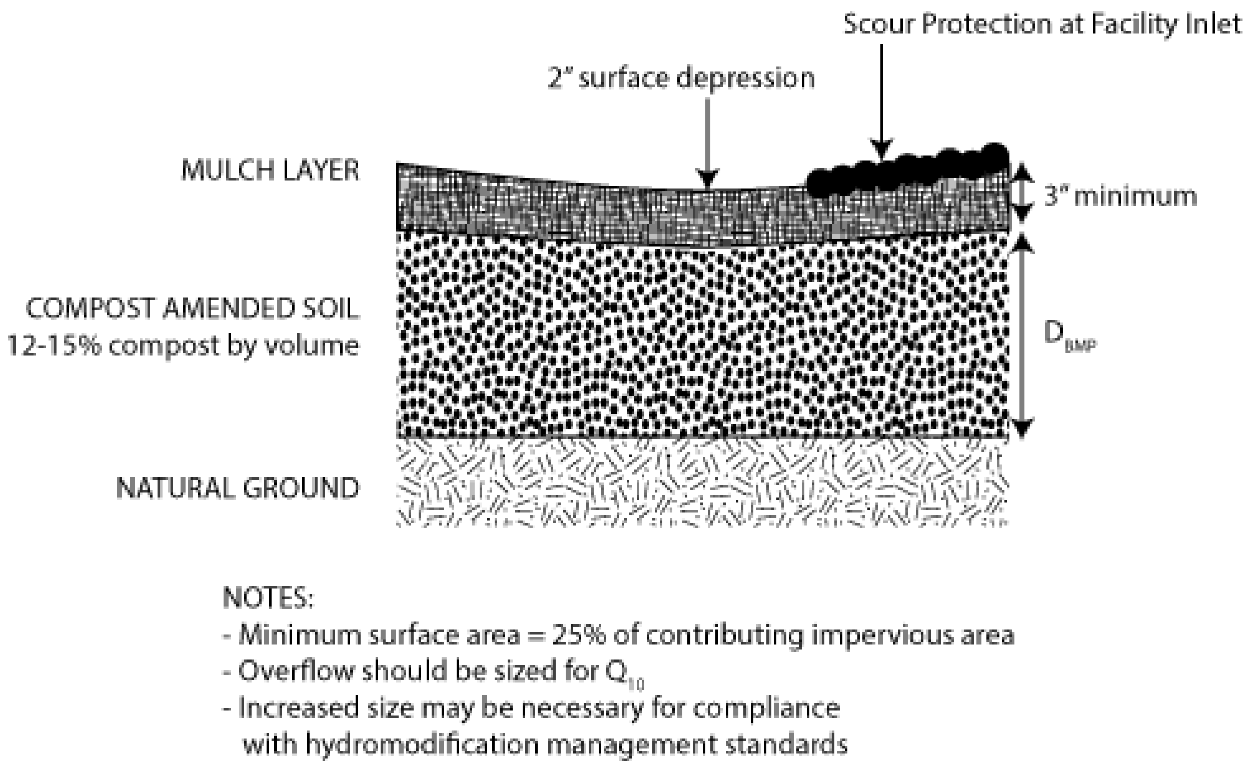

Figure CAS-1 Compost-Amended Soil Section

Construction Considerations

- Cultivate or hand-turn the compost matter thoroughly into the soil, while taking care not to encapsulate compost in clay or other native soils.

Long term Maintenance

The local permitting agencies in the Sacramento area will require execution of a maintenance agreement or permit with the property owner for projects including a compost-amended soil area. Check with the local permitting agency about the timing for execution of the agreement. Such agreements will typically include requirements such as those outlined in Table CAS-2. The property owner or his/her designee will be responsible for compliance. See Appendix B for additional information about maintenance requirements and sample agreement language.

Table CAS-2 Inspection and Maintenance Recommendations for Compost-Amended Soils

Activity	Schedule
Trim vegetation (as applicable) and remove weeds to limit unwanted vegetation.	As needed
Add/replace mulch	As needed, typically every 1-2 years
Remove litter and debris from compost-amended soil area.	As needed
Use integrated pest management (IPM) techniques to reduce use of chemical pesticides and herbicides.	Monitor for pests regularly and take other action as needed.
Inspect the compost-amended soil area to determine if runoff is infiltrating properly (within 48 hrs).	At least twice per year during storm events. Additional inspections after periods of heavy runoff are desirable.
If infiltration does not meet the time requirement, perform mechanical aeration, deep tilling, and use of additional amendments. If that is not effective, remove and replace compost-amended soil in its entirety. Any diseased vegetation should be removed and replaced	May be required every 5 to 10 years or more frequently, depending on sediment loads.

References Used to Develop This Fact Sheet

- Low Impact Development Center, *Fairfax County – LID BMP Fact Sheet – Soil Amendments*, February 28, 2005. http://www.lowimpactdevelopment.org/ffxcty/5-1_soilamendments_draft.pdf
- Colorado State University Extension, *Choosing a Soil Amendment*, Fact Sheet No. 7.235, June 2000 (revised February 2013). http://www.ext.colostate.edu/pubs/garden/07235.pdf
- Colorado State University Extension, *Soil Amendments*, CMG GardenNotes #241. http://www.ext.colostate.edu/mg/gardennotes/241.html.
- Low Impact Development Center, *Fairfax County – LID BMP Fact Sheet – Soil Amendments*, February 28, 2005. http://www.lowimpactdevelopment.org/ffxcty/5-1_soilamendments_draft.pdf
- Office of Water Protection, *Low Impact Development Standards Development, Stormwater Quality Design Manual Update and BMP Sizing Tool Enhancement – Task 1: Develop Low Impact Development (LID) Standards for New Development and Redevelopment Projects and Associated Work*, June 23, 2012.
- Virginia Cooperative Extension, *Best Management Practice Fact Sheet 4: Soil Restoration*, Publication 426-123. http://pubs.ext.vt.edu/BSE/BSE-24/BSE-24_pdf.pdf

Table CAS-3. Design Data Summary Sheet for Compost-Amended Soils

Designer: ____________________ **Date:** ____________

Company: ____________________

Project: ____________________

Location: ____________________

1. Design Compost-Amended Soil Surface Area (A_s)

A_s = 0.25* Contributing Impervious Area — A_s = ____ ft²

2a. Determine Design Water Quality Volume

a. Contributing drainage area — Area = ____ ft²

b. Water Quality Volume — WQV = ____ ft³

2b. Adjust Volume for Hydromodification Compliance (If Required)	PARAMETERS MODELED IN SAHM	ACTUAL DESIGN ON PLANS
Compost-Amended Soil Depth (D_{BMP} =)		
Compost-Amended Soil Porosity		N/A
Native Infiltration Applied in Sub Grade (inches per hour)		N/A
Total Storage Provided, Including 2" Surface Depression (ft³)		

SAHM Model Demonstrates Compliance with Flow Duration Standards — (Yes or No)________

2c. Double Check Design Depth (D_{BMP})

$$D_{BMP} = \frac{D_{DR} * R_V}{\varnothing * \frac{A_{BMP}}{A_{BMP} + A_I}}$$

D_{BMP} = ____ ft

3. Relief Drain (check type used)

☐ Relief Drain Provided ☐ Relief Drain Not Provided

☐ Nutrient Impairment or TMDL ☐ No Nutrient Impairment or TMDL

Description of Relief Drain (Size, Elevation, etc.)

4. Overflow Device (check type used or describe "Other")

☐ Curb Cut ☐ Standpipe

☐ Other ____________________

Notes: ____________________

Constructed Wetland Basin

Description

A constructed wetland basin is an earthen basin treatment system with a permanent pool of water that includes four zones: a forebay, an open-water zone, a wetland zone with aquatic plants, and an outlet zone. The basin contains an area above the permanent pool to retain runoff from the stormwater quality design storm (water quality volume or WQV) and slowly release excess water over a specified drawdown period. Constructed wetland basins provide a significant natural amenity to a community. The basin pictured is located near Village Homes in Davis.

West David Pond. Photo: Larry Walker Associates

Siting Considerations

- Contributing Drainage Area: typically greater than 20 acres.
- Soil Type: Most appropriate for Type C and D soils. For Type A and B soils, use an impermeable (e.g., clay) liner.
- Topography: Not appropriate on fill or steep slopes.

Pollutant Removal Effectiveness	
Sediment	High
Nutrients	Medium
Trash	High
Metals	High
Bacteria	High
Oil and Grease	High
Organics	High

The following is a partial list of the most common target pollutants for the Sacramento area: copper, lead, mercury, pathogens, diazinon, and chlorpyrifos. For more complete information refer to:

http://www.waterboards.ca.gov/water_issues/programs/tmdl/integrated2010.shtml

Source: CASQA California Stormwater BMP Handbook, January 2003

Vector Considerations

- Potential for mosquitoes exists due to permanent water pool. However, proper design of permanent pool zones, routine vegetation management, and introduction of mosquito fish will minimize the risk.

Advantages

- Reduces stormwater discharge to surface waters during most storm events.
- Reduces peak flows during small storm events.
- Can provide wildlife habitat, high aesthetic value, and passive recreational opportunities.
- Potential LEED Credits
    - Credit 6.2 – Stormwater Design – Quality Control

Limitations

- Supplemental water supply or perennial base flow is required to maintain the permanent pool.
- Public safety related to access must be considered; security fencing is generally required by most permitting agencies in urban settings.
- Will typically require five years to establish.

General Maintenance Recommendations (Moderate to High)

- Inspect basin annually in early spring.
- Periodically remove debris from inlet and outlet structures, and wetland basin itself.
- Regularly harvest vegetation and stock with mosquito fish for mosquito control.
- Remove accumulated sediment from forebay and other water zones as needed.
- Inspect seasonally for abnormal algae growth and address as needed.

How Does a Constructed Wetland Basin Work?

Permanent pools of water are located throughout the constructed wetland basin, within: the forebay (which allows settling out of larger particles); an open water zone and a wetland zone with emergent vegetation (providing desired biodiversity); and the outlet zone (from which water is discharged to the downstream storm drain system or receiving water). An area above the permanent pool is designed to retain the stormwater quality design volume (WQV). The retained water mixes with and displaces water from the permanent pool, which drains to the downstream storm drain system or receiving water over the design drawdown period (48 hours for WQV). Much of the water discharged during and following a storm event is water displaced from the permanent pool which has previously been treated by natural processes.

Constructed wetland basins should not be confused with wet detention basins (wet ponds) which are presented elsewhere in this manual. Constructed wetland basins are shallower and feature more vegetative coverage than wet detention basins.

Treatment of the runoff occurs through a variety of natural mechanisms that occur in the wetland, including sedimentation, filtration, adsorption, and biological uptake. The aquatic plants provide energy dissipation and pollutant removal by enhancing sedimentation and providing biological uptake.

Supplemental water or perennial baseflow is needed to maintain the permanent pool at all times.

Planning and Siting Considerations

- Integrate constructed wetland basins into open space, natural areas, and other planned landscaped areas when possible. Avoid placing features in open space and wetland preserves where future maintenance of the water quality facility will be restricted or prohibited.
- Provide aesthetic security fencing if required by the permitting agency.

Design Criteria

Design criteria for constructed wetland basins are listed in Table CWB-1. Use the Design Data Summary Sheet provided at the end of this fact sheet (Table CWB-4) to record design information for the permitting agency's review.

Design Procedure

Step 1a – Calculate Water Quality Volume (WQV)

Using the Appendix E in this Design Manual, determine the contributing drainage area and stormwater quality design volume (WQV) for 48-hour drawdown.

Step 1b – SAHM Modeling for Hydromodification Management (If applicable)

*Use the **Design Data Summary Sheet** (Table CWB-4) to record design information for the permitting agency's review.*

Upsize the constructed wetland basin volume as necessary based upon modeling results if implementing as a hydromodification control. Maintain depth so as to adhere with 48–hour maximum drawdown for WQV.

Step 2 – Determine Basin Minimum Volume for Permanent Pool

The volume of the permanent wetland pool (V_{pp}) shall be not less than 75% of the WQV.

$$V_{pp} \geq 0.75 \times WQV$$

Step 3 – Determine Basin Depths and Surface Areas

Distribution of the wetland area is needed to achieve desired biodiversity. Distribute component areas as indicated in Table CWB-2.

- Estimate average depth of permanent pool (D_{avg}) including all zones
- Estimate the water surface area of the permanent pool (A_{pp}) based on actual V_{pp}

$$A_{pp} = V_{pp} / D_{avg}$$

- Estimate water surface elevation of the permanent pool (WS $Elev_{pp}$) based on site elevations.

Table CWB-1. Constructed Wetland Basin Design Criteria

Design Parameter	Criteria	Notes
Design volume	WQV or as dictated greater by SAHM modeling (for projects with hydromodification requirement)	See *Standard Calculation Fact Sheet*
Maximum drawdown time for WQV	48 hours	Based on WQV
Minimum permanent pool volume	75%	Percentage of WQV
Liner	Clay	Required in areas with very permeable soils (e.g., Types A,B)
Inlet/outlet erosion control	-	Provide energy dissipaters to reduce velocity, subject to the approval of the permitting agency
Forebay Volume Area Depth Liner	 5-10% 5-10% 4 ft	 Percentage of WQV Percentage of permanent pool surface area Minimum Concrete, to facilitate maintenance
Open-water Zone Area (including forebay) Depth	 10-50% 4 ft	 Percentage of permanent pool surface area Minimum
Wetland Zone Area Depth	 50-70% 0.5-1 ft	 Percentage of permanent pool surface area 30 to 50% should be 1.0 ft deep
Outlet Zone Area Depth	 5-10% 3 ft	 Percentage of permanent pool surface area Minimum
Surcharge depth above permanent pool	2 ft	Maximum
Basin length to width ratio	2:1	Minimum (larger preferred)
Basin freeboard	1 ft	Minimum
Wetland zone bottom slope	10%	Maximum
Embankment side slope (H:V)	4:1 3:1	(or steeper) Inside Outside (without retaining walls)
Side slopes (H:V)	5:1	
Maintenance access ramp slope (H:V)	10:1	or flatter
Maintenance access ramp width	5-20 ft	Minimum. Paved with concrete or porous pavement, subject to approval of permitting agency

Table CWB-2. Distribution of Wetland Components

Components	% Permanent Pool Surface Area	Design Water Depth
Forebay	5-10%	4 feet (minimum)
Open water zone	10-50%	4 feet (minimum)
Wetland zones with emergent vegetation	50-70%	6 to 12 inches (30 to 50% of this area should be 1 foot deep with bottom slope $\leq$ 10%)
Outlet zone	5-10%	3 feet (minimum)

Step 4 – Determine Surcharge Depth of WQV above Permanent Pool and Maximum Water Surface Elevation

The surcharge depth of the WQV above the permanent pool's water surface (D_{WQV}) should be $\leq$ 2.0 feet.

- Estimate WQV surcharge depth (D_{WQV}) based on A_{pp}.

$$D_{WQV} = WQV/A_{pp}$$

- If $D_{WQV} > 2.0$ feet, adjust value of V_{pp} and/or D_{avg} to increase A_{pp} and yield $D_{WQV} \leq 2.0$. The water surface of the basin will be greater than A_{pp} when the WQV is added to the permanent pool.

- Estimate maximum water surface area (A_{WQV}) with WQV based on basin shape.
- Recalculate Final D_{WQV} based on A_{WQV} and A_{pp}. Note: V_{pp} and/or D_{avg} can be adjusted to yield Final $D_{WQV} \leq 2.0$ feet.

$$\text{Final } D_{WQV} = WQV/((A_{WQV} + A_{pp})/2)$$

- Calculate maximum water surface elevation in basin with WQV.

$$\text{WS Elev}_{WQV} = \text{WS Elev}_{pp} + \text{Final } D_{WQV}$$

Step 5 – Determine Inflow Requirement

A net inflow of water must be available at all times through a perennial base flow or supplemental water source. Use the following equation and parameters to estimate the quantity of monthly inflow required at various times of the year. The maximum monthly requirement will govern the design requirement.

$$Q_{inflow} = Q_{E\text{-}P} + Q_{seepage} + Q_{ET}$$

Where:

Q_{inflow} = Estimated base flow (acre-ft/mo.) (Estimate by seasonal measurements and/or comparison to similar watersheds)

$Q_{E\text{-}P}$ = Loss due to evaporation minus the gain due to precipitation (acre-ft/mo.)

$Q_{seepage}$ = Loss or gain due to seepage to groundwater (acre-ft/mo.)

Q_{ET} = Loss due to evapotranspiration (additional loss through plant area above water surface not including the water surface) (acre-ft/mo.)

Note that an impermeable liner may be required to maintain permanent pool level in areas with extremely permeable soils.

Step 6 – Design Basin Forebay

The forebay provides a location for sedimentation of larger particles and has a solid bottom surface to facilitate mechanical removal of accumulated sediment. The forebay is part of the permanent pool and has a water surface area comprising 5 to 10% of the permanent pool water surface area and a volume comprising 5 to 10% of the WQV. The depth of permanent pool in the forebay should be a minimum of 4 feet. Provide the forebay inlet with an energy dissipation structure and/or erosion protection. Trash screens at the inlet are recommended to keep trash out of the basin.

Step 7 – Design Outlet Works

Provide outlet works that limit the maximum water surface elevation to WS $Elev_{WQV}$. The outlet works are to be designed to release the WQV over a 48-hour period. Protect the outlet from clogging with a trash rack and a skimmer shield that extends below the outlet and above the maximum WQV depth. A single orifice outlet control is shown in Figure CWB-1.

- For single orifice outlet control or single row of orifices at the permanent pool elevation (WS Elevpp) (see Figure CWB-1), use the orifice equation based on the WQV (ft3) and depth of water above orifice centerline D (ft) to determine orifice area (ft2):
  Orifice Equation

  $Q = C \times A \times (2gD)^{1/2}$

  Where:

  Q = Flow rate, (cfs)

  C = Orifice coefficient (use 0.61)

  A = Area of orifice, (ft^2)

  g = Acceleration due to gravity (32.2 ft/sec^2)

  D = Depth of water above orifice centerline (D_{WQV})

  The equation can be solved for A based on the WQV and using a design drawdown time (t) of 48 hours.

- For perforated pipe outlets or vertical plates with multiple orifices, use the following equation to determine required area per row of perforations, based on the WQV (acre-ft) and depth of water above centerline of the bottom perforation D (ft).

$$\text{Area/row (in}^2\text{)} = WQV/K_{48}$$

Where:

$$K_{48} = 0.012D^2 + 0.14D - 0.06$$ (from Denver UDFCD, 1999)

Select appropriate perforation diameter and number of perforations per row (columns) with the objective of minimizing the number of columns and using a maximum perforation diameter of 2 inches. Rows are spaced at 4 inches on center from the bottom perforation. Thus, there will be 3 rows for each foot of depth plus the top row. The number of rows (nr) may be determined as follows:

$$nr = 1 + (D \times 3)$$

Calculate total outlet area by multiplying the area per row by number of rows.

$$\text{Total Orifice Area} = \text{area/row} \times nr$$

Step 8 – Design Basin Shape

Whenever possible, shape the basin with a gradual expansion from the inlet and a gradual contraction toward the outlet. The recommended length to width ratio is between 2:1 to 4:1, with 3:1 optimal. Internal baffling with berms or modification of inlet and outlet points may be necessary to achieve this ratio.

Step 9 – Design Basin Side Slopes

Side slopes should be stable and sufficiently gentle to limit rill erosion and to facilitate maintenance. Internal side slopes should be no steeper than 4:1; external side slopes should be no steeper than 3:1.

Step 10 – Design Maintenance Access

Provide for all-weather access for maintenance vehicles to the bottom and outlet works. Maximum grades of access ramps should be 10 percent and minimum width will vary according to local permitting agency requirements, but usually between 15-20 feet. Pave ramps with concrete or porous pavement, subject to the approval of the permitting agency.

Step 11 – Design Security Fencing

To protect habitat and for safety reasons, provide aesthetic security fencing approved by the permitting agency around the basin, except when specifically waived by the permitting agency.

Step 12 – Select Vegetation

Select wetland vegetation appropriate for planting in the wetland bottom. Consider the water fluctuations that are likely to occur. Consult a qualified wetland specialist regarding selection and establishment of plants. The shallow littoral bench should have a 4- to 6-inch layer of organic topsoil. Berms and sidesloping areas should be planted with native or irrigated turf grasses. Shrubs and trees may also be incorporated where appropriate.

Construction Considerations

- If possible, stabilize the entire contributing drainage area to the basin before construction begins. If this is not possible, divert flow around the basin to protect it from sediment loads during construction. If sediment does enter the facility during construction, the contractor will be required to remove soil from the basin floor after the entire site has been stabilized, to the satisfaction of the permitting agency inspector.
- Prevent construction traffic from entering basin.
- Ensure that final grading produces a level basin bottom without low spots or depressions.
- Install seepage collars on outlet piping to prevent seepage through embankments.

Maintenance during Vegetation Establishment

- Control the permanent pool water levels as necessary to allow establishment of wetland plants (typically up to 5 years); raise it to the final operating level after plants are established.
- Inspect frequently during vegetation establishment, and identify and re-plant areas immediately as needed.

Long-term Maintenance

The local permitting agencies in the Sacramento area will require execution of a maintenance agreement or permit with the property owner for projects including a constructed wetland basin. Check with the local permitting agency about the timing for execution of the agreement. Such agreements will typically include requirements such as those outlined in Table CWB-3. The property owner or his/her designee will be responsible for compliance. See Appendix B for additional information about maintenance requirements and sample agreement language.

Table CWB-3. Inspection and Maintenance Recommendations for Constructed Wetland Basins

Activity	Schedule
Inspect basin to identify potential problems such as trash and debris accumulation, damage from burrowing animals, and sediment accumulation.	At beginning and end of the wet season. Additional inspections after periods of heavy runoff are desirable.
Remove litter and debris from constructed wetland basin area.	As required.
Pruning and general tree care, if applicable.	Every 3-5 years.
Stock basin with mosquito fish to enhance natural mosquito and midge control. Contact the local vector control district for assistance.	As required.
Harvest vegetation for vector control and to maintain open water surface area.	Annually or more frequently if required.
Remove sediment from forebay and other zones when accumulation reaches 10 percent of original design depth or if re-suspension is observed. (Note: Sediment removal may not be required in the main pool area for as long as 20 years.)	Clean in early spring so vegetation damaged during cleaning has time to reestablish.
Reconstruct or replace the control measure when it is no longer functioning properly.	See projected lifespan in Appendix B for informational purposes.

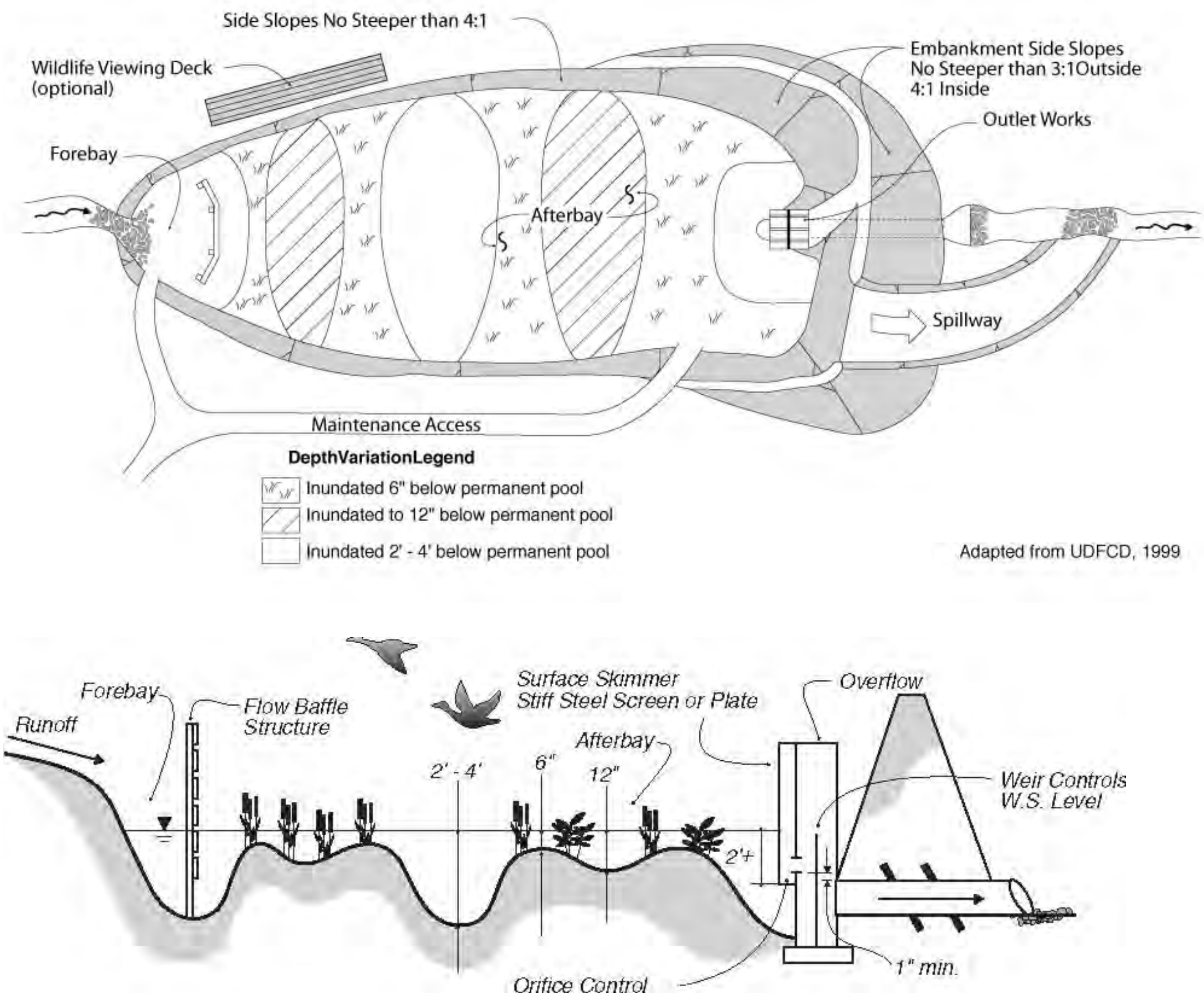

Figure CWB-1. Constructed Wetland Basin

Table CWB-4. Design Data Summary Sheet for Constructed Wetland Basin (Page 1 of 3)

Designer:		**Date:**	
Company:			
Project:			
Location:			

1a. Design Water Quality Volume

a. Contributing drainage area	Area =		ft^2
b. Water Quality Volume	WQV =		ft^3

1b. Adjust Volume Up for Hydromodification Management
(If Applicable) Based upon SAHM Modeling

a. Water Quality Volume based on SAHM modeling	V =		ft^3
b. SAHM Model Demonstrates Compliance with Flow Duration Standards	(Yes or No)		

2. Wetland Basin Minimum Permanent Pool Volume

($Vol_{pp} \geq 0.75 \times WQV$)	Vol_{pp} =		acre-ft

3. Wetland Basin Depths and Water Surface Areas — **ACTUAL DESIGN**

a. Permanent pool volume (Vol_{pp})	Vol_{pp} =		acre-ft
Average depth of permanent pool (D_{avg})	D_{avg} =		ft
Water surface area of permanent pool (A_{pp})	A_{pp} =		ft^2
Water surface elevation of permanent pool (WS $Elev_{pp}$)	WS $Elev_{pp}$ =		ft
b. Forebay			
Depth range = minimum 4 ft	Depth =		ft
Volume range = 5-10% of WQV	Volume =		acre-ft
Water surface area range = 5-10% of A_{pp}	WS Area =		ft^2
c. Open Water Zone			
Depth Range = minimum 4 ft	Depth =		ft
Water surface area range = 30-50% of A_{pp}	WS Area =		ft^2
d. Wetland Zones with Emergent Vegetation			
Depth Range = 6-12 inches	Depth =		ft
Water surface area range = 50-70% of A_{pp}	WS Area =		ft^2
e. Outlet Pool			
Depth Range = minimum 3 ft	Depth =		ft
Water surface area range = 5-10% of A_{pp}	WS Area =		ft^2

Design Data Summary Sheet for Constructed Wetland Basin (Page 2 of 3)

Project: ____________________

4. Surcharge Depth of WQV and Max WS Elevation

a. Maximum water surface area with WQV (A_{WQV}) — A_{WQV} = ________ ft²

b. Surcharge depth of WQV ($D_{WQV} \leq 2.0$ ft) — D_{WQV} = ________ ft
Final $D_{WQV} = WQV/((A_{WQV} + A_{pp})/2)$

c. Maximum water surface elevation with WQV (WS $Elev_{WQV}$) — WQ $Elev_{WQV}$ = ________ Ft

5. Determine Maximum Month Inflow Requirement

$Q_{inflow} = - Q_{E-P} + Q_{seepage} + Q_{ET}$

Q_{E-P} = ________ acre-ft/mo
$Q_{seepage}$ = ________ acre-ft/mo
Q_{ET} = ________ acre-ft/mo
Q_{inflow} = ________ acre-ft/mo

6. Outlet Works

a. Outlet Type (check one)

☐ Single Orifice ☐ Multi-orifice Plate
☐ Perforated Pipe ☐ Other

b. Depth of water above bottom orifice (D_{WQV}) — Depth = ________ ft

c. Single Orifice Outlet
Total Area — A = ________ in²
Diameter (or L x W) — D = ________ in

d. Multiple Orifice Outlet
Area per Row of Perforations — A = ________ in²
Perforation Diameter (2 inch maximum) — D = ________ in
No. of Perforations (columns) per Row — Perforations = ________
No. of Rows (4-inch spacing) — Rows = ________
Total Orifice Area
(Area per Row) x (No. of Rows) — Area = ________ in²

7. Basin Shape: Length-Width Ratio (2:1 minimum) — Ratio = ________ L:W

8. Embankment Side Slope

a. Interior Side Slope (4:1 or steeper) — Slope = ________ L:W
b. Exterior Side Slope (3:1) — Slope = ________ L:W

9. Maintenance Access Ramp

a. Slope (10% maximum) — Slope = ________ %
b. Width (15 to 20 feet) — Width = ________ ft

Design Data Summary Sheet for Constructed Wetland Basin (Page 3 of 3)

Project: ____________________

10. Vegetation (describe)

Native Grasses ____________________

Irrigated Turf ____________________

Emergent Aquatic Plants (specify type/density) ____________________

____

Other ____________________

Notes: ____________________

____

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Disconnected Pavement

Description

Divided sidewalks in a new residential subdivision are one form of disconnected pavement. Photo: ECORP Consulting

Disconnected pavement is any impervious pavement designed to sheet flow runoff over adjoining vegetated areas or porous pavement before it reaches the storm drain system. As the runoff slows and travels though vegetation or over a porous surface, water is infiltrated into the soil with some pollutant removal through filtration.

It is recommended that you read the Porous Pavement BMP Fact Sheet before using this one. Also, Alternative Driveway Design is a technique which employs principles from this and the Porous Pavement BMP Fact Sheet.

Siting Considerations

- Soils: Appropriate for all soil types but porous pavement requires an underdrain for soil types C and D.
- Grade: 10% maximum.
- Traffic loading: Select and design surface material with consideration of anticipated load.

Vector Considerations

- Potential for mosquitoes due to standing water in vegetated features will be greatly reduced or eliminated if the feature is properly designed, constructed, and maintained to ensure complete drainage.

Advantages

- Takes advantage of already-required landscape areas; no additional space required.
- Can reduce size of downstream stormwater quality treatment measures by reducing the volume required to treat.
- Vegetated areas provide green space. Combination of impervious and porous pavement can be more attractive than traditional installation.
- Potential LEED Credits
    - Credit 6.1 – Stormwater Design – Quantity Control

Limitations

- Do not use without appropriate source control BMPs on sites with a likelihood of oil, grease or other hazardous spills.

Maintenance Recommendations (Low to Moderate[1])

- See inspection and maintenance recommendations in the Porous Pavement fact sheet.

How Does Disconnected Pavement Work?

Gravel walkway in the River Garden, The City of Elk Grove

Impervious surfaces, such as those paved with regular asphalt or concrete, that convey stormwater to a storm drain system without allowing the water to flow over any impervious surface are considered "directly connected." Compared to pervious areas, directly connected impervious surfaces contribute increased runoff and associated pollutants to the downstream storm drain system. "Disconnection" of impervious surfaces can be achieved by sloping surfaces toward relatively small or narrow vegetated or porous areas where the water is filtered before entering the storm drain system, and/or infiltrated into the underlying soils. Areas that can be disconnected include parking lots, driveways, sport courts, sidewalks, patios, courtyards, and roadways.

Other names: Not directly connected pavement, divided sidewalks, separated sidewalks, bifurcated walk.

Planning and Siting Considerations

- Maximize the use of landscaping and natural areas that are planned for the site already. Design landscaping to sit below adjacent impervious surfaces. The width of the vegetation needed is dependent on the area of contributing pavement; the ratio of impervious to pervious surface should be 2:1 or less.
- When draining pavement to open spaces, avoid environmentally-sensitive and protected wetlands areas. These applications will not qualify for the runoff reduction credits discussed in this fact sheet.
- Check with the local permitting agency to determine if credit will be given for paved surfaces draining to vegetated creek buffer areas.

[1] As compared to treatment control measures.

- Locate porous features in well drained soils (Types A or B) whenever possible. If porous pavement is used in C or D soils, an underdrain will be required.
- Eliminate curbs and slope pavement to sheet flow into vegetation where possible. Where curbs are required for safety or other reasons, use curb cutouts to convey flow into the vegetation.
- Maximize the use of Porous Pavement (as an alternative to conventional pavement) where it can double as a disconnected conveyance zone. When draining an impervious area into porous pavement, refer to Porous Pavement Fact Sheet elsewhere in this chapter for planning and design requirements.

Suitable Land Use Types

Residential: Driveways, patios, and walkways can be disconnected. Also see Alternative Driveways Fact Sheet elsewhere in this chapter.

Commercial: Plazas and courtyards, parking lots/stalls, overflow parking areas, some types of storage areas, walkways, and as entryway features. Not appropriate for retail gas outlets, auto maintenance businesses or locations where spills may occur.

Industrial: Employee parking stalls, entryway, and pedestrian walk features. Not appropriate for processing/manufacturing areas involving extractive, chemical/petroleum, food, printing processes, and chemical storage areas.

Roadways: Slope roadways to drain across vegetation or other porous surfaces.

Parks and Open Space: Parking lots, park hardscape areas, pedestrian and bike trails, sports courts and playgrounds. See notes above about draining to natural open spaces, environmentally-sensitive areas and creek buffers.

Variations

Two variations of disconnected pavement that qualify for runoff reduction credits are discussed in this fact sheet: 1) Pavement draining to landscaping, and 2) pavement draining to porous pavement.

Curb cutouts deliver runoff from a parking lot to a vegetated swale. Vegetation must be lower than pavement to prevent clogging and sediment build-up at the curb. Photo: City of Fremont

Pavement Draining to Landscaping

Vegetated areas used to disconnect impervious surfaces can include either uniformly graded formal landscape features or densely vegetated open space/natural areas on the site. The impervious surface must sheet flow into and through the vegetated area to promote filtration and settling. These vegetated features differ from Vegetated Filter Strips (see fact sheet elsewhere in this chapter) as they collect runoff from very small areas, more variability in dimension is allowed and they do not qualify as "treatment" techniques per Table 3-2 (Selection Matrix). Look for opportunities to use small pockets of landscaping and strips of turf grass for this application. The ratio of impervious to pervious surfaces must be 2:1 or less to qualify for the runoff reduction credits presented in this manual.

Examples:

Sidewalks – Establish a vegetated strip between sidewalks and the curb and gutter system in the street to allow for infiltration and filtration of sidewalk runoff.

Use of reinforced grass pavement ("grasscrete") allows for pedestrian access without vegetation damage and reduces runoff through infiltration. Photo: Alameda Countywide Clean Water Program

Driveways – Slope residential driveways toward yard vegetation or divert flow from the driveway to the yard through a slotted trench or other approved means. See the Alternative Driveways Fact Sheet elsewhere in this chapter for more information.

Plazas, patios and walkways – Consider constructing these surfaces using porous pavement materials (see Porous Pavement fact sheet elsewhere in this chapter) to reduce imperviousness and reduce runoff. If that is not possible, slope the impervious areas to sheet flow into adjacent vegetated areas.

Photo: Lions Park, The City of Folsom

Commercial parking lots –Parking lot landscape areas between stalls or at the lot perimeter (typically already required by permitting agency codes) can be designed to double as stormwater quality control measures. As a first choice, design these areas to treat and filter parking lot runoff by integrating vegetated swales or bioretention planters (see fact sheets for these measures elsewhere in this chapter). For smaller landscape pockets where it is infeasible to run the water through vegetated swales or bioretention planters, apply the disconnected pavement concept to reduce runoff. Grade the parking areas to drain to these features, with slotted curbs or curb cutouts to allow the runoff to flow into and through the vegetation (see photo). This may help reduce the size of needed downstream treatment measures for the site.

Pavement Draining to Porous Pavement

Consider replacing or combining conventional paved surfaces (concrete, asphalt) with porous paved surfaces to meet paving area requirements, in order to accept and infiltrate runoff from adjoining impervious surfaces. The porous pavement may be any of the variations described in the Porous Pavement fact sheet presented elsewhere in this chapter.

Examples:

Divided Sidewalks and parking lot medians – Consider the use of porous pavement in vegetated sidewalk strips and parking lot medians to provide paths for pedestrians to walk across the area without damaging vegetation. See photo.

Pavers in parking lot. Photo: City of Emeryville

Hybrid Parking Lot - Traffic loading requirements typically differ between parking lot drive aisles and stalls in parking lots. More durable conventional pavement surfaces will typically be required for the main drive aisles and areas used by garbage, delivery and fire trucks, while porous pavement may be appropriate for the stalls (or a portion of the stalls) used by cars. The permeable stalls may be used to carry flow from the main drive aisles to the storm drain system, allowing for infiltration and disconnecting the main aisle pavement from the system. A water barrier may be required between regular load-bearing pavement/streets and porous pavement materials to keep water from undermining the regular pavement subbase; verify this with the local permitting agency.

This hybrid parking lot concept has been applied successfully in many areas of the country, including the San Francisco Bay Area. Generally, pervious pavement or cobblestone block set in sand will be preferred by the permitting agency, however, depending on frequency and type of use, modular block pavement, reinforced grass, or gravel may be appropriate. For example, these techniques could work well in a seasonal overflow parking lot, a public park or a trailhead.

In hybrid parking lots, stall markings can be indicated with one of several techniques, depending on the type of permeable surface: wood headers laid in a field of pervious pavement, a change in cobblestone block color, concrete bands, or rounded raised pavement markers similar to those used on highways (“Botts’ Dots”). (*Start at the Source, 1999*)

Bike and Pedestrian Trails –Consider the use of gravel or other porous material alongside bike and pedestrian trails to infiltrate and filter some of the runoff. For example, the City of Folsom requires a gravel shoulder for its Class I bike trails.

Design Criteria

Design criteria for disconnected pavement are listed in Table DP-1.

Construction Considerations

- Ensure that flow entering a porous area from an impervious surface is spread evenly and the area accepting the flow is lower than the impervious surface.
- If using porous pavement, follow the construction guidelines given in the Porous Pavement Fact Sheet located elsewhere in this chapter.
- Once construction is complete, stabilize the entire contributing drainage area and the vegetation within the feature itself, before allowing runoff to enter the feature.

Long-term Maintenance Recommendations

Refer to the inspection and maintenance recommendations in the Porous Pavement fact sheet.

Table DP-1. Disconnected Pavement Design Criteria

Variation/Design Parameter	Criteria
Pavement Draining to Landscaping	
Impervious Surface	Spread sheet flow into vegetated area (to maximize contact with vegetation) using curb cutouts or notches as acceptable to local permitting agency.
Impervious-Porous Ratio	2:1 maximum (see Appendix D)
Vegetation	Ensure that there are no channels, low conveyance areas, or other features that would cause short-circuiting. Plant with dense vegetation appropriate for erosive flows. Carefully select proper trees and root barriers as needed.
Drainage	Place an area drain in vegetated feature, located to maximize travel distance of flow through landscaping, or allow for overflow water to sheet flow out of vegetated area to drainage system, as approved by local permitting agency.
Pavement Draining to Porous Pavement	
Impervious-Porous Ratio	2:1 maximum (see Appendix D)
Other	See design criteria for Porous Pavement Fact Sheet elsewhere in this chapter.
Sources: Ventura and Denver	

References

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Disconnected Roof Drains

Description

Source: City of Portland

Roof drains can be disconnected from the storm drain system by directing the roof runoff across vegetation or into subsurface infiltration devices where it is filtered or infiltrates into the ground. The water may be directed across lawns, through dense groundcover, into devices such as a dispersal trench or infiltration well, if acceptable to the permitting agency. Roof runoff can also be directed into vegetated swales and bioretention planters for stormwater quality treatment (see fact sheets for these measures elsewhere in this chapter).

Consult a geotechnical engineer about site suitability and other design considerations.

Siting Considerations

- Soils: Infiltration structures are generally suitable for Type A and B soils.
- Depth to groundwater: For infiltration structures, minimum vertical separation to groundwater table is 10 feet below bottom of facility.
- Setback: Infiltration structures must be min. 20 feet from buildings, min. 150 horizontal separation from drinking water wells (smaller setback maybe allowed with geotechnical engineer approval, verify with local permitting agency).
- Slope: up to 25%
- Vegetation: Sufficient vegetated area must be available for overland conveyance.

Vector Considerations

- Potential for mosquitoes due to standing water in vegetated features will be greatly reduced or eliminated if the feature is properly designed, constructed, and maintained to ensure complete drainage.

Advantages

- Takes advantage of existing/planned landscape areas; no additional space required.
- Can reduce size of downstream stormwater quality treatment measures by reducing the volume required to treat.
- Potential LEED Credits
    - Credit 6.1 – Stormwater Design – Quantity Control

Limitations

- Plant materials in landscaped areas receiving the runoff should be designed to withstand occasional inundation.
- Subsurface infiltration devices may eventually clog with sediment, requiring costly reconstruction.
- Soil permeability may limit applicability of subsurface infiltration structures.

Maintenance Recommendations

- Irrigate and maintain vegetated areas to maintain infiltration and filtering capacity.
- Periodically check for clogging of any subsurface pipes or infiltration systems and repair as needed.

How Do Disconnected Roof Drains Work?

Disconnected roof drains effectively disconnect the rooftop from the local storm system, which helps reduce runoff and provides incidental pollutant removal as the water travels over and through the vegetation and soil. In this approach, roof runoff is directed to spread over a vegetated area (the surface conveyance zone), or into underground infiltration devices, if approved by the local permitting agency. Greater surface area and contact time within the surface conveyance zone promote greater runoff treatment efficiencies.

Other Names: Disconnected downspouts, disconnected roof leaders

Planning and Siting Considerations

- Consult a geotechnical engineer about site suitability and other design considerations. The geotechnical report shall include information regarding proximity to hazardous spills or contaminated plumes within a 1000 feet radius of the project site using GeoTracker (https://www.waterboards.ca.gov/gama/geotracker_gama.shtml)
- Assess soil permeability to determine if infiltration option is viable for the type of system desired. Consult a geotechnical engineer if needed, particularly in areas adjacent to building foundations.
- Design buildings to take advantage of vegetated areas. Direct roof flow away from paved surfaces.
- Design site with a minimum of 2% positive slope away from building foundations.
- Maximize the length, and minimize the slope, of the surface conveyance zone. The land surrounding the downspout/emitter should be graded to spread and convey storm water (minimum 2 feet wide) and prevent concentration of flows.
- Integrate the disconnected roof drain system into the site landscaping plan.
- Consider using infiltration wells or dispersal trenches where the surface conveyance zone slope exceeds 25% and local permitting agency allows. Such devices must typically be located a minimum of 20 feet from any buildings, but verify with local permitting agency.

- Use of dispersal trenches and infiltration wells is restricted on commercial and industrial projects depending on pollutant potential; check with local permitting agency.

Variations

Four types of disconnected roof drain systems are discussed in this fact sheet: 1) splash block, 2) pop-up drainage emitter, and 3) dispersal trench and 4) infiltration well. Check with the local permitting agency to determine if all types are allowed and if they have any local specifications or details to add to, or replace, those shown here.

Splash Block

Splash Blocks reduce the velocity and impact of water exiting the roof downspout and direct water to a pervious surface conveyance zone. Storm water traveling across the surface conveyance zone is filtered and infiltrated. Where the slope of the surface conveyance zone is greater than 8%, a gravel level spreader is required at the end of the splash block. A gravel spreader is a pocket of gravel that collects water and encourages sheet flow. The spreader may be covered with geotextile, soil and vegetation to fit with site landscaping.

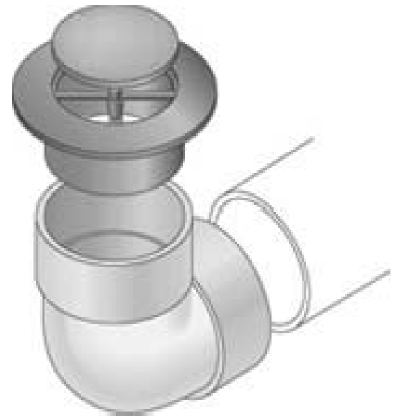
Source: Alemeda Countywide Clean Water Program

For single family residential sites, the stormwater must flow across appropriate vegetation throughout the entire surface conveyance zone (from the downspout to the sidewalk). For commercial and multi-family sites, minimum travel distances across vegetation are specified based on contributing roof area (see Table DRD-1).

Table DRD-1. Surface Conveyance Zone for Splash Blocks and Pop-up Drainage Emitters: Commercial and Multi-Family Residential Areas

Maximum Roof Size (sf)	*Minimum Travel Distance Across Vegetation*
3,500	21 feet
5,000	24 feet
7,500	28 feet
10,000	32 feet

Pop-up Drainage Emitter



(Check with local permitting agency for any local specifications before using this information).

Pop-up drainage emitters are appropriate when it is not possible to convey water directly from the downspout due to grading, paving or other site constraints. Pop-up Drainage Emitters are also useful in conveying storm water from backyard downspouts to front yard conveyance zones. Roof runoff is piped then released through a capped device that opens with water pressure. Yard drains may be used as component of the pop-up emitter system. For example, roof-top runoff directed to a back yard may be collected in a yard drain, then directed to a front yard pop-up emitter system.

For single-family residential development, pop-up emitters must daylight no closer than five feet from the building with positive drainage away from building foundations and slabs for another five feet, where possible. The five feet limit is to allow for maximum travel distance across the yard.

Dispersal Trench

(Check with local permitting agency for any local specifications before using this information).

A Dispersal Trench is appropriate for situations where the slope from the building does not meet the slope requirements or there is limited surface conveyance zone area available. The downspout may be piped directly to a Dispersal Trench through a perforated or slotted pipe that allows water to seep into the drain rock and surrounding soil. A maximum of 1750 square feet of roof area can be allowed to drain into one 8-foot long dispersal trench. These underground structures may be topped with geotextile fabric and 6 inches of soil for planting. See Figure DRD-1 for an example of the dispersal trench system design.

A debris collection point, or pretreatment sump, is required to prevent sedimentation and clogging of the dispersal trench. Once the pretreatment sump has filled with debris, it should cause a noticeable amount of overland flow bypassing the dispersal trench, which indicates that it is time to maintain the device.

The roof gutters should be fitted with mesh screens to prevent leaf litter and other debris from entering the system where there is tree cover. The expected growth of newly planted trees should be considered.

An overflow outlet should be provided on the downspout at the surface elevation to allow flow to bypass the system when either the infiltration trench or pretreatment sump are clogged or when hydrologic capacity is exceeded.

To reduce the potential for costly maintenance and/or system reconstruction, it is strongly recommended that dispersal trenches be located in lawn areas (or other vegetated areas) and as close to the surface as possible.

Other names: Perforated Pipe System, French Drain

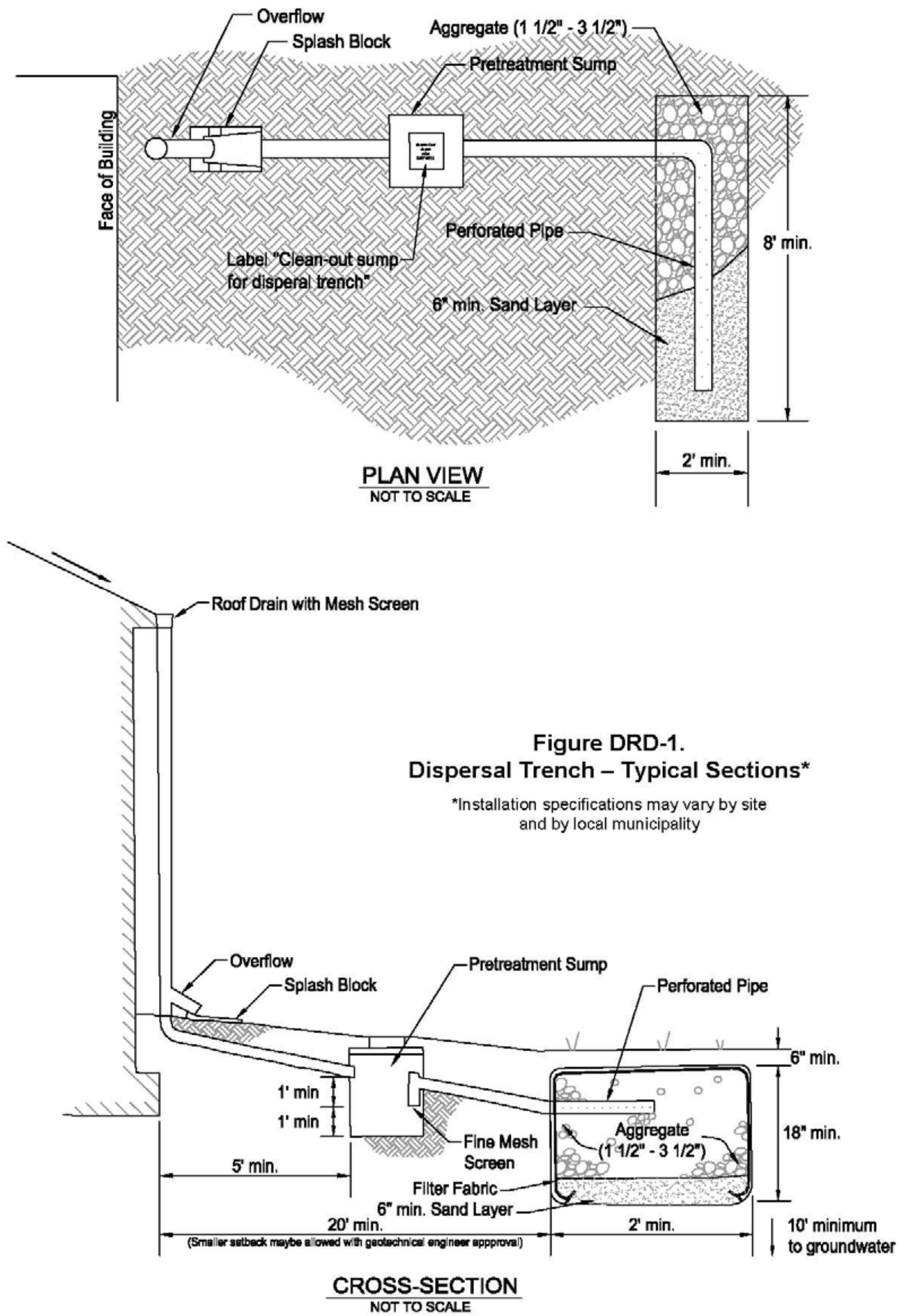


Figure DRD-1. Dispersal Trench – Typical Sections

Installation specifications may vary by site and by local municipality

Infiltration Wells

(Check with local permitting agency for any local specifications before using this information).

Infiltration Wells are similar to Dispersal Trenches except that the dimensions maybe different. The infiltration well may be concrete or plastic (or other approved material), cylindrical or square, with perforations large enough to take full advantage of the infiltration capacity of the surrounding soil. Infiltration wells have a maximum depth of 4 feet.

Bilby Road, The City of Elk Grove

All design requirements related to pretreatment sumps, gutter protection, and overflows are the same as those for Dispersal Trenches. See Figure DRD-2 for an example of the infiltration well design.

These underground structures may be topped with geotextile fabric and 6 inches (or more depending on approved specifications) of soil for planting.

The sizing and design requirements in this fact sheet are only applicable to infiltration wells with the sole purpose of disconnecting roof drains.

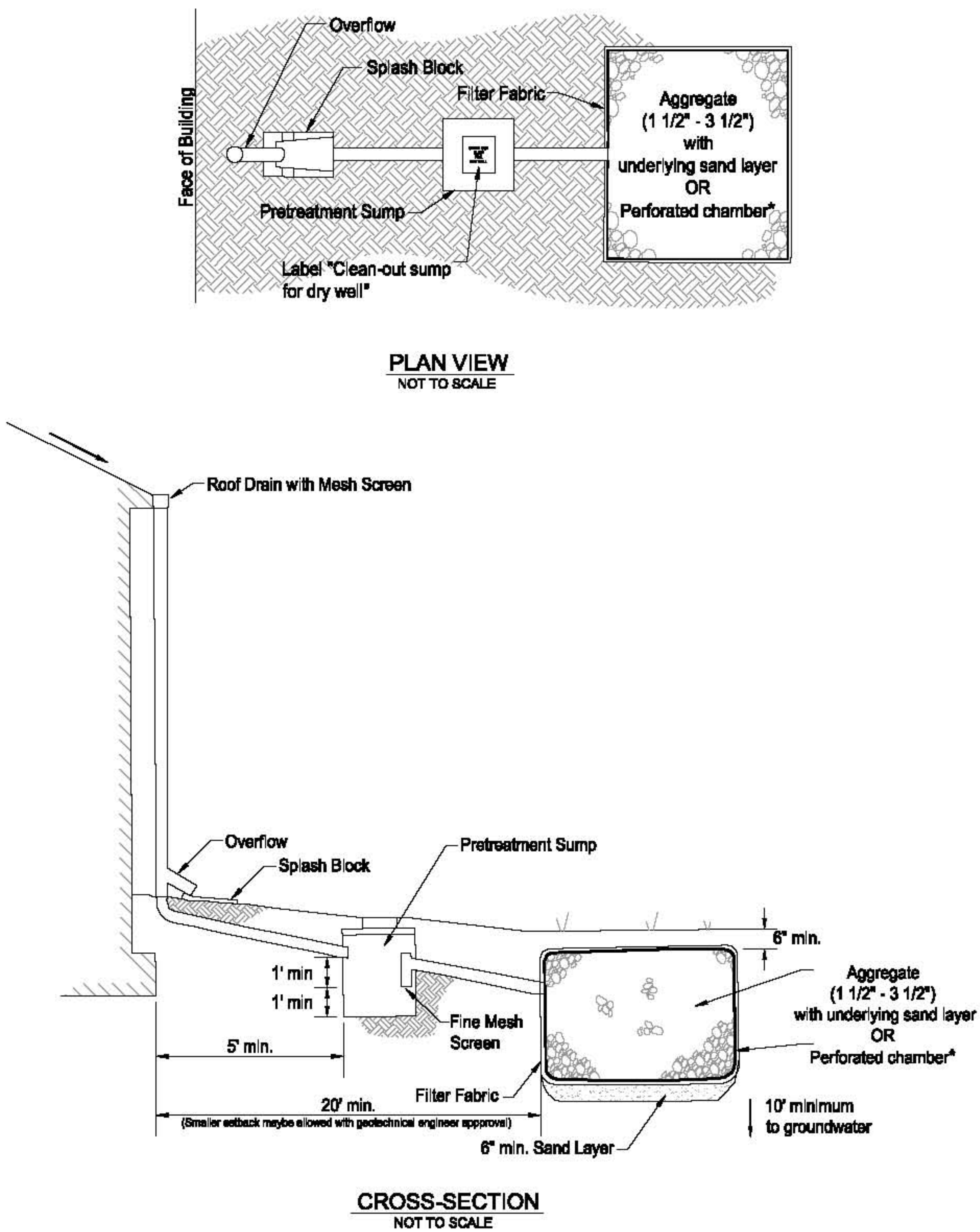
Design Criteria

Design criteria for disconnected roof drains and discharge variations are listed in Table DRD-2.

Construction Considerations

Splash Block and Pop-up Drainage Emitter

- Site must be graded to prevent ponding of water at base of building.
- Splash blocks must be secured in place over compacted soil.
- Roof drainage conveyance areas must be protected from erosion during vegetation establishment period. Temporary measures such as erosion control blanketing may be used, however it may be necessary to bypass the stormwater around the surface conveyance zone during the stabilization period.



* Subject to approval of permitting agency. Manufacture's specifications and additional restrictions apply (consult permitting agency).

Figure DRD-2. Infiltration Well – Typical Sections

Installation specifications may vary by site and by local municipality

Dispersal Trench and Infiltration Well

- Do not allow soil below trench area to be compacted during construction.
- The floor of the trench/well must be level to allow for spreading of flow across the trench.
- To prevent sedimentation of the structure, the inlet pipe must be plugged until soil on the site is stabilized. To protect the structure *during* construction, provisions for sediment control must be included in the design.

Long-term Maintenance Recommendations

Table DRD-3 presents inspection and maintenance recommendations for disconnected roof drains in general and two design variations related to disconnected roof drains (dispersal trench and infiltration well). The local permitting agencies require that the property owner be responsible for maintaining the features to ensure continued, long-term performance (refer to Appendix B). The pervious features should not be removed or replaced or all water quality benefits will be lost. In general, a maintenance agreement will not be required for this type of installation. However, developers are responsible for educating new homeowners that such devices are installed on their property and should be maintained following the recommendations provided in Table DRD-3. Where possible, such recommendations should be included in Covenants, Codes and Restrictions for new residential subdivisions.

Table DRD-2. Disconnected Roof Drains Design Criteria

Variation/Parameter	**Criteria**
Splash Block/Pop-up Drainage Emitter	
Surface	Minimum 2% positive slope away from building foundations for 4 feet minimum. Surface must be contoured to allow for sheet flow at least 5 feet wide. Must be planted with erosion resistant vegetation (turf or dense groundcover). Ground cover use limited to slopes less than 4%.
Splash Block	Must be at least 24 inches long, 2 inches deep and 10-12 inches wide where it meets the surface conveyance zone. Must weigh at least 10 pounds and be sloped away from building.
Spreader	Where slope more than 8%, spreader required at end of splash block; spreader must be drain rock, 24 inches long, 6 inches wide, and 8 inches deep, and level at surface. Gravel may be placed below surface and covered with geotextile fabric, 4 inches of soil and grass.
Emitter/pipe	Pipe must be at least 6 inches below the surface and a minimum of 4 inches in diameter (may not be suitable for large contributing roof areas). Emitter elevation must be lower than the finished grade of the base of the downspout and the yard drain (if used). Emitter must daylight no less than 5 feet from building (residential only).
Travel Distance	See Table DRD-1 and Appendix D.

Variation/Parameter	Criteria
Infiltration Systems: Dispersal Trench and Infiltration Well	
Soils	Soil type extending 3 feet from bottom of facility must have infiltration rate between 0.5 inches per hour and 8 inches per hour. Soil may be amended to achieve infiltration rate.
Setback	Must be located a minimum of 20 feet from building. A smaller setback maybe allowed with geotechnical engineer approval.
Pretreatment Sump	Must be located a minimum of 5 feet from building. Must be labeled at surface "clean-out sump for dispersal trench or infiltration well."
Overflow	Must be set on splash block.
Loading	Must demonstrate that the appropriate loading tolerance is achieved for proposed use of surface. Provide psi rating for structure/design.
Surface	Minimum 2% positive slope away from building foundations (4 feet minimum) (per Building Code).
Surface Label	Surface identification label may be required; check with the local permitting agency.
Dispersal Trench Only	
Configuration	Must be installed parallel to site contours; must be a minimum of 2 feet wide and 18 inches deep; maximum depth is 4 feet; must be a minimum of 8 feet long; must be lined with geotextile fabric (sides and top) and filled with drain rock.
Perforated Pipe	Must be a minimum of 6 inches below grade.
Infiltration Well Only	
Capacity	Must design a minimum 24 cubic feet of storage capacity for every 1750 square feet of contributing roof area for infiltration wells intended solely for disconnection of roof drains. Maximum depth is 4 feet.
Drain Rock	Must be filled with drain rock or use perforated chamber (with or without rock) upon approval of permitting agency.
Perforated Chamber (if allowed)	Perforated chambers must be designed and installed according to manufacturer's specifications. Perforations in structure must allow for discharge of water at a rate higher than soil infiltration rate. Must be lined with geotextile fabric. Consult manufacturer's specifications for additional design requirements.

Source: High Point Community Site Drainage Technical Standards. Seattle, Washington.

Table DRD-3. Inspection and Maintenance Recommendations for Dispersal Trenches and Infiltration Wells

Disconnected Roof Drains – General	
Gutters	▪ When cleaning gutters, repair wire mesh as needed to keep leaves and debris out of drain pipes.
Overflow	▪ Periodically inspect and clear overflow pipe.
Dispersal Trench and Infiltration Well	
Surface and Vegetation Maintenance	▪ Keep the surface clean and free of leaves, weeds, debris, and sediment, and do not replace or cover it with an impermeable paving surface. ▪ Do not store loose material such as bark or sand over infiltration well or trench area; this can clog the infiltration facility. ▪ Do not plant trees or shrubs over infiltration structures. Grass and plants (especially drought-tolerant varieties) are best. ▪ Use integrated pesticide management techniques and minimize use of fertilizers, herbicides and insecticides in vegetated areas. ▪ Remove grass clippings in grass areas over infiltration structures. ▪ Reseed grasses when needed and keep healthy and dense enough to provide filtering while protecting underlying soils from erosion.
Pretreatment Sump	▪ Inspect sump monthly and after heavy rainfall and clean out accumulated sediment/debris as needed.
Ponding Water/Mosquito Control	▪ Check for and eliminate any ponding water that does not drain within 48 hours, since that provides an environment for insect larvae. ▪ Standing water is usually an indication that the facility is clogged (the overflow and/or the sump needs to be cleaned and/or the device needs to be reconstructed).
Manufacturer's Recommendations	▪ For manufactured products, follow manufacturer's maintenance recommendations. ▪ Make structural repairs when necessary to restore function.
Replacement	▪ Reconstruct or replace when it is no longer functioning properly. For planning purposes, estimated life expectancies are as follows: dispersal trench - 30 years, infiltration well – 30 years. (Source: City of Portland, Oregon)

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Green Roof

Description

Premier Automotive North American Headquarters, Irvine, California. Photo: Roofscapes, Inc.

A green roof is a multi-layered, vegetated rooftop system designed for filtering, absorbing, and retaining stormwater. Green roofs comprise lightweight growth media and a specialized mix of vegetation underlain by a root barrier, a drainage layer, and a waterproofing membrane that protects the building structure. A green roof captures stormwater within the pore space of the growth medium and then releases the water slowly via evaporation, transpiration and discharge to the roof drains. There are two types of green roofs – extensive (shallow growth media, simple vegetation) and intensive (deeper growth media, complex vegetation).

Siting Considerations

- Space requirements: No additional space needed.
- Land use: Most appropriate for commercial or multi-family land uses, particularly infill development and multi-story buildings in dense urban areas, parking garage and retail/warehouse roofs.

Vector Considerations

- Proper design, plant selection, construction, and maintenance of green roofs will greatly reduce or eliminate the potential for vector issues.
- Vector issues may arise due to standing water from leaky taps, air conditioning units, or other excess moisture sources on the roof. Also, rats, mice, and other vectors may be attracted to planted vegetation that produces nuts, fruit, or seeds.

Advantages

- Requires no additional land.
- Improves outdoor air quality; aids in smog reduction.
- Decreases roof and runoff temperature (heat island effect).
- Provides insulation and lowers building cooling costs.

- Protects underlying roof material from climatic extremes, ultraviolet light, and costly long-term damage.
- Can provide green space for building occupants to enjoy.
- Provides habitat for wildlife, particularly birds.
- Potential LEED Credits
    - Credit 6.1 – Stormwater Design – Quantity Control
    - Credit 6.2 – Stormwater Design – Quality Control

Limitations

- Special structural design requirements to support green roof, irrigation needs and leak protection elements (due to roof irrigation) are likely to increase building costs.
- Erosion controls such as jute or cellulose netting and/or soil stabilizers will be required; additional controls such as cross-battens or steps may be required on sloped roofs.
- Not appropriate for wood frame construction.

General Maintenance Requirements (Moderate to High)

- Irrigate to establish vegetation (first two years) and thereafter as needed.
- Routinely inspect and maintain the roof membrane, drainage layer flow paths and irrigation system.
- Repair eroded areas and replace vegetation as needed to maintain required cover.

How Does a Green Roof Work?

Green roofs are a proven technology and have been used/tested in Europe for over 40 years. They are gaining recognition in the U.S. for the environmental, economic, and social benefits they provide. There are now numerous applications in the San Francisco/ San Jose Bay Area of California.

Green roofs reduce runoff volume and peak flow through several mechanisms. When it rains, the green roof's foliage, growth medium, and root uptake zone retain a substantial portion of the stormwater that would otherwise flow from the roof to the storm drain system. The retention volume depends on many factors, including rainfall amount, depth and composition of the growth medium, and the type, diversity, and maturity of the vegetation. Some of the retained stormwater is released to the atmosphere via evaporation and transpiration (uptake by plants). The remainder slowly infiltrates through the growth medium to the roof underdrains and is discharged to the storm drain system with the volume and peak flow rate reduced.

Green roofs improve runoff water quality through a variety of biological, physical, and chemical processes within the plants and growth media. At the roof surface, airborne particulate matter (encompassing a range of organic and inorganic compounds) is intercepted and taken up by plant foliage. When it rains, stormwater (and associated air pollutants) is retained within and filtered through the growth media and root uptake zone. Contaminants sorb to clay and organic matter within the growth media. Further pollutant removal is achieved by bioremediation and phytoremediation, carried out by bacteria and fungi present within the root systems. Pollutant removal increases as the vegetation and root systems mature.

Other Names: Ecoroof, green rooftop, nature roofs, vegetated roof covers

Planning and Siting Considerations

- Involve the landscape architect, licensed structural engineer and mechanical engineer early in the design process with the project architect, since architectural roof style (pitch/slope, configuration), roof structural requirements, building heating/cooling needs, vegetation selection, and irrigation needs go hand in hand.
- Proper design and management of drainage is essential. Inadequate drainage may result in more load that the roof can sustain; plant mortality; degeneration of the growth medium; and/or vector control issues.
- Choose plants suitable for the local climate, rooftop microclimate and considering desired future irrigation. Check with the local permitting agency for recommended plants and planting guides for green roofs. Plants included in green roofs designed for stormwater management must be able to tolerate fluctuations between quick drainage and complete saturation of the soil. Limited studies have found the plants with greatest potential for stormwater management are grasses, herbaceous perennials, and mosses.
- Consider designing the green roof to serve as a greenspace amenity accessible to building tenants and/or the general public. This is particularly important quality of life benefit in dense, downtown urban areas where space for parks and natural areas is at a premium.

Pedestrian Walkway on Stanford University Parking Garage Green Roof, Palo Alto, California. Design by Rana Creek Living Architecture.

*Use the **Design Data Summary Sheet** (Table GR-3) to record design information for the permitting agency's review.*

Design Criteria

Table GR-1 provides design criteria for green roofs; many parameters vary depending on the type of green roof (intensive or extensive). A Design Data Summary Sheet for green roofs (Table GR-3) is provided at the end of this fact sheet. Presently, the only widely-accepted, established standards for green roof construction are the comprehensive FLL standards developed in Germany. An American

Standard Testing Methods (ASTM) task group is developing new standards for green roof installation; this fact sheet will be updated after the new standards are approved and published.

Table GR-1. Green Roof Design Criteria

Design Criteria	Extensive Green Roof	Intensive Green Roof
Design Volume	WQV, see Appendix D in this Design Manual for design requirements for volume-based control measures	Same
Design Drawdown time	12 hours	12 hours
Growth Media[1]	Typical depth: < 6 in.	Typical depth: 12+ in.
Vegetation	Low-growing, low water-use vegetation such as Sedum, herbs, grasses, and perennials	More complex gardens including the species listed for extensive green roofs, but also incorporating trees, shrubs
Load[1]	12-54 lbs/ft^2 average weight of saturated extensive roots is 17 lbs/ft^2, comparable to gravel ballast in some conventional roofs	72+ lbs/ft^2
Roof Slope	5:1 maximum	5:1 maximum
Access	Required for maintenance. Not generally designed for public access.	Required for maintenance. Public access often accommodated and encouraged.
Maintenance	Generally minimal once established.	Significant maintenance required due to greater loading and complex plantings.
Irrigation	Simple irrigation. If roof well-designed, needed only during plant establishment and droughts.	Complex irrigation.
Drainage	Simple drainage system.	Complex drainage system.

Source: Adapted from USEPA website on Green Roofs, www.epa.gov/hiri/strategies/greenroofs.html
Notes: 1. Range of values obtained from description of Roofmeadow® products: www.roofmeadow.com/assemblies.html

Design Procedure

General Design

Green roofs vary from small-scale designs using a single plant species to complex gardens with many types of plants. A typical configuration for multi-layer green roof systems is provided in Figure GR-1 and the design steps are briefly discussed below.

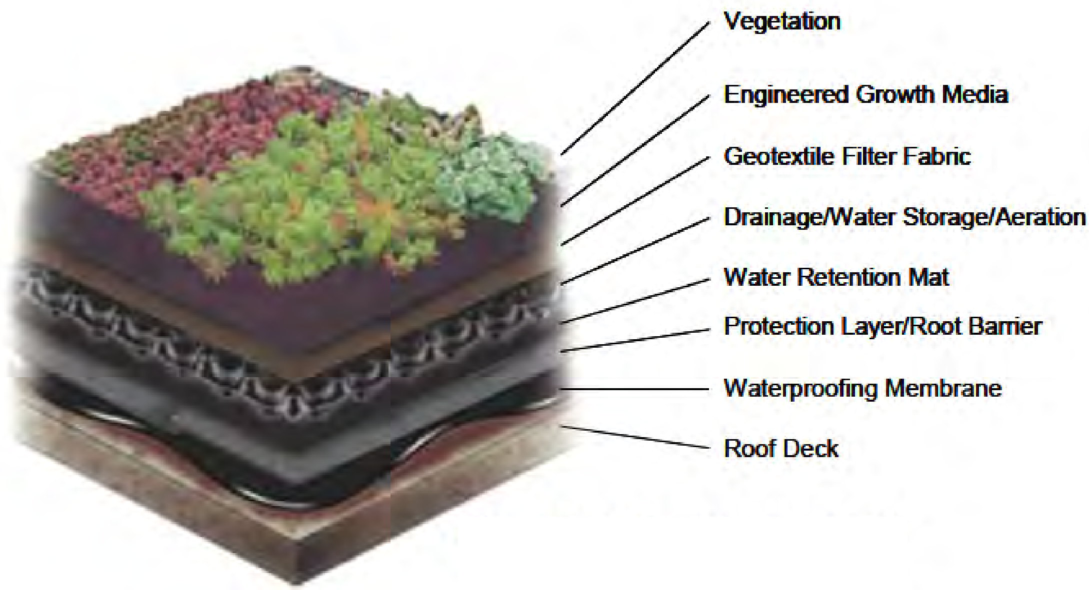

Figure GR-1. Typical Green Roof Configuration

Image source: American Hydrotech, Inc. ®, www.hydrotechusa.com. Text detail added.

Step 1 – Choose Vendor and Specialized Consultants

Green roofs are typically designed and installed by an established vendor. At a minimum, also consult:

- Structural engineer – to ensure the roof loading capacity is adequate
- Architect – to integrate green roof design with the building design, including planning for possible use by future building occupants
- Landscape architect – to design the planting areas, select vegetation and design the irrigation system
- Mechanical engineer – to calculate the heating and cooling implications of the green roof and to discuss how to integrate the green roof with rooftop mechanical equipment and drainage needs

Step 2a – Calculate Water Quality Volume (WQV)

The growth media volume is a key criterion governing the sizing of the green roof. Provide sufficient volume within the pore space of the growth medium to contain the water quality design volume (WQV), which is determined using Appendix E information, based on a 12-hour drawdown period. Take into account the presence of established vegetation when determining the needed pore space. To calculate the volume of growth medium required to contain the WQV in the available pore space, use the following equation:

Volume of growth medium = WQV/Porosity of growth media (with vegetation)

Step 2b – SAHM Modeling for Hydromodification Management (If applicable)

Upsize the green roof volume as necessary based upon modeling results if implementing as a hydromodification control.

Step 3 – Select Green Roof Type

Decide whether to install an extensive or intensive green roof. Extensive green roofs, which have simple vegetation and shallow growth medium, are characterized by their low weight, low capital cost, and low maintenance, and can be retrofitted onto existing structures with little or no additional structural support. Intensive green roofs, which have complex vegetation and deeper growth medium, are characterized by their higher weight, capital cost, and higher maintenance requirements. They are more elaborate in design (sometimes even incorporating fountains and ponds), are typically intended for human use and interaction, and need to be engineered to conform to the load requirements. Characteristics of each green roof type are summarized in Table GR-1.

Make the decision whether or not to provide public access in this step, since this affects green roof type and load design (Step 4). If access will be provided, then, at a minimum, foot traffic must be accommodated with walkways or turf grass. (Turf grass must be irrigated and requires the deeper growth media of an intensive green roof.) Typically, green roofs with public access have a complex array of vegetation (i.e., are intensive green roofs) and may even have other garden features such as a fountain, ornamental pond, or patio/deck.

Step 4 – Determine Required Structural Support and Green Roof Design

Design the structure to support the green roof, considering the saturated weight of the mature green roof system and the expected live load from human activity on the roof (e.g., maintenance staff, tenants, visitors). If a green roof is planned for a new building, the architects and structural engineers need to factor the green roof into the architectural and building design process. To retrofit an existing building, confer with an architect, structural engineer, and/or green roof consultant to ensure the proposed green roof can be supported – either as is or with additional support such as additional decking, roof trusses, joists, columns, and/or foundations, as indicated in Table GR-1.

If the roof will be accessible to the public, design the traffic flow paths and integrate decks, patios, or pavers into the design. Turf grass will stand up to regular foot traffic but requires an intensive green roof system with deeper soil and mandatory irrigation. Alternatively, less intrusive, lightweight stepping stones or decomposed gravel walkways can be used to provide access and interpretation with extensive green roofs. Design roof entrance and exit routes to design standards to be safe and efficient for maintenance staff or the public.

Step 5 – Select Component Layers

Green roof systems typically contain the following specialized component layers (see Figure GR-1):

- Waterproofing Membrane – Choose an adequate waterproof membrane that resists penetration by roots. The waterproofing component is essential to the long-term success of a green roof. Generally, a composite of several layers of protective materials is used. Materials used include modified asphalts (bitumens), synthetic rubber (EPDM), hypolan (CPSE), and reinforced PVC.
- Protection Layer/Root Barrier – The need for a separate root barrier (dense materials that inhibit root penetration) depends on the selected waterproof membrane. Modified asphalts usually require a root barrier, while synthetic rubber (EPDM) and reinforced PVC generally do not. Check with the manufacturer to determine if a root barrier is required for a particular product.
- Insulation/Air Barrier (optional) – If the thermal requirements of a building necessitate additional insulation, a layer of moisture-resistant insulation may be added.
- Water Retention Mat – If additional water retention is necessary to sustain the selected vegetation, a moisture retention mat may be used.
- Drainage/Water Storage/Aeration Layers – A green roof must safely drain runoff from the roof to an approved stormwater destination. Provide a drainage layer over the entire roof area to convey excess water to the building's drainage system. Drainage layers usually consist of molded drainage channels and retention cups.
- Geotextile Filter Fabric – Include a geotextile filter fabric layer to keep the growth media out of the drainage layer.
- Engineered Growth Media – Green roof growth media differ from soil in that they generally comprise lightweight mineral material containing a minimum of organic matter. Use a growth medium that meets established FLL or ASTM guidelines for both water retention and drainage. Growth media need to remain viable for decades for both plant growth and water control. The growth medium used in green roofs should:
    - Not degrade or compress over time;
    - Be accompanied by third-party laboratory data confirming its essential properties; and
    - Be covered under warranty if it is defective or degrades within a certain timeframe.

- Gravel Ballast (if needed) – Gravel ballast is sometimes placed along the roof perimeter and at air vents or other vertical elements. The need for ballast depends on operational and structural design issues. Ballast is sometimes used to provide maintenance access, especially to vertical elements requiring periodic maintenance. In some situations, a header or separation board may be placed between the gravel ballast and adjacent elements (e.g., growth media, drains). If a root barrier is used, it must extend under the gravel ballast and growth medium and up the side of the vertical elements.

Step 6 – Select Vegetation

Hire experienced horticulturists and/or landscape/green roof contractors who understand the local climate as well as the restrictions of a rooftop environment to select, install and maintain vegetation for the green roof.

Typical green roof vegetation ranges from low-growing succulent plants (e.g., sedums) or groundcovers (characteristic of extensive green roofs) to an assortment of native grasses, shrubs, and trees (more typical of intensive green roofs). Select plants that:

- Are adapted to the local climate, considering seasonal temperature ranges and average rainfall, the harsh rooftop environment (exposure to direct sun, frost, wind) and desired irrigation
- Will tolerate short periods of inundation from storm events during the wet season (October 1 – April 30)
- Possess shallow root systems suited for the depth of the growth media
- Require little or no irrigation after establishment
- Are primarily non-deciduous to provide adequate foliage cover year-round and reduce erosion potential
- Have good regenerative qualities (i.e., perennial or self-sowing)
- Are low maintenance (i.e., no need for fertilizers, pesticides, or herbicides, little or no mowing or trimming)
- Have growth patterns allowing vegetation to thoroughly cover the soil (at least 90% surface area coverage should be achieved within 2 years).
- Are compatible with the aesthetic preferences of the owner and future building occupants who may utilize the roof as a green space

Plants of the genus *Sedum* (family Crassulaceae), which are low-growing succulents, are often used for green roofs because of their resistance to wind, frost, drought, and fire. A mix of *Sedum* and other succulent plants is recommended because they possess many of the recommended attributes. Herbs, forbs, grasses, and other low groundcovers may also be used but typically require more irrigation and maintenance. Although the use of native vegetation is preferred when possible, some natives may not thrive in the rooftop environment. Thus, a mix of approximately 80%

Sedum/succulent plants and 20% native plants generally recognized for their hardiness is recommended, particularly for extensive green roofs. (Velazquez, 2005)

Step 7 – Determine Irrigation Needs

Determine irrigation needs based on the vegetation selected; at a minimum, temporary irrigation is recommended during the first two years of plant establishment. Potable water may be used in a permanent irrigation system, but consider using recycled, non-potable water, such as air conditioning condensate. Analyze any alternative water source to make sure it doesn't contain compounds harmful to the plants.

Step 8 – Incorporate Fire Breaks

A Berlin study found that green roofs are more fire resistant than gravel roofs. The City of Portland's Fire Bureau recently converted a fire station conventional roof to a green roof. Green roofs may help slow the spread of fire to and from the building through the roof, particularly when the growth medium is saturated. Succulents such as *Sedum* offer good fire resistance due to their high water content. However, if the plants themselves are dry, they may present a fire hazard. The integration of vegetation-free "fire breaks" at regular intervals across the roof, at the roof perimeter, and around all roof protrusions is recommended. These breaks should be made of a non-combustible material such as crushed gravel, pebbles, or concrete pavers; be 12 to 36 inches wide; and be situated every 130 feet in all directions. Another option for fire prevention is a sprinkler irrigation system connected to the fire alarm. (Köhler 2004; Peck and Kuhn; Velazquez 2005)

Construction Considerations

Consider hiring an environmental/green roof specialist to oversee the construction process.

- Throughout the construction process, protect green roof components, particularly the vegetation, until established.
- Prevent erosion by covering the growth media with mulch, jute/cellulose netting, or other approved protection methods prior to seeding or planting.
- Require consultants and installers to follow appropriate safety measures for working on industrial/commercial rooftops.

Long-Term Maintenance

The local permitting agencies in the Sacramento area require execution of a maintenance agreement or permit with the property owner prior to final acceptance of a private development project that includes a green roof. Such agreements or permits will typically include requirements such as those outlined in Table GR-2. The property owner or his/her designee is responsible for compliance.

Table GR-2. Inspection and Maintenance Recommendations for Green Roofs

Activity	Schedule
Irrigation	
Irrigation can be accomplished by hand watering or automatic sprinkler systems (preferable). Follow the short and long-term watering regimes designed by the landscape designer, based on the selected plants and their water needs.	Irrigate plants regularly until they are established and thereafter as needed.
Vegetation	
Inspect and maintain vegetation to ensure at least 90% vegetative cover (visual guideline) at the end of the plant establishment period and thereafter. Replace dead plants as needed. Use fertilizers sparingly, if at all.	Inspect monthly during vegetation establishment period; thereafter, annually or as needed.
Remove fallen leaves and debris from deciduous plant foliage. Repair/replace damaged or dead vegetation to maintain required cover.	As needed.
Employ integrated pest management (IPM) practices to minimize or eliminate use of chemical pesticides and herbicides. Remove weeds manually whenever possible.	As needed. Remove weeds during growing season.
During drought conditions, apply mulch or shade cloth as needed to prevent excess solar damage and water loss.	As needed.
Mow grasses and remove clippings.	As needed.
Component Layers	
Inspect/maintain waterproof membrane for proper operation, waterproofing integrity, and structural stability.	2-3 times per year.
Inspect/maintain drainage layer flow paths for proper operation. Determine if drain pipes and inlets are in good condition and check drain inlets for obstructions. Clear inlet pipe of growth media, vegetation, debris or other materials. Identify and correct sources of obstructions.	At least twice per year during wet season, preferably during and after storms. Additional inspections after periods of heavy runoff are desirable.
Inspect growth medium for evidence of erosion from wind or water. If erosion channels are evident, stabilize with additional growth medium and plants.	2-3 times per year. Additional inspections after periods of heavy runoff are desirable.
Other	
Use spill prevention measures for rooftop mechanical systems when handling substances that can contaminate stormwater. Correct any identified releases of pollutants.	As needed.
Remove litter/trash from landscape area to prevent clogging of inlet drains and interference with plant growth.	As needed.

Activity	Schedule
Manage mosquitos by eliminating any observed standing water; use integrated pest management (IPM) techniques and seek advice of local vector control district.	Weekly during peak mosquito season (April – October); as needed thereafter.
Maintain green roof aesthetics. Repair any damage or vandalism and remove any trash or debris.	As needed.
Reconstruct or replace the control measure when it is no longer functioning properly.	See projected lifespan in Appendix B for informational purposes.
Source: Adapted from the City of Portland's Stormwater Management Manual.	

Helpful Links and Resources

- Ecoroofs Everywhere: www.ecoroodseverywhere.org
- Greenroof Directory: www.greenroofs.com
- City of Portland, Oregon, Bureau of Environmental Services, Ecoroofs*: www.portlandonline.com/bes/index.cfm?c=34663 (includes the excellent publication "Portland Ecoroof Tours")
- San Francisco Bay Area Stormwater Management Agencies Association (BASMAA), Site Design Guidebooks for Northern SF Bay Area, Alameda and Santa Clara Counties*: www.basmaa.org/documents/index.cfm?fuseaction=documents&doctypeID=3
- *Green Roof Plants: A Resource and Planting Guide*, Edmund C. Snodgrass and Lucie L. Snodgrass, 2006. Timber Press, Portland, OR.

*These links contain project examples.

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Table GR-3. Design Data Summary Sheet for Green Roof

Designer: ____________________ Date: ____________

Company: ____________________

Project: ____________________

Location: ____________________

---

1. Determine Design Water Quality Volume — WQV = ____________ ft³

2a. Determine growth medium volume based on porosity of growth media with vegetation.
Volume of growth medium = WQV/Porosity — V = ____________ ft³

2b. Adjust Volume Up for Hydromodification Management (If Applicable) Based upon SAHM Modeling

Volume required based on SAHM modeling — V = ____________ ft³

SAHM Model Demonstrates Compliance with Flow Duration Standards — (Yes or No)________

---

3. Select green roof type — ☐ Extensive ☐ Intensive

---

4. Determine Required Structural Support ____________________

---

5. Check that system includes all component layers

☐ Waterproofing Membrane	☐ Protection Layer/Root Barrier
☐ Insulation/Air Barrier (optional)	☐ Water Retention Mat
☐ Drainage/Water Storage/Aeration Layers	☐ Geotextile Filter Fabric
☐ Engineered Growth Media	☐ Gravel Ballast (if needed)

---

6. Select Vegetation and Describe

☐ 80% *Sedum* ____________________

☐ 20% Native species ____________________

---

7. Determine Irrigation Needs ____________________

---

8. Incorporate Vegetation-Free Zones or Fire Breaks ____________________

Notes:

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Infiltration Basin

Description

An infiltration basin is a shallow earthen basin constructed in naturally pervious soils (usually Type A or B) and designed for infiltrating stormwater. An infiltration basin functions by retaining runoff and allowing it to percolate into the underlying native soils and into the groundwater table over a specified drawdown period. The bottoms and side slopes of infiltration basins are typically vegetated with dryland grasses or irrigated turf grass.

Photo credit: Wisconsin DNR

Siting Considerations

- Contributing drainage area: Up to 50 acres.
- Soil Infiltration Rate: 0.5-2.0 in/hr (permeability test required). Soils with higher infiltration rates require pretreatment device.
- Depth to groundwater: Minimum vertical separation to groundwater table is 10 ft from basin bottom
- Setback requirements: 150 ft from drinking water wells; 20 ft downslope and 100 ft upslope from foundations. Smaller setback maybe allowed with geotechnical engineer approval, verify with local permitting agency.
- Topography: Not appropriate on fill or steep slopes.

Pollutant Removal Effectiveness	
Sediment	High
Nutrients	High
Trash	High
Metals	High
Bacteria	High
Oil and Grease	High
Organics	High
Pyrethroids	High

The following is a partial list of the most common target pollutants for the Sacramento area: copper, lead, mercury, pathogens, diazinon, and chlorpyrifos. For more complete information refer to:

http://www.waterboards.ca.gov/water_issues/programs/tmdl/integrated2010.shtml

Source: CASQA California Stormwater BMP Handbook, January 2003

Vector Considerations

- Potential for mosquitoes due to standing water will be greatly reduced or eliminated if the basin is properly designed, constructed, and operated to maintain its infiltration capacity and drawdown time.

Advantages

- Reduces or eliminates stormwater discharge to surface waters during most storm events
- Reduces peak flows during small storm events.
- Can be incorporated into site landscape features or multi-use facilities such as parks or athletic fields.
- Potential LEED Credits
  - Credit 6.1 – Stormwater Design – Quantity Control
  - Credit 6.2 – Stormwater Design – Quality Control

Limitations

- Not appropriate for areas with slowly permeable soils, high groundwater or existing groundwater contamination.
- Not appropriate for industrial sites or locations where spills may occur.
- Must be protected from high sediment loads. Once clogged with sediment, restoration of basin infiltration capacity may be difficult.

General Maintenance Recommendations (Low to Moderate)

- Maintain vegetation as in any landscaped area.
- Periodically remove debris and sediment from basin floor.
- Repair/replace vegetation as necessary to maintain desired cover.
- Check and record drawdown time during and after major storm events to document infiltration rates.
- Remove sediment and/or scarify basin bottom to restore infiltration capacity when maximum drawdown time for WQV is exceeded.

How Does an Infiltration Basin Work?

Do not confuse an Infiltration Basin with an Extended Dry Detention Basin, which is designed to infiltrate some runoff and release the rest, as described elsewhere in this chapter.

An infiltration basin is designed to retain the stormwater quality design volume (WQV) within a basin and to allow that volume to infiltrate into the native soil profile over the design drawdown period. Infiltrated water typically reaches and recharges the underlying groundwater. Treatment of the runoff occurs through a variety of natural mechanisms as the water flows through the soil profile. To ensure adequate treatment, the depth of unsaturated soil between the infiltration basin bottom and the seasonal maximum groundwater surface level should be at least 10 feet. See Figure IB-1 for a typical infiltration basin configuration.

Other Names: retention basin, percolation basin

Planning and Siting Considerations

- Soil permeability, depth to groundwater, and design safety factors should be determined by a qualified geotechnical engineer or geologist to ensure that conditions conform to the criteria listed in Table IB-1. A soil permeability test will be required by permitting agency to confirm acceptable saturated permeability. Number of soil borings will depend on size of facility. Consult a geotechnical engineer and the permitting agency for guidance on soil permeability test details.
- The geotechnical report shall include information regarding proximity to hazardous spills or contaminated plumes within a 1000 feet radius of the project site using GeoTracker (https://www.waterboards.ca.gov/gama/geotracker_gama.shtml)
- Not suitable for areas with existing groundwater contamination.
- Integrate infiltration basins into open space buffers, undisturbed natural areas, and other landscape areas when possible. Avoid placing features in open space and wetland preserves where future maintenance of the water quality facility will be restricted or prohibited.
- Not suitable for active parkland/recreation use.
- Irrigation may be required to maintain vegetation on the slopes and bottom of the basin. If irrigation is needed, coordinate its design with that of the general landscape irrigation system for the project.
- Plan for setback requirements (see Table IB-1).

Design Criteria

Design criteria for infiltration basins are listed in Table IB-1. Use the Design Data Summary Sheet provided at the end of this fact sheet (Table IB-3) to record design information for the permitting agency's review.

Table IB-1. Infiltration Basin Design Criteria

Design Parameter	Criteria	Notes
Contributing Drainage Area	≤ 50 acres	
Design Volume	WQV or as dictated greater by SAHM modeling (for projects with hydromodification requirement)	See Appendix E in this Design Manual
Soil Infiltration Rate	0.5-2.0 in/hr	To be confirmed by permeability test.[1] Higher permeability allowed if pretreatment provided.
Maximum Drawdown Time	48 hrs	Based on WQV (see Appendix E)
Minimum Groundwater Separation	10 ft	Between basin bottom and top of seasonally high groundwater table
Freeboard (minimum)	1 ft	

Design Parameter	Criteria	Notes
Setbacks	150 ft 20 ft 100 ft	From drinking water wells, tanks, fields, springs Downslope from foundations Upslope from foundations
Inlet/outlet erosion control	-	Use energy dissipator to reduce inlet/outlet velocity
Forebay settling basin volume/drain time	5-10%/45 minutes	Based on WQV
Embankment side slope (H:V)	≥ 4:1 ≥ 3:1	Inside Outside (without retaining walls)
Maintenance access ramp slope (H:V)	10:1	Or flatter
Maintenance access ramp width	15 to 20 ft	Check with permitting agency for their minimum width. Pave approach with concrete or porous pavement materials, subject to approval of permitting agency.
Relief underdrain pipe diameter	4 inches	Perforated plastic pipe
Vegetation	-	Side slopes and bottom (may require irrigation)

1 Consult with geotechnical engineer and permitting agency for permeability test details.

Design Procedure

*Use the **Design Data Summary Sheet** (Table IB-3) to record design information for the permitting agency's review.*

Step 1a – Calculate Water Quality Volume (WQV)

Using the Appendix E in this Design Manual, determine the contributing drainage area and stormwater quality design volume (WQV) for 48-hour drawdown.

Step 1b – SAHM Modeling for Hydromodification Management (If applicable)

Upsize the infiltration basin volume as necessary based upon modeling results if implementing as a hydromodification control. Maintain depth so as to adhere with 48–hour maximum drawdown for WQV.

Step 2 – Calculate Design Depth of Water Surcharge in Infiltration Basin (D_{max})

$$D_{max} = \frac{t_{max} \times I}{12 \times s}$$

Where:

t_{max} = Maximum drawdown time = 48 hrs

I = Site infiltration rate (soil permeability) (in/hr)

s = Safety factor

In the formula for maximum allowable depth, the safety factor accounts for the variability in soil permeability at the site and the relative uncertainty in the infiltration rate measurements. The more variable the soil conditions and the less certain the infiltration rate, the higher the safety factor should be. Safety factors typically range between two (2) and ten (10) and should be determined by a qualified geotechnical engineer or geologist based on field measurements of saturated vertical permeability at the proposed site. Note that soils with permeability greater than two (2) inches per hour may be used if full pretreatment is provided using one of the approved treatment controls from this manual.

Step 3 – Calculate Minimum Surface Area of Infiltration Basin Bottom (A_{min})

$$A_{min} = WQV/D_{max}$$

Where:

A_{min} = minimum area required (ft^2)

D_{max} = maximum allowable depth (ft)

Step 4 – Design Forebay Settling Basin

The forebay provides a zone for removal of course sediment by sedimentation. Design the forebay volume to be five (5) to ten (10) percent of the WQV. Separate the forebay from the basin by a berm or similar feature. Provide an outlet pipe connecting the bottom of the forebay and the basin and size it to allow the forebay volume to drain within 45 minutes.

Step 5 – Design Embankments

Interior slopes (H:V) should be no steeper than 4:1 and exterior slopes no steeper than 3:1. Flatter slopes are preferable.

Step 6 – Design Maintenance Access

Provide for all-weather access for maintenance vehicles to the bottom and outlet works. Maximum grades of access ramps should be ten (10) percent and minimum width will vary according to local permitting agency requirements, but usually between 15-20 feet. Pave ramps with concrete that is colored to blend with surroundings.

Florin Mall Dr. The City of Sacramento

Step 7 – Design Security Fencing

To protect habitat and for safety reasons, provide aesthetic security fencing approved by the permitting agency around the infiltration basin, except when specifically waived by the permitting agency.

Step 8 – Design Bypass

Provide for bypass or overflow of runoff volumes in excess of the WQV. Provide stabilized spillway or overflow structures, as applicable (see Figure IB-1).

Step 9 – Design Relief Drain

Provide 4-inch diameter perforated plastic relief underdrain with a valved outlet to allow removal of standing water in the event of loss of soil infiltration capacity. Cutoff collars are recommended along drain pipes running under the embankment at 10 to 20 feet intervals to prevent the water from piping through the fill. The portion of the relief drain that is under the embankment should not be perforated.

Step 10 – Select Vegetation

Plant basin bottoms, berms, and side slopes with native grasses or with irrigated turf. Vegetation provides erosion protection and filters sediment out of the runoff. Shrubs and trees may also be incorporated where appropriate.

Step 11 – Design irrigation system

Provide an irrigation system to maintain viability of vegetation (short-term establishment and long-term needs). Refer to the Efficient Irrigation fact sheet (EI-1) at the end of Chapter 4.

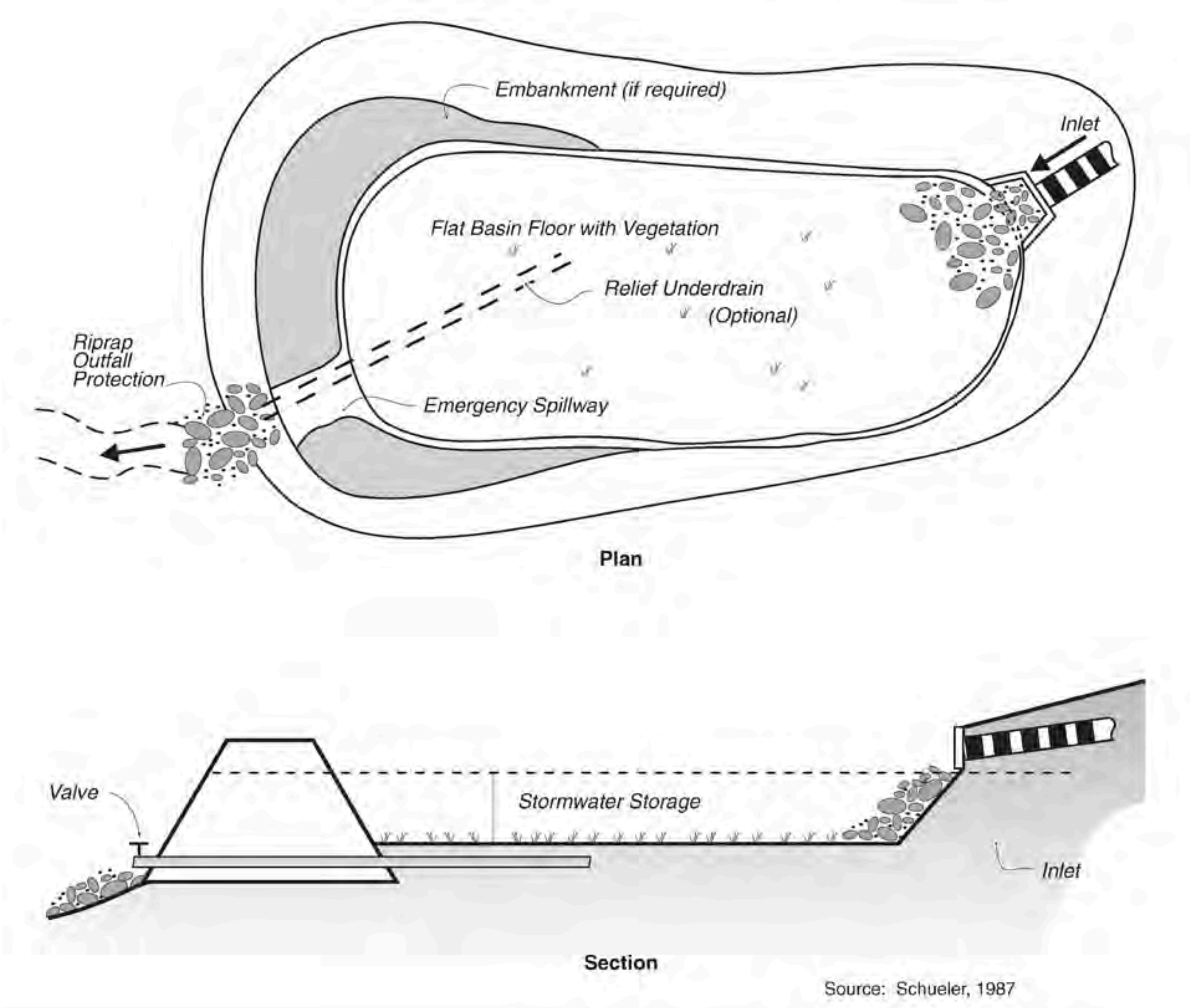


Figure IB-1. Infiltration Basin

Construction Considerations

- If possible, stabilize the entire contributing drainage area to the infiltration basin before construction begins. If this is not possible, divert flow around the basin to protect it from sediment loads during construction. If sediment does enter the facility during construction, the contractor will be required to remove soil from the basin floor after the entire site has been stabilized, to the satisfaction of the permitting agency inspector.
- Construct basin using equipment with extra wide, low-pressure tires. Prevent construction traffic from entering basin.
- Ensure that final grading produces a level basin bottom without low spots or depressions.
- After final grading, deep till the basin bottom.
- Once construction is complete, stabilize the entire contributing drainage area to the basin and the vegetation within the basin itself, before allowing runoff to enter the infiltration facility.
- Divert runoff (other than necessary irrigation) during the period of basin vegetation establishment.
- Inspect frequently during vegetation establishment, and repair, seed, or re-plant damaged areas immediately.
- Provide cleanout stakes in the forebay and main basin to facilitate inspection and maintenance.
- Do not plant trees on compacted embankment.

Long-term Maintenance

The local permitting agencies in the Sacramento area require execution of a maintenance agreement or permit with the property owner for projects including an infiltration basin. Check with the local permitting agency about the timing for execution of the agreement. Such agreements will typically include requirements such as those outlined in Table IB-2. The property owner or his/her designee will be responsible for compliance. See Appendix B for additional information about maintenance requirements and sample agreement language.

Table IB-2. Inspection and Maintenance Recommendations for Infiltration Basins

Activity	**Schedule**
Monitor infiltration rate in basin after storm events by recording the drop-in water depth versus time using a calibrated rod or staff gauge.	Several times during first year. Thereafter at the beginning and end of the wet season. Additional monitoring after periods of heavy runoff is recommended.
If drawdown time is observed to have increased significantly over the design drawdown time, clean, re-grade, and till basin bottom to restore infiltrative capacity. This maintenance activity is expensive and the need for it can be minimized by preventing upstream erosion.	As needed.
Inspect basin to identify potential problems such as erosion of the basin side slopes and invert, standing water, trash and debris, and sediment accumulation.	At beginning and end of the wet season. Additional inspections after periods of heavy runoff are desirable.
If erosion is occurring within the basin, stabilize with erosion control mulch or mat and seed or re-vegetate immediately.	As needed.
Monitor health of vegetation and replace as needed.	Routinely monitor vegetation.
Trim vegetation to prevent the establishment of woody vegetation and for aesthetic and vector control reasons.	At the beginning and end of the wet season.
Remove litter and debris from infiltration basin area.	As needed.
Remove accumulated sediment and re-grade when the accumulated sediment volume exceeds ten (10) percent of the basin volume. Note: scarification or other activities creating disturbance should only be performed when there are actual signs of clogging, rather than on a routine basis.	As required for both forebay and basin.
Reconstruct or replace the control measure when it is no longer functioning properly.	See projected lifespan in Appendix B for informational purposes.
Prune trees (if applicable).	Every 3-5 years.

Table IB-3. Design Data Summary Sheet for Infiltration Basin

Designer: ______________________ **Date:** __________

Company: ______________________

Project: ______________________

Location: ______________________

1a. Determine Design Water Quality Volume			
a. Contributing drainage area	Area =		ft^2
b. Water Quality Volume	WQV =		ft^3
1b. Adjust Volume Up for Hydromodification Management (If Applicable) Based upon SAHM Modeling			
a. Water Quality Volume based on SAHM modeling	V =		ft^3
b. SAHM Model Demonstrates Compliance with Flow Duration Standards	(Yes or No)		
2. Determine Maximum Allowable Depth ($D_{max} \leq 10$ ft)			
a. Maximum drawdown time (t=48 hours)	t =	48	hrs
b. Site infiltration rate (I)	I =		in/hr
c. Safety factor (s)	s =		
d. $D_{max} = \frac{t_{max} \times I}{12 \times s}$	D_{max} =		ft
3. Determine Minimum Allowable Basin Bottom Area ($A_{min} = WQV/D_{max}$)	A_{min} =		ft^2
4. Forebay Volume (VFB)	VFB =		ft^3

5. Bypass/Outlet Control Structure (check type)

☐ Overflow Structure ☐ Spillway

6. Vegetation (check type used or describe "other")

☐ Native grasses ☐ Irrigated turf grass

☐ Trees/Other: ______________________

Notes: ______________________

Infiltration Trench

Description

An infiltration trench is a long, narrow trench constructed in naturally pervious soils (types A or B) and filled with gravel (and sand if desired). Runoff is stored in the trench until it infiltrates into the soil profile over a specified drawdown period. Overflow drains are often provided to allow drainage if the infiltration trench becomes clogged. Infiltration vaults and infiltration leach fields are subsurface variations of the infiltration trench concept; runoff is distributed to the upper zone of a subsurface gravel bed by means of perforated pipes.

Photo credit: CASQA, 2003

Siting Considerations

- Contributing Drainage area: Up to 5 acres. Contributing areas should have a low potential for erosion.
- Soil Infiltration Rate: 0.5-2.0 in/hr (permeability test required). Soils with higher permeability will require pretreatment device.
- Depth to groundwater: Minimum vertical separation to groundwater table is 10 ft from trench bottom
- Setback requirements: 150 ft from drinking water wells; 20 ft downslope and 100 ft upslope from foundations. Smaller setback maybe allowed with geotechnical engineer approval, verify with local permitting agency.
- Maximum contributing area slope: 5%, maximum downstream slope: 20%

Pollutant Removal Effectiveness	
Sediment	High
Nutrients	High
Trash	High
Metals	High
Bacteria	High
Oil and Grease	High
Organics	High
Pyrethroids	High

The following is a partial list of the most common target pollutants for the Sacramento area: copper, lead, mercury, pathogens, diazinon, and chlorpyrifos. For more complete information refer to:

http://www.waterboards.ca.gov/water_issues/programs/tmdl/integrated2010.shtml

Source: CASQA California Stormwater BMP Handbook, January 2003

Vector Considerations

- Potential for mosquitoes due to standing water will be greatly reduced or eliminated if the trench is properly designed, constructed, and operated to maintain its infiltration capacity and drawdown time.

Advantages

- Reduces or eliminates stormwater discharge to surface waters during most storm events.
- Reduces peak flows during small storm events.
- Can be incorporated into site landscaping.
- Potential LEED Credits
  - Credit 6.1 – Stormwater Design – Quantity Control
  - Credit 6.2 – Stormwater Design – Quality Control

Limitations

- Not appropriate for areas with slowly permeable soil or high groundwater.
- Must be protected from high sediment loads; difficult to restore functionality when clogged.
- Not appropriate for industrial sites or locations where spills may occur.

General Maintenance Recommendations (Low to Moderate)

- Repair/replace vegetation buffer as necessary to maintain full cover and prevent erosion.
- Periodically remove debris from trench surface.
- Check and record infiltration rate during and after major storm events to document infiltration rates.
- Repair or replace trench material to restore infiltration capacity when infiltration rate falls below design rate.

How Does an Infiltration Trench Work?

An infiltration trench is designed to retain the stormwater quality design volume (or WQV) in the trench and allow that volume to infiltrate into the native soil profile over the design drawdown period. Infiltrated water typically reaches and can recharge the underlying groundwater. Treatment of the runoff occurs through a variety of natural mechanisms as the water flows through the trench media and the soil profile. To ensure adequate treatment and protect groundwater, the depth of unsaturated soil between the trench bottom and the highest seasonal groundwater surface level should be at least 10 feet. See Figure IT-1 for a typical infiltration trench configuration.

> ***Prevent Clogging!***
> *Infiltration trenches need to be protected from sediment loads to prevent clogging; a grass buffer is required. If sediment deposition significantly reduces soil infiltration rates, the cost of restoring the trench can be high.*

Infiltration vaults (Figure IT-2) and infiltration leach fields (Figure IT-3) are similar to infiltration trenches except they are entirely below ground; runoff is conveyed to the upper zone of the gravel bed media via perforated pipes.

Other Names: Percolation trench

Planning and Siting Considerations

- Conduct an on-site permeability test to confirm suitable infiltration rate prior to beginning design. At least one soil boring in proposed trench location is recommended; consult with a geotechnical engineer for guidance on soil permeability test details. Local permitting agency will require results before accepting design.
- The geotechnical report shall include information regarding proximity to hazardous spills or contaminated plumes within a 1000 feet radius of the project site using GeoTracker (https://www.waterboards.ca.gov/gama/geotracker_gama.shtml)
- Not suitable for areas with existing groundwater contamination.
- Integrate infiltration trenches into open space buffers, undisturbed natural areas, and other landscape areas when possible.
- Plan for setback requirements as listed in Table IT-1.
- Do not locate infiltration trenches under tree drip lines.
- Install a pretreatment grass buffer strip to filter out sediment and protect the trench from high sediment loads (see Figure IT-1).

Design Criteria

Design criteria for infiltration trenches are listed in Table IT-1. Use the Design Data Summary Sheet provided at the end of this fact sheet (Table IT-3) to record design information for the permitting agency's review.

Table IT-1. Infiltration Trench Design Criteria

Design Parameter	Criteria	Notes
Contributing Drainage Area	$\leq$ 5 acres	
Design Volume	WQV or as dictated greater by SAHM modeling (for projects with hydromodification requirement)	See Appendix E in this Design Manual
Maximum Drawdown Time for WQV	48 hrs	Based on WQV
Soil Infiltration Rate	0.5-2 in/hr	(soil permeability test required)
Minimum Groundwater Separation	10 ft	Between trench bottom and top of seasonally high groundwater table
Maximum Trench Surcharge Depth (D_{max})	10 ft	
Setbacks	150 ft	From drinking water wells, tanks, fields, springs

Design Parameter	Criteria	Notes
	20 ft 100 ft -	Downslope from foundations Upslope from foundations Do not locate under tree drip-lines
Trench media material size/type	3 in. diameter	Washed gravel 6-12 inches deep sand (if desired)
Trench lining material	-	Geotextile fabric prevents clogging
Observation well size	4-6 in	Perforated PVC pipe with removable cap
Pretreatment grass buffer strip length/slope	10 ft/4%	Minimum length/maximum slope in flow direction

Design Procedure

Step 1a – Calculate Water Quality Volume (WQV)

*Use the **Design Data Summary Sheet** (Table IT-3) to record design information for the permitting agency's review.*

Using the Appendix E in this Design Manual, determine the contributing drainage area and stormwater quality design volume (WQV) for 48-hour drawdown.

Step 1b – SAHM Modeling for Hydromodification Management (If applicable)

Upsize the infiltration trench volume as necessary based upon modeling results if implementing as a hydromodification control. Maintain depth so as to adhere with 48–hour maximum drawdown for WQV.

Step 2 – Calculate Design Depth of Water Surcharge in Infiltration Trench (D_{max})

Maximum depth should not exceed ten (10) feet.

$$D_{max} = \frac{t_{max} \times I}{12 \times s \times P}$$

Where:

t_{max} = Maximum drawdown time = 48 hrs

I = Site infiltration rate (soil permeability) (in/hr)

s = Safety factor

P = Porosity of infiltration trench gravel material (use 0.30)

In the formula for maximum allowable depth, the safety factor accounts for the variability in soil permeability at the site and the relative uncertainty in the infiltration rate measurements. The more variable the soil conditions and the less certain the infiltration rate, the higher the safety factor should be. Safety factors typically range between two (2) and ten (10) and should be determined by a qualified geotechnical engineer or geologist based on field measurements of saturated vertical permeability at the proposed site. Note that soils with permeability greater than two (2) inches per hour may be used if full pretreatment is provided using one of the approved treatment controls from this manual (e.g., vegetated filter strip, vegetated swale).

Step 3 – Calculate Minimum Surface Area of Infiltration Trench Bottom (A_{min})

$$A_{min} = WQV/D_{max}$$

Where:

A_{min} = minimum area required (ft^2)

D_{max} = maximum allowable depth (ft)

Step 4 – Design Observation Well

Provide a vertical section of perforated PVC pipe, four (4) to six (6) inches in diameter, installed flush with the top of the infiltration trench on a PVC footplate and with a locking, removable cap. The observation well is needed to monitor the infiltration rate in the infiltration trench and is useful for marking the location of the trench.

Step 5 – Design Bypass

Provide for bypass or overflow of runoff volumes in excess of the WQV by means of a screened overflow pipe connected to the downstream storm drain system or a grated overflow outlet.

Construction Considerations

- If possible, stabilize the entire contributing drainage area to the infiltration trench before construction begins. If this is not possible, divert flow around the trench site to protect it from sediment loads during construction.
- Once construction is complete, stabilize the entire contributing drainage area to the trench before allowing runoff to enter the trench facility.
- Install filter fabric on sides, bottom, and one foot below the surface of the trench (see Figure IT- 1). Provide generous overlap at all seams.

Valley-Hi Library, The City of Sacramento

- Store excavated material at least 10 feet from the trench to avoid backsliding and cave-ins.
- Place clean, washed 1-3 inch gravel in the excavated trench in lifts and lightly compact it with a plate compactor. Using unwashed gravel can result in clogging.

Long-term Maintenance

The local permitting agencies in the Sacramento area will require execution of a maintenance agreement or permit with the property owner for projects including an infiltration trench. Check with the local permitting agency about the timing for execution of the agreement. Such agreements will typically include requirements such as those outlined in Table IT-2. The property owner or his/her designee will be responsible for compliance. See Appendix B for additional information about maintenance requirements and sample agreement language.

Table IT-2. Inspection and Maintenance Recommendations for Infiltration Trenches

Activity	**Schedule**
Monitor the infiltration rate in the trench during and after storms by recording the drop-in water depth versus time using a calibrated rod or staff gauge.	Several times during first year then near the beginning and end of each wet season. Additional monitoring after periods of heavy runoff is desirable.
Clean the trench when the infiltration rate decreases significantly over the design rate. To clean it, remove the top layer of gravel and clogged filter fabric, install a new layer of filter fabric, wash the removed gravel, and place the washed gravel back into the trench. This maintenance activity is expensive and can be avoided by preventing upstream erosion and maintaining the pretreatment buffer strip.	As required.
Inspect grass buffer strip to identify potential channelization and erosion problems.	At beginning and end of the wet season. Additional inspections after periods of heavy runoff are desirable.
If channels are forming or erosion is occurring within the grass buffer strip, add soil as needed and stabilize with erosion control mulch or mat and re-seed or re-vegetate immediately. See the Vegetated Filter Strip fact sheet elsewhere in this chapter for more information.	As needed.
Inspect trench to identify potential problems such as standing water, trash and debris, and sediment accumulation.	At beginning and end of the wet season. Additional inspections after periods of heavy runoff are desirable.
Remove pioneer trees that sprout in the trench vicinity so that roots don’t puncture the filter fabric, allowing sediment to enter the trench.	As needed.
Trim adjacent trees so the canopy doesn’t extend over the trench surface.	As needed
Remove litter and debris from trench area.	As needed.
Reconstruct or replace the control measure when it is no longer functioning properly.	See projected lifespan in Appendix B for informational purposes.

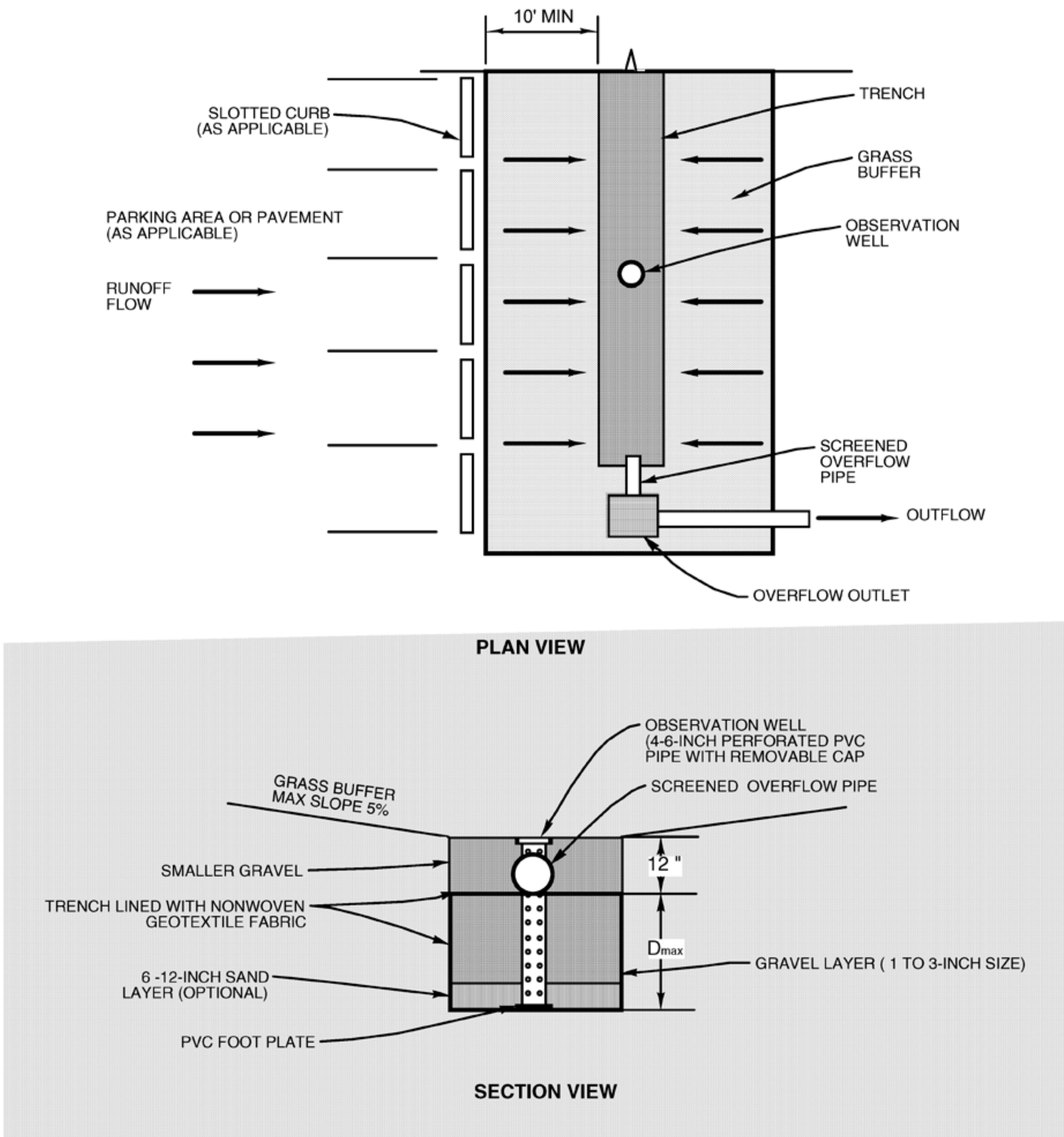


Figure IT-1. Infiltration Trench

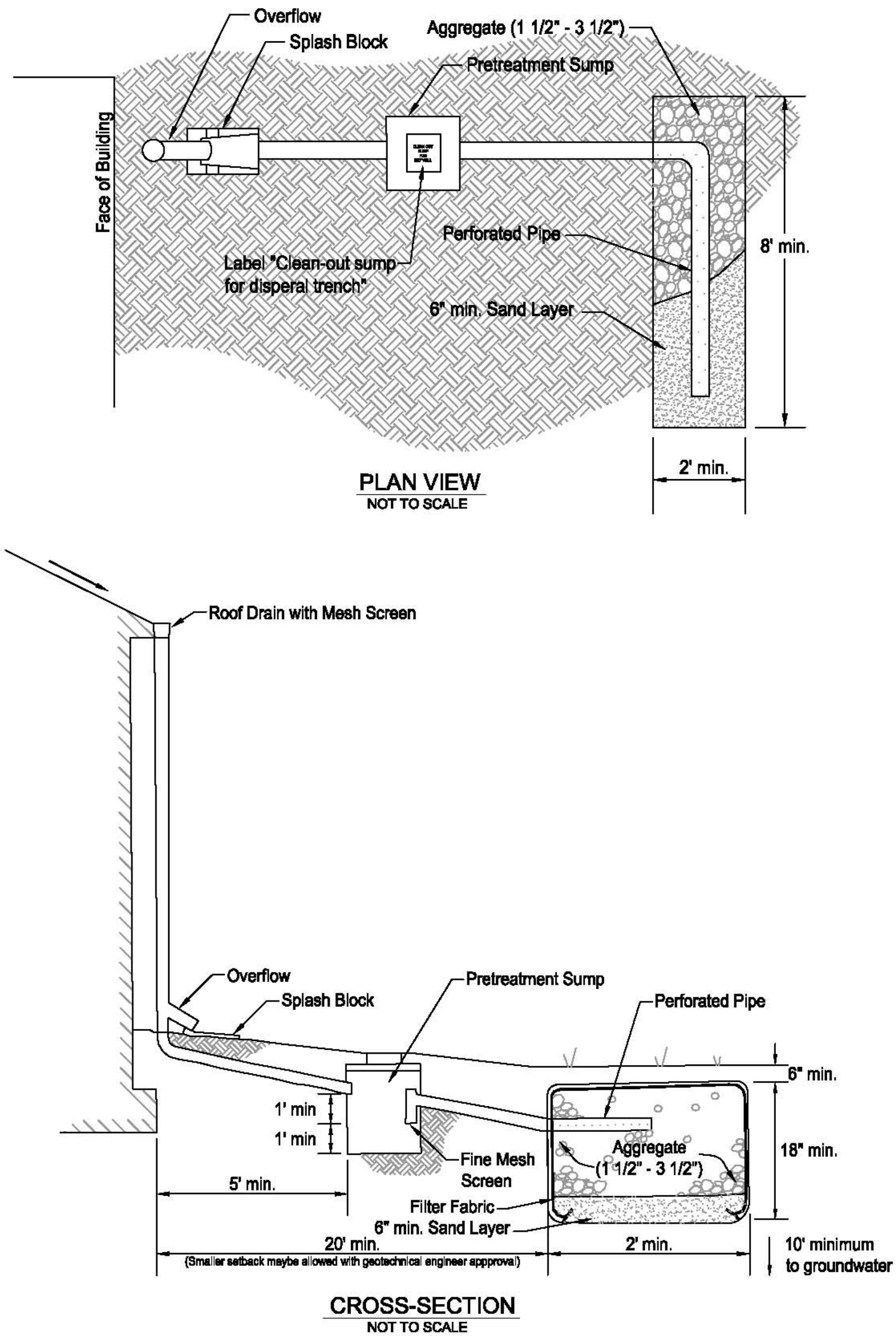


Figure IT-2. Infiltration Vault

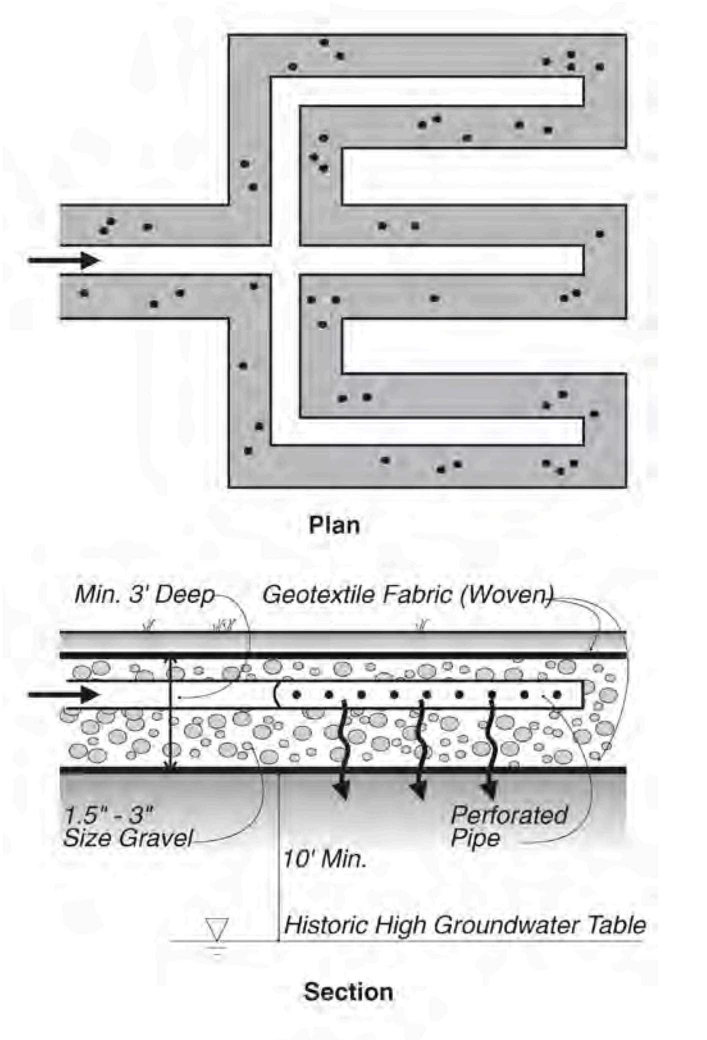


Figure IT-3. Infiltration Leach Field

Table IT-3. Design Data Summary Sheet for Infiltration Trench

Designer: ______________________ **Date:** ____________

Company: ______________________

Project: ______________________

Location: ______________________

1a. Determine Design Water Quality Volume

a. Contributing drainage area	Area =		ft^2
b. Water Quality Volume	WQV =		ft^3

1b. Adjust Volume Up for Hydromodification Management (If Applicable) Based upon SAHM Modeling

a. Water Quality Volume based on SAHM modeling	V =		ft^3
b. SAHM Model Demonstrates Compliance with Flow Duration Standards	(Yes or No)		

2. Determine Maximum Allowable Depth ($D_{max} \leq 10$ ft)

a. Maximum drawdown time (t=48 hours)	t =	48	hrs
b. Site infiltration rate (I)	I =		in/hr
c. Safety factor (s)	s =		
d. Gravel porosity (P)	P =	0.30	
e. $D_{max} = \frac{t_{max} \times I}{12 \times s \times P}$	D_{max} =		ft

3. Determine Minimum Trench Bottom Surface Area

($A_{min} = WQV/D_{max}$)	A_{min} =		ft^2

4. Final Design Trench Dimensions

a. Trench length (L)	L =		ft
b. Trench width (W)	W =		ft
c. Trench depth (D)	D =		ft

5. Observation well diameter	Diam. =		in

Notes: ______________________

Interceptor Trees

Description

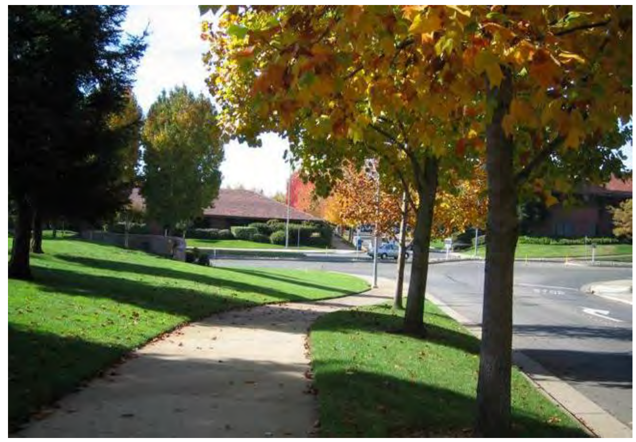


Photo source unknown

Interceptor trees are those used in residential and commercial settings as part of the stormwater quality management plan to reduce runoff and pollution from the development project. Interceptor trees can be placed on residential lots, throughout landscape corridors, in commercial parking lots, and along street frontages. Trees installed in municipal right-of-ways may be protected through ordinances and can provide years of aesthetic benefit.

Siting Considerations

- Soils: Drainage and soil type must support selected tree species.
- Location: Locate within 25 feet of impervious surface (and as close as practical depending on the species and cultivar).
- Other structures: Maintain appropriate distance from infrastructure and structures that could be damaged by roots and avoid overhead power lines, underground utilities, septic systems, sidewalks, curbs, patios, etc.

Vector Considerations

- Potential for mosquitoes due to standing water where excess irrigation is applied or planter box is not designed to properly drain.

Advantages

- Reduces the amount of pollutants entering the storm drain system.
- Can reduce size of downstream stormwater quality treatment measure(s) by reducing the volume required to treat.
- Enhances aesthetic values.
- Provides shade to cool pavement and reduces surface runoff temperatures.
- Aids in removal of air pollutants and noise reduction.
- Shade trees required by the permitting agency may be counted as interceptor trees.

- Extends life of asphalt paving.
- Potential LEED Credits
    - Credit 6.1 – Stormwater Design – Quantity Control

Limitations

- Fire safety may be a consideration in areas with increased risk for fire hazard.
- Root systems can damage pavement and other structures if trees are not selected and installed correctly.
- Incorrect tree selection can result in high irrigation costs and pest infestation.

Maintenance Recommendations

- Pruning of trees may be required to maintain tree, ensure safety, and prevent damage to structures.
- Diseased/damaged trees, and those with poor structure, should be removed and replaced as soon as possible.
- Irrigation system may be required in perpetuity.

How Do Interceptor Trees Protect Water Quality?

Interceptor trees are ideal for all projects, including those where space is limited, in which trees can be placed along street frontages and in common space. Urban areas with higher numbers of trees exhibit hydrology more similar to natural conditions compared to urban areas without a tree canopy. Trees intercept storm water and retain a significant volume of the captured water on their leaves and branches allowing for evaporation and providing runoff reduction benefits. For example, a large oak tree can intercept and retain more than 500 to 1,000 gallons of rainfall in a given year (Cappiella, 2004). While the most effective Interceptor Trees are large canopied evergreen trees, deciduous trees can also provide a benefit. For example, a leafless Bradford pear will retain more than one half the amount of precipitation intercepted by an evergreen cork oak (Xiao et al., 2000).

The shade provided by trees keeps the ground under the trees cooler, thereby reducing the amount of heat gained in runoff that flows over the surface under the trees. This attenuation of heat in storm water helps control increases in stream temperatures. On slopes, tree roots hold soil in place and prevent erosion. Mulch provided under the tree will also help trap moisture.

Planning and Siting Considerations

Check with the local permitting agency about requirements for trees located in public utility easements. A tree permit may be required to plant, prune or remove such trees. Also, consultation with an arborist and the local master tree list is recommended for selecting and locating appropriate tree species for the unique site conditions. When trees are planted in the right-of-way, consider including curb cuts to provide additional water to the trees and potentially improve management of street runoff.

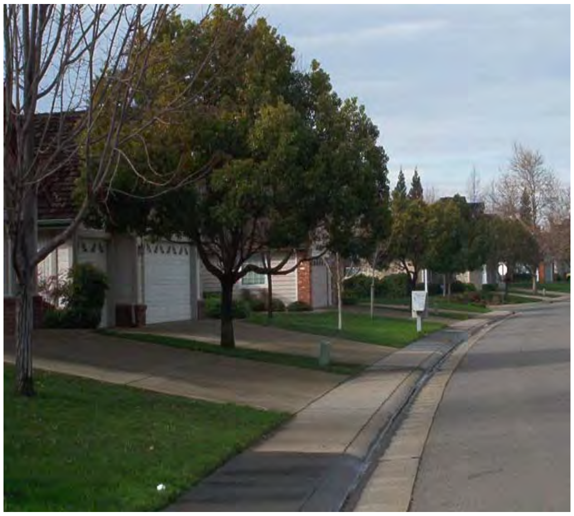
New trees

- Select trees from a list of approved species established by the permitting agency (see Table INT-1 for examples, but check with appropriate agency for verification). Native species and those with a larger canopy at maturity are generally preferred, depending on available space for root and canopy. Match hydro-zone of existing trees where possible.
- Select tree species based on the soils found on the site, available water, and aesthetics. Consult a landscape architect or arborist to ensure suitability of species for site conditions and design intent.
- Do not plant monocultures of same family, genus and/or cultivar. Do not plant trees too close together. Plant selection and spacing should be per the recommendations of the landscape architect or arborist.
- Interceptor trees should be incorporated into the site's general landscaping plan, but trees designated for storm water credits must be clearly labeled on plans submitted for local agency approval and other planning submittals.
- Do not place trees near structures that may be damaged by the growing root system. These include, but are not limited to, overhead utilities and lighting, underground utilities, fire hydrants, signage, septic systems, curb/gutter and sidewalks, paved surfaces, building foundations and existing trees. Consideration should also be given to fire truck access routes and pedestrian pathways. Utilize approved root barriers (deflectors) when trees are planted close to infrastructure, per the local permitting agency standards.
- Plan for parking lot shading that may be required, depending on the jurisdiction.

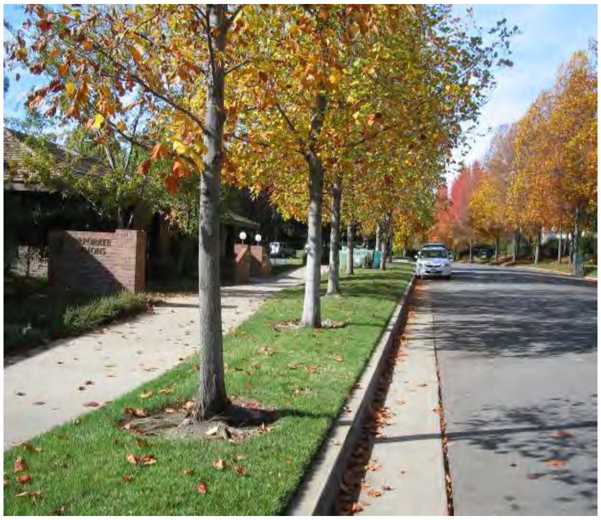
Existing trees

- New landscaping under existing trees must be carefully planned to avoid any grade changes and any excess moisture in trunk area, depending on tree species. Existing plants which are compatible as to irrigation requirements and which complement the trees as to color, texture and form are to be saved.
- Grade changes greater than six inches within the critical root zone should be avoided. Also, soil compaction and texture in the drip-line area greatly affect tree survival.

Examples of Suitable Uses of Interceptor Trees



Residential: large and small subdivisions, small-scale developments, located in or out of municipal right-of-way. The tree pictured is an evergreen Camphor.



Commercial: plazas and courtyards, landscape areas in parking lots and road frontages.

Industrial: Employee parking lots, entryway features, and road frontages.

Parks and Open Space: parking lots, park hardscape areas.

Variations

Three types of interceptor trees are discussed in this fact sheet: 1) new evergreen trees, 2) new deciduous trees, and 3) existing trees.

New Evergreen Trees

Evergreen trees provide the greatest benefit to water quality. Generally, the larger the tree and the smaller the leaves, the more rain is intercepted. Further, evergreen trees retain their leaves throughout the rainy season.

New Deciduous Trees

Since the interceptor tree's water quality benefit increases with increasing surface area of leaves and branches, deciduous trees, which lose their leaves early in the Central Valley's rainy season, have less value than evergreen trees. However, even deciduous trees contribute to interception and shading, and credits are applied for inclusion of such trees in site plans.

Existing Trees

Conservation of existing trees provides aesthetic value to a site as well as a water quality benefit. Credits may be applied for protected trees located within 25 feet of an impervious surface, as long as the trees are not located in the designated "open space" for the project, for which credit has already been applied.

Design Criteria

Design criteria for interceptor trees are listed in Table INT-1.

Table INT-1. Design Criteria for Interceptor Trees

Also see Appendix D for information on calculating runoff reduction credits and a list of Trees Qualifying for Interceptor Tree Runoff Reduction Credits.

Variation/Parameter	Criteria
All Planted Trees	
Size	15 gallon container (minimum) or as acceptable by the local agency
Location	Must be planted within 25 feet of ground-level impervious surfaces. Must be spaced such that the crowns do not overlap (at 15 years of growth).
Installation and Irrigation	Trees must be installed and irrigated in accordance with local permitting agency Landscaping Standards.

Variation/Parameter	Criteria
New Evergreen and Deciduous Trees	
Size and Species	See Appendix D for suggested tree species meeting size requirement.
Existing Trees	
Species	Any appropriate tree species.

Construction Considerations

New Trees

- Do not allow soil in planter areas to be compacted during construction.
- Do not allow soil in planter areas to become contaminated with construction related materials such as lime or limestone gravel, concrete, sheetrock, or paint.
- Install irrigation system according to proper specifications.
- When installing lawn around trees, install the grass no closer than 24 inches from the trunk.
- Install protective fencing if construction is ongoing, to avoid damage to new trees.
- Mulch with hardwood chips (not redwood or cedar) 4”-6” installed depth (2”-3” settled depth).
- Do not use pressure treated stakes. Do not stake into or through the root ball. Stakes should be set perpendicular to the prevailing wind. Stakes should be cut off 1”-2” above the highest tree tie.

Existing Trees

- Proposed development plans and specifications must clearly state protection procedures for trees that are to be preserved.
- Existing trees must be protected during construction through the use of high-visibility construction fencing set at the outer limit of the critical root zone. The fence must prevent equipment traffic and storage under the trees. Excavation within this zone should be accomplished by hand, and roots 1/2" and larger should be preserved. It is recommended that pruning of the branches or roots be completed by, or under the supervision of, an arborist. Soil compaction under trees should to be avoided.
- Ensure that trees that receive irrigation continue to be watered during and after construction.

Long-term Maintenance

Maintenance recommendations for interceptor trees are provided in Table INT-2. The property owner is responsible for all costs associated with the maintenance.

Trees that are removed or die should be replaced with similar species, or all water quality benefits will be lost. Trees should be properly pruned for safety purposes, to protect structures, or for the improvement of the health and structure of the tree. The property owner is responsible for all costs associated with the replacement of interceptor trees.

Table INT-2. Inspection and Maintenance Recommendations for Interceptor Trees

Activity	Description
Removal of Leaves and Debris	Fallen leaves and debris from tree foliage should be raked and removed regularly to prevent the material from being washed into the storm water. Nuisance vegetation around the tree should be removed when discovered. Dead vegetation should be pruned from the tree on a regular basis.
Pruning	It is recommended that a certified arborist or similarly qualified professional be retained to prune trees, or the property owner should learn proper pruning methods. A tree should never be topped. Topping is the practice of removing major portions of a large tree's crown by cutting branches to stubs or to the trunk. Tree topping shortens the life of the tree, creates weakly attached limbs prone to breakage, decay and disfigures the tree. It also eliminates the interception canopy.
Mulching	Add 4-6 inch deep hardwood mulch around newly planted trees and shrubs (avoid redwood and cedar, it is light and blows away and does not decompose fast enough to be beneficial to the soil health and tree's growth).
Irrigation	An irrigation system should be installed at the time of planting and maintained during the establishment period or, if necessary to maintain the tree, in perpetuity.
Pesticides and Fertilizers	Minimize the use of chemicals to only what is necessary to maintain the health of the tree. Consider using mulch around the base of the tree as a substitute to fertilizer. Do not place mulch within six inches of the trunk of the tree.
Lawn Maintenance	Keep lawn at least 24 inches from trunk of tree. Competition from turfgrass stunts tree growth, and even additional fertilizer and water will not overcome this effect. A bare area around the trunk also helps prevent injury to the tree from a mower or string trimmer. Trunk wounds to a young tree can have a severe dwarfing effect.
Other Activities	Plant evergreen shrubs and ground covers around trees when possible. Care should be taken when digging near tree roots. Once tree has become established, planting of vegetation near base of tree and subsequent watering of such vegetation may result in over-saturation and damage to the tree.
Removal/ Replacement	See Long-term Maintenance

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Photo credits: All photographs provided by Dena Parish and Shannon Brown, ECORP Consulting, Inc., Rocklin, CA

Porous Pavement

Description

Porous pavement allows stormwater runoff to infiltrate into the ground through voids in the pavement materials. There are many types of porous pavement, including pervious concrete and asphalt, modular block, reinforced grass, cobblestone block and gravel. When properly installed, and in the proper setting, porous pavement can be as functional and durable as traditional surfaces.

Photo source: City of Elk Grove

Siting Considerations

- Soil permeability.
- Depth to groundwater: minimum 10 feet below aggregate base.
- Grade: 10% maximum.
- Loading: pavement material and design must accommodate anticipated load.

Vector Considerations

- Potential for mosquitoes due to standing water (at or near the surface) will be greatly reduced or eliminated if the porous pavement is properly designed, constructed, and operated to maintain its infiltration capacity.

Advantages

- Replaces regular pavement, so does not require additional land on the site.
- Can reduce size of downstream stormwater quality treatment measures by reducing the volume required to treat.
- Allows for tree preservation in areas requiring pavement.
- Sometimes more attractive than traditional pavement.
- Potential LEED Credits
    - Credit 6.1 – Stormwater Design – Quantity Control
    - Credit 6.2 – Stormwater Design – Quality Control

Limitations

- Do not use on sites with a likelihood of oil, grease or other hazardous spills.
- Certain types (e.g., modular block pavement) may not be acceptable to local fire authority.

- Porous asphalt will be considered on case-by-case basis.
- Pervious pavements may need to be replaced after several years, depending on the amount of fine material deposited on the surface.

General Maintenance Recommendations (Low to Moderate[1])

- Block pavers with voids filled with sand or sandy loam may require occasional replacement of fill material if infiltration capacity is lost.
- All of the hard surfaces will benefit from occasional vacuuming.
- Grassed pavements require regular mowing.

How Does Porous Pavement Work?

Porous pavements include a variety of stabilized surfaces with void spaces designed to infiltrate stormwater runoff into the ground or slowly release the water into a subsurface drainage system. Using porous pavement minimizes impervious areas, thereby reducing the amount of site runoff requiring treatment.

Planning and Siting Considerations

Development Type / Land Use

In developments where it is difficult to provide stormwater treatment (such as small or redeveloping sites or high-density residential developments), porous pavement may provide the best or only opportunity to reduce site imperviousness.

All land uses contain potentially suitable locations for porous pavement. Consider porous pavement for:

- Residential driveways, patios, and walkways (also see Alternative Driveway Fact Sheet elsewhere in this chapter).
- Commercial plazas and courtyards, overflow parking areas, parking stalls, some types of storage areas, walkways, and entryway features.
- Employee parking and entryway features at industrial sites.
- Fire lanes, maintenance access roads and other roadways where infrequent or low traffic loads and volume are expected (check with fire department for minimum specifications).
- Within parks and open space for parking areas, sports courts, playgrounds, and pedestrian/bike trails.

Porous pavement is not suitable for commercial drive aisles, loading areas, and waste management areas. It is also not appropriate where spills may occur, due to the potential for soil and groundwater contamination. Such areas include retail gas outlets, auto maintenance businesses, processing/manufacturing areas, food-handling businesses, and chemical handling/storage areas.

[1] Compared to stormwater quality treatment control measures.

Other Siting Considerations

A water barrier or interceptor drain will be required between regular load-bearing pavement/streets and porous pavement materials. Photo: City of Portland

- Consult a geotechnical engineer to determine what types of porous pavement are suitable for the expected traffic load, speed, and volume.
- Consult a geotechnical engineer to determine set back from building foundation, or use 10 feet.
- Determine site soil type and permeability before selecting porous pavement as a runoff reduction strategy. The local permitting agencies will require a permeability soils test to verify infiltration capacity of native soils. May be used over soils with low permeability in selected situations if underdrain is provided (check with permitting agency to verify).
- Address seasonal shrink/swell in sites with expansive subgrade. Use the expansion index test (ASTM D4828) to provide insight as to degree of surface deformation in choosing paving sections.
- Consider opportunities for directing runoff from impervious surfaces across porous pavement to achieve runoff reduction credits. See the Disconnected Pavement Fact Sheet located elsewhere in this chapter.
- Select the porous pavement type based on the type of anticipated pedestrian traffic; most types of porous pavement can be designed to be Americans with Disabilities Act (ADA) compliant.
- A water barrier or interceptor drain will be required where porous material abuts regular asphalt/concrete pavement and there is concern about water infiltrating the regular pavement subbase. The water barrier should run down the 12-inch deep excavation and 12 inches under the drain rock. Interceptor drains should tie into an open landscape area or treatment control measure to quickly relieve the water pressure in the pavement section and prolong the pavement life.
- For manufactured products, check the manufacturer's specifications for any additional siting considerations.

Porous Pavement Types

Six types of porous pavement material are presented in this fact sheet: 1) pervious concrete, 2) pervious asphalt (considered on case-by-case basis), 3) modular block, 4) reinforced grass, 5) cobblestone block and 6) gravel. Additional types may be allowed on a case-by-case basis; check with the local permitting agency for verification before proceeding with design.

Pervious Concrete and Asphalt

Pervious concrete and pervious asphalt have a higher load-bearing capacity than the other porous pavement options discussed in this chapter. Table PP-1 (presented later in this chapter) lists and compares the design criteria for all featured porous pavement types.

Pervious concrete parking lot; Bannister Park, Fair Oaks, CA. Photo: CNCPC and Fair Oaks Recreation and Parks District

Pervious concrete is poured like traditional concrete pavement, but is made from a specially formulated mixture of Portland Cement and no sand; the result is 15% to 21% void space. See Figure PP-1 for a typical installation detail.

Colorants can be added for aesthetic reasons, and surfaces can be ground for smoothness. Owners, architects, and engineers are encouraged to visit local sites where pervious concrete has been installed before deciding to use the material (see list of selected local installations in Table PP-3 at the end of this fact sheet).

Pervious asphalt roadway. Photo: City of Portland

Pervious asphalt consists of an open-graded coarse aggregate, bound together by asphalt cement into a coherent mass, with sufficient interconnected voids to provide a high rate of permeability. As long as the appropriate asphalt mix and design specification is used, pervious asphalt may be as durable as regular asphalt (Adams 2003). Pervious asphalt is less expensive than pervious concrete, but both types cost more than regular asphalt or concrete.

Most available pervious asphalt design specifications include the use of a collection system and underlying recharge bed, which at this time are not being proposed. Pervious asphalt installations are currently being examined, and it is anticipated that applicable design standards will soon be available. Pervious asphalt may be accepted for installation as specifications are developed, and at the discretion of the permitting agency. Additional information will be included in future manual updates.

The key to success with both pervious concrete and asphalt is proper installation by certified or otherwise experience contractors, and protection during construction activities to prevent clogging by fine construction sediment.

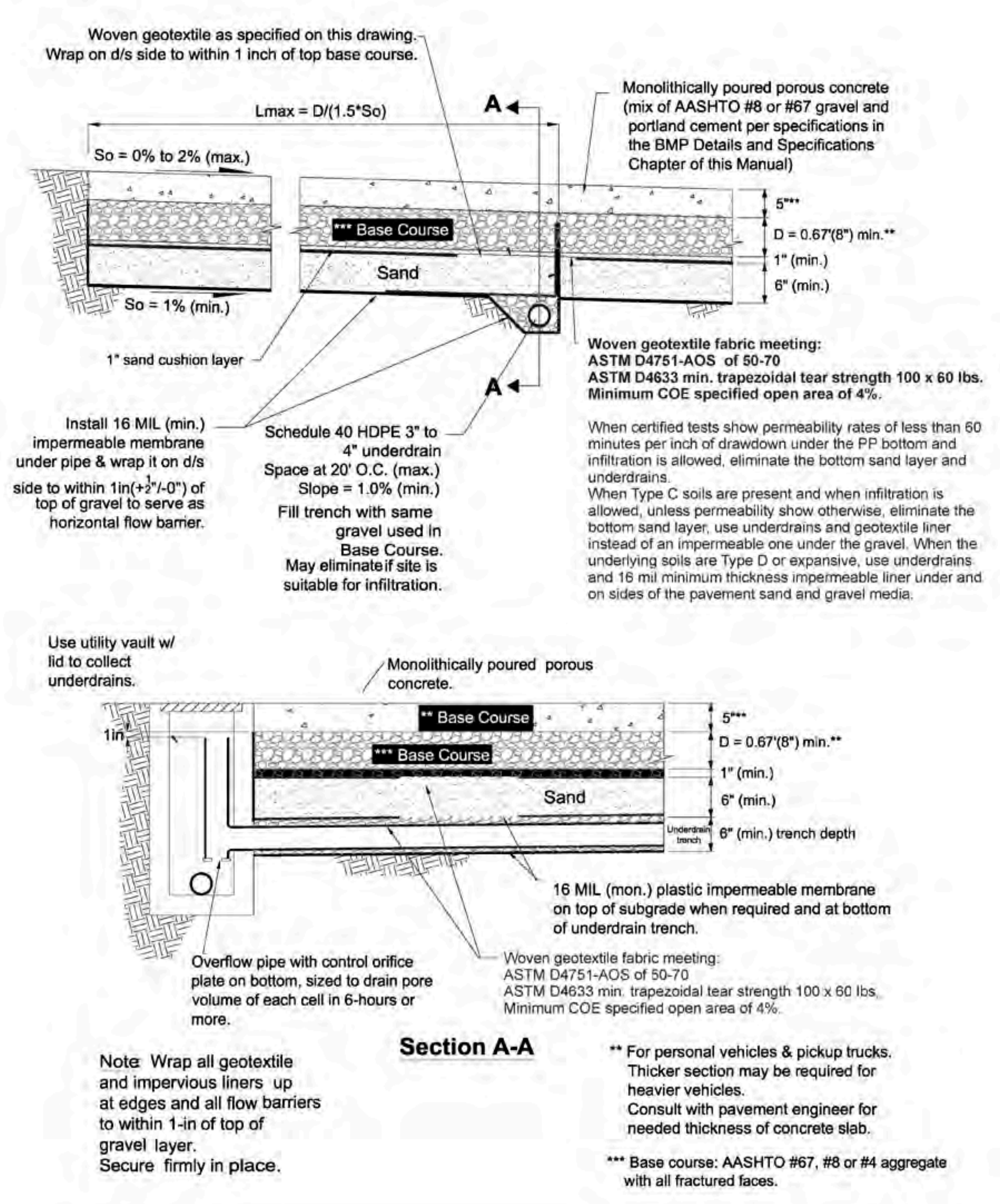


*Figure PP-1. Typical Pervious Concrete Sections**

(Source: adapted from Denver)

**Installation specifications may vary by site; check with local permitting agency.*

Modular Block Pavement

Photo: M&C Pavers, Florida

Porous modular block pavement (Figure PP-2) consists of concrete blocks with 20% or more open area, which is filled with sand or sandy loam turf. The units are installed over a gravel subgrade. This type of pavement is best suited for areas with low traffic loadings and seasonal/infrequent vehicle traffic, such as courtyards, driveways, overflow parking areas, and maintenance access roads. Check with the local fire authority about whether this option is acceptable for fire access lanes. One benefit is that it does not require utility cuts; instead the blocks can be taken out and replaced after utilities have been installed. Refer to Table PP-1 for design criteria for this type of porous pavement.

Other Names: Open-celled unit pavers, turf block, Grasscrete™

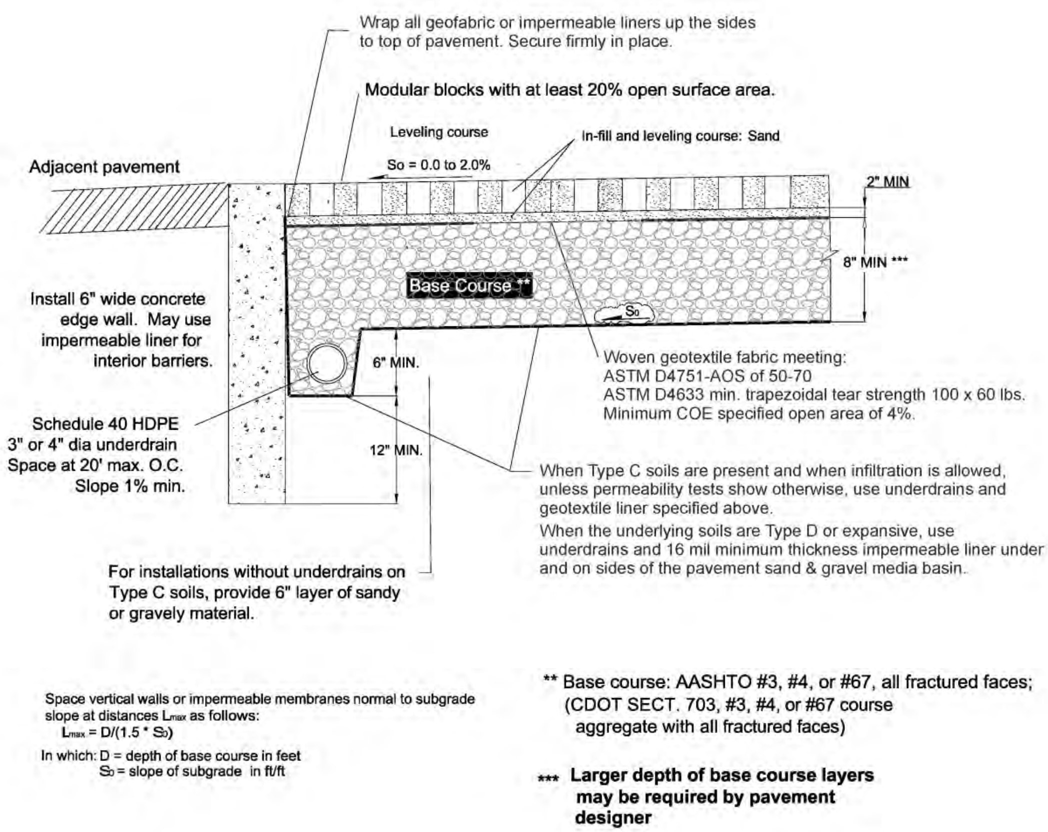


*Figure PP-2. Modular Block Pavement, Typical Section**

(Source: adapted from Denver)

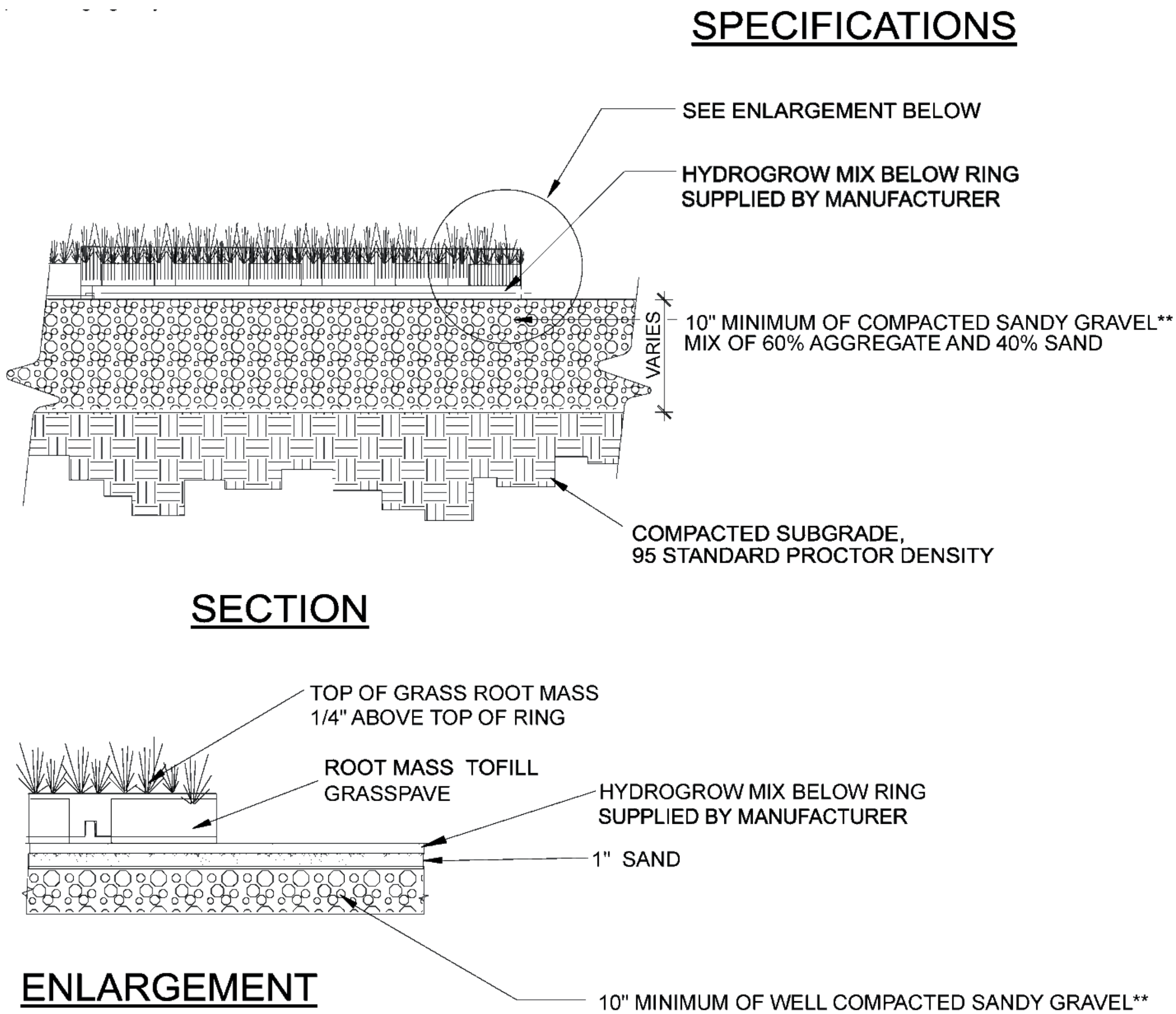
**Installation specifications may vary by site; check with local permitting agency.*

Reinforced Grass Pavement

New installation of reinforced grass pavement. Photo: Puget Sound Action Team, WA

Reinforced grass pavement (Figure PP-3) consists of an irrigated surface, typically stabilized with a manufactured product over which soil and seed mix is spread. Of the various porous pavement options, this may provide the greatest stormwater quality benefit due to its high permeability and evapotranspiration and nutrient uptake by vegetation. This pavement type is well suited in low-traffic areas, such as overflow parking areas (stalls can be marked with athletic field paint) and maintenance roads (source: NEMO). However, it is not suitable for fire access lanes. Load-bearing capacity varies by product, so select the reinforcement grid based on anticipated load. Because of the reinforcement, the area can be used even when the ground is saturated. Irrigation is required to maintain the vegetation. Refer to Table PP-1 for design criteria for this type of porous pavement.

Other names: grid pavers, green parking, Grasspave™



NOTES:

1. INSTALL GRASSTURF REINFORCING LAYER PER MANUFACTURER'S RECOMMENDATIONS INCLUDE MODIFICATIONS SHOWN ON THIS DRAWING.

2. DETAIL BASED ON INVISIBLE STRUCTURES, INC., ET AL DETAILS, BUT MODIFIED TO SUIT USDCM REQUIREMENTS.

**GREATER DEPTH OF PAVEMENT MAYBE REQUIRED BY PAVEMENT DESIGNER

*Figure PP-3. Reinforced Grass Pavement, Typical Sections**

(Source: adapted from Denver)

**Installation specifications may vary by site; check with local permitting agency.*

Cobblestone Block Pavement

Cobblestone block pavement (Figure PP-4) consists of concrete block units with at least 8% void space where the beveled corners meet. The units are installed on a gravel subgrade, and the void space is filled with sand. This is one of the most attractive porous pavement options and allows for the greatest flexibility in pattern and color. Cobblestone block pavement can be used wherever modular block pavement is appropriate, and similarly, does not require utility cuts; instead the blocks can be taken out and replaced after utility installation. Refer to Table PP-1 for design criteria for this type of porous pavement.

Photo: Cobblestone block pavement at Fair Oaks Promenade; Fair Oaks, CA.

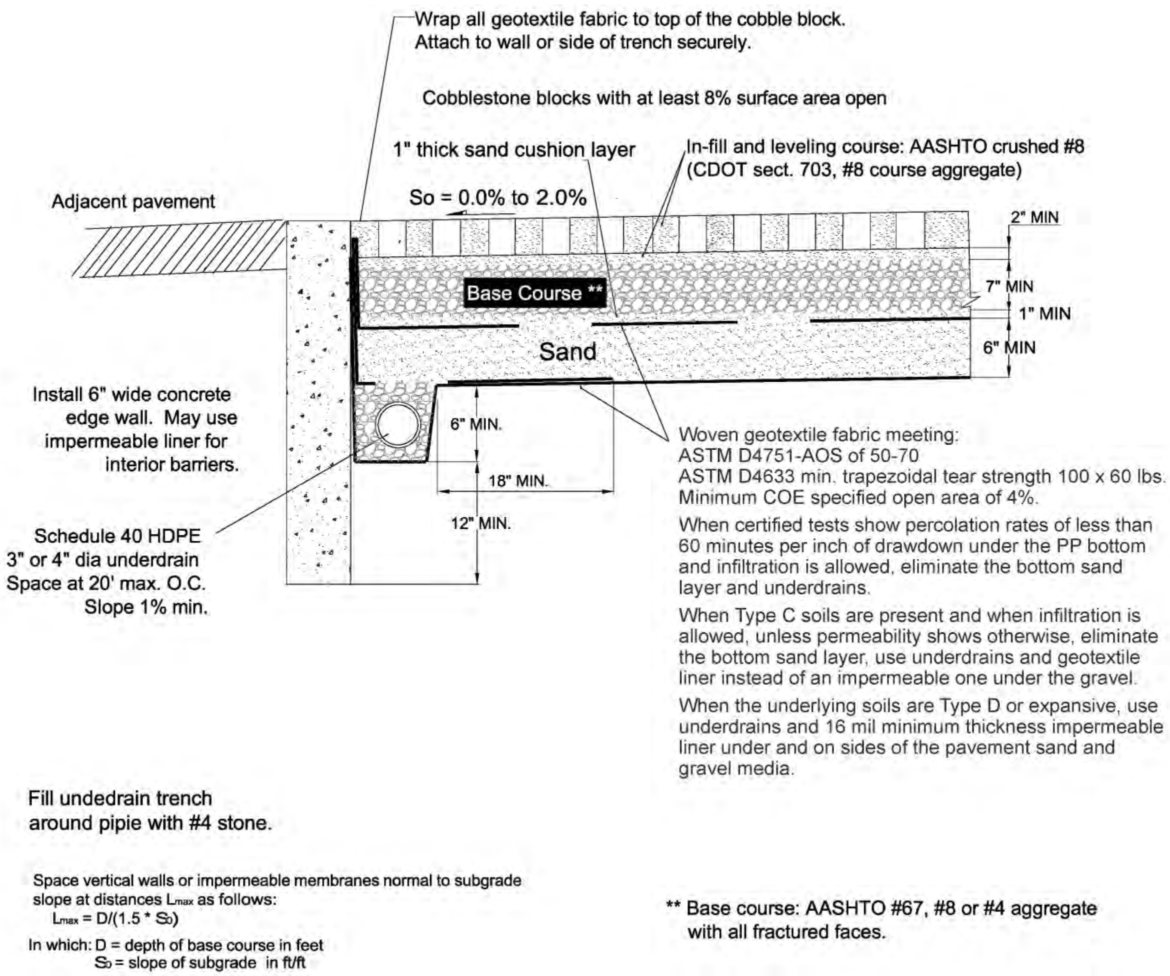


*Figure PP-4. Cobblestone Block Pavement, Typical Section**

(Source: adapted from Denver)

**Installation specifications may vary by site; check with local permitting agency*

Porous Gravel Pavement

Porous gravel pavement (Figure PP-5) consists of a loose gravel surface installed with or without additional stabilization depending on anticipated loads and traffic. This type of pavement must be placed over a sufficient aggregate base to allow for storage and infiltration. Where drainage is slow, an underdrain may be required. It is ideal for temporary use areas where permanent pavement would be too costly, as well as rural and park settings, overflow parking lots, maintenance roads, fire access lanes, and materials storage areas. However, check with the local permitting agency, since some agencies in the Sacramento area don't allow gravel except for certain types of storage yards. Refer to Table PP-1 for design criteria for this type of porous pavement.

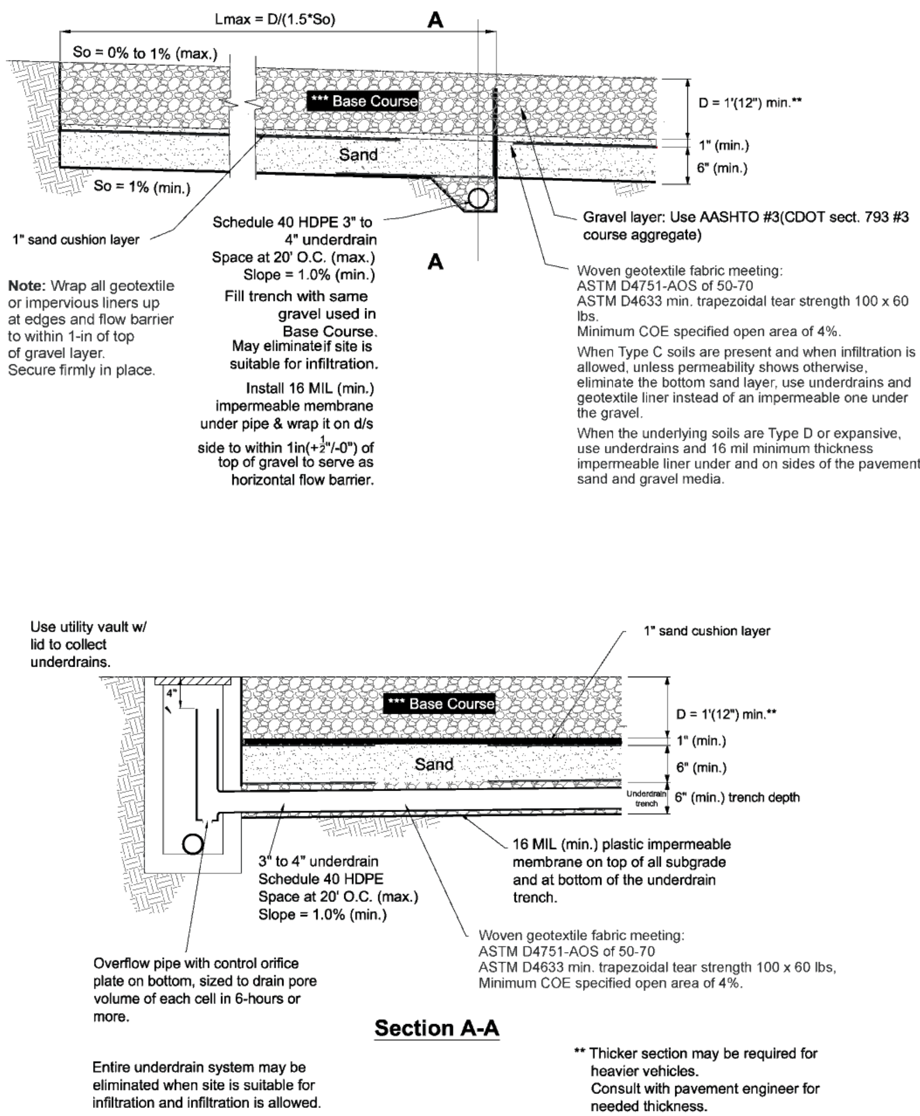


*Figure PP-5. Porous Gravel Pavement, Typical Sections**

(Source: adapted from Denver)

**Installation specifications may vary by site; check with local permitting agency*

Design Criteria

Design criteria for porous pavement are listed in Table PP-1.

*Table PP-1. Design Criteria for Porous Pavement**

Also see Appendix D for information on calculating runoff reduction credits.

Pavement Type/ Parameter	Criteria
Pervious Concrete (Figure PP-1)	
Void space	Minimum 15% throughout material
Base Course	With underdrain – 8" minimum of coarse aggregate over 7" minimum sand over 3" minimum coarse aggregate; without underdrain – 12" minimum coarse aggregate
Liner	Geotextile filter cloth with 60 to 80 pores per inch
Underdrain	Required when specified permeability range is not available in native soils. Use a gravel trench or perforated pipe embedded in a 6-12-inch layer of crushed rock. Connect to another LID element or the storm drain system (not sanitary sewer).
Water Barrier	Check with the geotechnical engineer.
Modular Block Pavement (Figure PP-2)	
Void space	Minimum 20% surface area as open annular spaces
Base Course	8" minimum of coarse aggregate
Liner	Same as pervious concrete.
Reinforced Grass Pavement (Figure PP-3)	
Base Course	12" minimum of compacted sandy gravel mix
Cobblestone Block Pavement (Figure PP-4)	
Void space	Minimum 8% surface area as open annular spaces
Base Course	7" minimum of coarse aggregate over 7" minimum of sand
Liner	Same as pervious concrete
Porous Gravel Pavement (Figure PP-5)	
General	With underdrain – 12" minimum of coarse aggregate over 7" minimum sand over 3" minimum coarse aggregate; without underdrain – 14" minimum coarse aggregate
Liner	Same as pervious concrete
Source: Urban Drainage and Flood Control District. Denver, Colorado **Design criteria may vary by permitting agency; check before proceeding with design. A permeability test will be required to verify suitability of this technique for the site. A qualified engineer must provide site-specific design specifications for pavement installation. In addition, the manufacturer's specifications apply.*	

Construction Considerations

- Proper installation is important for all porous pavement types, but it is especially critical for pervious concrete and asphalt, which must be installed by certified or otherwise qualified contractors. Certification programs are now offered by various National and State associations (contact National Ready Mixed Concrete Association for more information).

- The designer should define compaction criteria to protect infiltration capacity of pervious materials and satisfy roadway loading requirements.
- Weather conditions can affect the final product. Avoid extremely high or low temperatures during installation. The bottom of the crushed rock reservoir below the pavement should be flat so that runoff will be able to infiltrate across the entire sub surface area (unless subsurface drain required).
- Additional information must be incorporated into construction specifications depending on the type of porous pavement proposed and addressing site-specific pavement design. Manufacturer's recommendations could be incorporated into the project specifications.
- After installation, and as construction continues elsewhere on the site, prevent fine sediment from clogging the material by covering the surface with plastic, using staked straw wattles around the perimeter, etc.
- As soon as possible, stabilize the entire contributing drainage area to keep sediment-laden runoff from contacting the new pavement.

Long-term Maintenance Recommendations

Table PP-2 presents inspection and maintenance recommendations for porous pavement. The local permitting agencies will require that the property owner be responsible for maintaining the features to ensure continued, long-term performance. The pervious features should not be removed or replaced with impervious surfaces in the future, or all water quality benefits will be lost. Check with your local permitting agency to determine if and when a maintenance agreement will be required for your project.

Table PP-2. Inspection and Maintenance Recommendations for Porous Pavement

Surface Maintenance	▪ Keep the surface clean and free of leaves, debris, and sediment, and do not replace or cover it with an impermeable paving surface. ▪ Regularly sweep or vacuum pervious concrete and asphalt, modular block pavement, or cobblestone block pavement (typically three to four times per year). ▪ Do not store loose material such as bark or sand on porous pavement.
Care of Vegetation	▪ Mow, irrigate, fertilize, and—when necessary—reseed grasses planted in pavement. ▪ Keep grasses healthy and dense enough to provide filtering while protecting underlying soils from erosion. ▪ Mow grass to less than four inches and remove grass clippings. ▪ Avoid planting trees and shrubs near non-flexible porous pavement types because roots may crack pavement and excessive leaves may clog the surface. Use of structural soil material may alleviate this concern.

Vector Control	▪ Eliminate any standing water at the surface, since that provides an environment for insect larvae. ▪ If sprays are considered, then use a licensed pest controller to apply an approved mosquito larvicide.
Maintenance of Reinforcement Products	▪ Where reinforcement products are used to stabilize grass or gravel, replace individual grid sections when they become damaged.
Manufacturer's Recommendations	▪ For manufactured products, follow manufacturer's maintenance recommendations.
Replacement	▪ Reconstruct or replace when it is no longer functioning properly (see project lifespan in Appendix B for informational purposes).

Table PP-3. Selected Local Pervious Concrete Installations

Type	**Location**	**Contact**
Residential Driveway	4600 McDonald Drive, Sacramento, CA	Private residence (do not disturb residents)
Parking Lot	Bannister Park, Miller Park and Phoenix Community Park, Fair Oaks Mace Ranch Park, Davis	Fair Oaks Recreation and Park District City of Davis Parks Department
Garden (Pathways, etc.)	Fair Oaks Park Water Wise Garden, Fair Oaks UC Berkeley Botanical Gardens, Berkeley	Fair Oaks Recreation and Park District UC Berkeley
School	Linden High School Pervious Parking Lot, 3247 Linden Street, Linden, CA	
Municipal Bus/ Corporation Yard	City of Elk Grove Corporation Yard, Elk Grove	City of Elk Grove Public Works Department

Resources for More Information

- California Nevada Cement Association, www.cncement.org
- Concrete Promotion Council of Northern California, www.cpcnc.org
- National Ready Mixed Concrete Association (NRMCA), www.nrmca.org
- Pacific Southwest Concrete Alliance, www.concreteresources.net
- Northern California Asphalt Pavement Association, www.apaca.org
- National Precast Concrete Association, www.precast.org
- Portland Cement Association, www.portcement.org
- National Asphalt Pavement Association, www.hotmix.org
- Asphalt Emulsion Manufacturers Association, www.aema.org
- American Concrete Pavement Association – Southwest Chapter, www.acpa-southwest.org

- Association of Asphalt Paving Technologists, www.asphalttechnology.org
- American Concrete Paving Association, www.pavement.com

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Sand Filter

Description

A sand filter is a two-stage constructed treatment system including a pretreatment sedimentation basin and a filtration basin containing sand1. The filter bed is supported by a gravel base which includes an underdrain. As stormwater flows into and through the system, large particles settle out in the first basin and finer particles and other pollutants are removed in the second basin. Runoff from large storm events in excess of the water quality design volume (WQV) is bypassed around the system. There are several variations of sand filters; this fact sheet discusses the Austin Sand Filter.

Sand filter in parking lot.
City of Sacramento Department of Utilities

Siting Considerations

- Contributing drainage area: Up to 50 acres.
- Sizing basis: Water quality volume (WQV) with 48-hour drawdown. Storm volumes in excess of the WQV must be bypassed.
- Hydraulic head: about four feet of hydraulic head is required to achieve design flow through the Austin Sand Filter.
- Total filtration basin depth (minimum): 36 inches.

Vector Considerations

- Potential for mosquitoes due to standing water will be greatly reduced or eliminated if the sand filter is properly designed, constructed, and maintained.

POLLUTANT REMOVAL EFFECTIVENESS	
Sediment	High
Nutrients	Low
Trash	High
Metals	High
Bacteria	Medium
Oil and Grease	High
Organics	High

The following is a partial list of the most common target pollutants for the Sacramento area: copper, lead, mercury, pathogens, diazinon, and chlorpyrifos. For more complete information refer to:

http://www.waterboards.ca.gov/water_issues/programs/tmdl/integrated2010.shtml

Source: CASQA California Stormwater BMP Handbook, January 2003

Advantages

- Provides effective water quality enhancement through settling and filtering while requiring relatively small space.
- Can be placed above or below ground.

- Does not require irrigation or base flow.
- Suited for most soil conditions; permeable soils are not needed.
- Reduces peak flows during small storm events.
- Potential LEED Credits
    - Credit 6.2 – Stormwater Design – Quality Control

Limitations

- Upstream treatment controls may be needed to pretreat and remove sediment from runoff before it enters the sand filter. This will prevent or minimize clogging.
- Significant head loss through treatment units may limit use on flat sites.
- More expensive to construct than other types of treatment control measures.

General Maintenance Recommendations (Moderate to High)

- Periodically remove debris and sediment from sedimentation basin and surface of filtration basin.
- Periodically replace sand layer in filtration basin when filtration capacity is diminished.

How Does a Sand Filter Work?

A typical configuration of an Austin Sand Filter is shown in Figure SF-1. The principal components of the unit include a sedimentation basin and a filtration basin. The sedimentation basin is designed to hold the entire WQV and to release that volume to the filtration basin over the design drawdown time of 48 hours. Large sediment is removed from the runoff through this process. Fine particles and other pollutants are removed in the filtration basin as the runoff passes through the sand filter. Runoff in excess of the WQV is bypassed around the treatment unit.

Variations of Sand Filters

This fact sheet focuses on the Austin Sand Filter. Other variations (also named after the area of the country where they were developed) include the underground (DC) sand filter and the linear or perimeter (Delaware) sand filter. The size of the drainage area and the facility location typically dictate what type of filter is best. For large watersheds (i.e., up to 50 acres), an Austin Sand Filter is recommended. For small catchments up to 1.5 acres requiring underground facilities, a DC Underground Sand Filter is recommended. Delaware Linear Sand Filters are especially suitable for paved sites and industrial sites (catchments up to five acres in size) because they can be situated to accept sheet flow from adjacent pavement. The units also differ in hydraulic head requirements. Approximately four feet of hydraulic head is required to achieve design flow through the Austin and DC Underground Sand Filters, whereas Delaware Linear Sand Filters can operate with as little as two feet of head.

Planning and Siting Considerations

- Sand filters are generally suited for sites where there is no base flow and the influent sediment load is relatively low.
- Sand filters are well suited for drier areas and/or urban areas because they do not require vegetation or irrigation and require less space than most other treatment controls.
- Because the filter media is imported sand or engineered adsorptive material, sand filters are suited for most soil conditions, and the presence of permeable soils is not a requirement.
- The Austin Sand Filter may be constructed inside a concrete shell, or built directly into the terrain over an impermeable liner (e.g., clay), if site conditions allow. Figure SF-1 shows a unit within a concrete shell, with an enclosed sedimentation basin and the filtration basin open at the surface.
- Setback requirements: minimum of 10 ft vertical separation from groundwater table, and 150 ft horizontal separation from drinking water wells

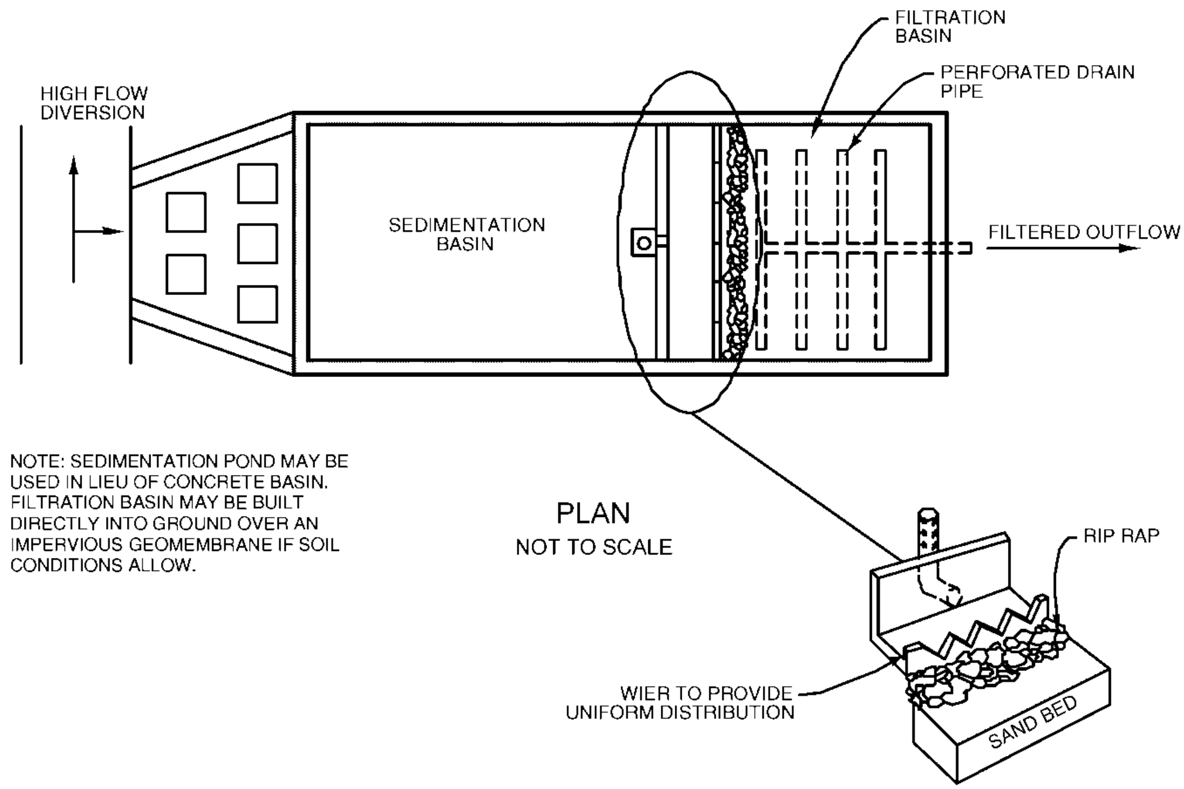
Design Criteria

Design criteria for the Austin Sand Filter are listed in Table SF-1. Use the Design Data Summary Sheet provided at the end of this fact sheet (Table SF-3) to record design information for the permitting agency's review.

Table SF-1. Austin Sand Filter Design Criteria

Design Parameter	Criteria	Notes
Sedimentation Basin		
Maximum contributing drainage area	50 acres	The larger the contributing drainage area, the larger the surface area of filter required.
Minimum basin volume	WQV or as dictated greater by SAHM modeling (for projects with hydromodification requirement)	See Appendix E in this Design Manual
Minimum/Maximum basin water depth (d_{SB})	3 ft/10 ft	
Minimum length:width ratio	2:1	
Maximum drawdown time	48 hrs	Based on WQV (see Appendix E)

Design Parameter	Criteria	Notes
Freeboard	1 ft	Above max water surface elevation
Maximum inlet velocity	3 ft/sec	Provide inlet energy dissipator as required to limit inlet velocity to 3 ft/sec
Filtration Basin		
Minimum gravel depth over sand filter (if applicable)	2 in	See Figures SF-3 and SF-4
Minimum storage volume above filter bed	20%	Based on WQV
Minimum storage depth above filter bed (d_s)	3 ft	
Minimum sand depth in filter bed (d_f)	18 in	Place geotextile fabric between sand and gravel layers
Coefficient of permeability for sand filter (k)	3.5 ft/day	0.146 ft/hour
Sand size, diameter	0.02-0.04 in	
Slope of sand filter surface	0%	Flat
Minimum gravel cover over underdrain	2 in	Gravel not required under the drain pipe
Underdrain gravel size, diameter	0.5-2 in	
Minimum inside diameter of underdrain	6 in	
Underdrain pipe type	PVC	Schedule 40 (or heavier)
Minimum slope of underdrain	1%	
Minimum underdrain perforation, diameter	0.375 in	3/8 inch
Minimum perforations per row	6	
Maximum drawdown time (t_f)	48 hrs	
Minimum gravel bed depth (d_g)	16 in	
Liner (if required)	clay	



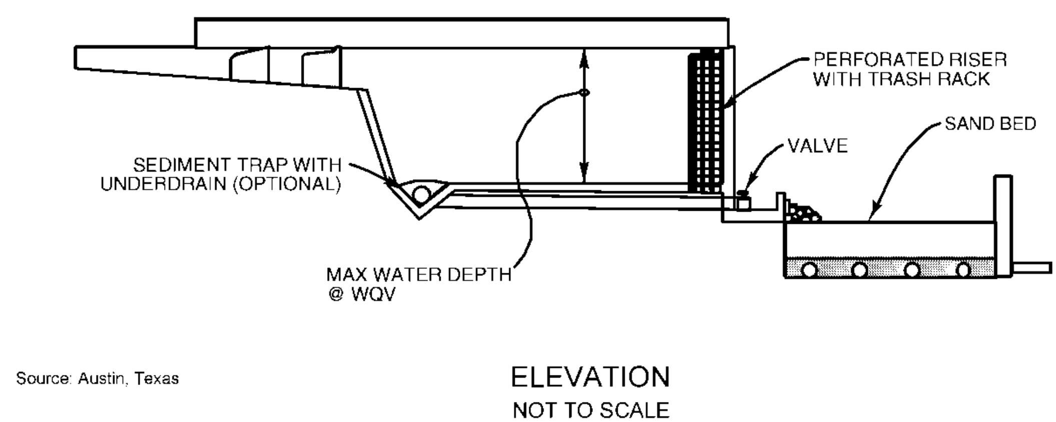


Figure SF-1. Sand Filter Configuration (Austin Sand Filter)

Design Procedure – Sedimentation Basin

*Use the **Design Data Summary Sheet** (Table SF-5) to record design information for the permitting agency's review.*

Step 1a – Determine Water Quality Volume (WQV)

Using the Appendix E in this Design Manual, determine the contributing drainage area and stormwater quality design volume (WQV) for 48-hour drawdown.

Step 1b – SAHM Modeling for Hydromodification Management (If applicable)

Upsize the sedimentation basin volume as necessary based upon modeling results if implementing as a hydromodification control. Maintain depth so as to adhere with 48–hour maximum drawdown for WQV.

Step 2 – Determine Sedimentation Basin Volume (V_{sb})

The volume of the sedimentation basin must be greater than or equal to the WQV.

$$V_{sb} = WQV \text{ (minimum)}$$

Step 3 – Determine Sedimentation Basin Water Depth (d_{sb})

The allowable water depth in the sedimentation basin will be governed by the available hydraulic head, which will be based on the difference in elevation between the sedimentation basin inlet and the filtration basin outlet. The design d_{sb} value should be ≥ 3 ft and ≤ 10 ft. Select a design depth in the allowable range that yields the required V_{sb} given any footprint area constraints.

Step 4 – Determine Sedimentation Basin Area (A_{sb})

$$A_{sb} = V_{sb} / d_{sb}$$

Step 5 – Determine Sedimentation Basin Shape

Determine overall length (L_{sb}) and width (W_{sb}) dimensions to yield the A_{sb} for the basin, given any footprint area constraints.

$$A_{sb} = L_{sb} \times W_{sb}$$

The length-to-width ratio should be at least 2:1. If necessary, provide internal baffling to achieve this ratio and to mitigate short-circuiting and/or dead storage problems

If the basin is not rectangular, shape the basin with a gradual expansion from the inlet and a gradual contraction toward the outlet. Design the basin to maximize the distance from the inlet (near where heavier sediment will be deposited) to the outlet structure. This configuration improves basin performance and reduces maintenance requirements.

Step 6 – Determine Inlet/Outlet Design

Design the inlet structure to convey the water quality volume to the unit and bypass flows in excess of this volume directly to the downstream storm drain system. Provide energy dissipation at the inlet to maintain quiescent conditions needed for effective sedimentation; keep inlet velocities at three (3) feet per second or less.

The outlet structure conveys the water quality volume from the sedimentation basin to the filtration basin and should be a perforated riser pipe equipped with a trash rack to prevent clogging. Trash racks allow easy access for inspecting and cleaning outlet orifices. Size trash racks to prevent clogging of the outlet without restricting the hydraulic capacity of the outlet control orifices.

A trash rack shall be provided for the outlet. Opening in the rack should not exceed 1/3 the diameter of the vertical riser pipe. The rack should be made of durable material, resistant to rust and ultraviolet rays. The bottom rows of perforations of the riser pipe should be protected from clogging. To prevent clogging of the bottom perforations, it is recommended that geotextile fabric be wrapped over the pipe's bottom rows and that a cone of one (1) to three (3) inch diameter gravel be placed around the pipe. If a geotextile fabric wrap is not used, the gravel must be large enough not to enter the riser piper perforations. An alternative design, such as geocomposite drain, may also be approved by the local permitting agency.

Step 7 – Design the Basin to Avoid Short-Circuiting

Design the sedimentation basin with baffles as needed to avoid short-circuiting (i.e., flow reaching the outlet before it passes through the sedimentation basin volume).

Step 8 – Design the Sediment Trap (Optional)

A sediment trap is a storage area that captures sediment and removes it from the basin flow regime, thereby inhibiting re-suspension of solids during subsequent runoff events and improving long-term removal efficiency. The trap also helps the basin maintain adequate storage volume by reducing sediment that would otherwise accumulate within it; this, in turn, can reduce maintenance needs. If a sediment trap is provided, size the volume to be equal to 10 percent of the sedimentation basin volume and design it to completely drain within 48 hours. Place the invert of the drain pipe above the surface of the sand bed of the filtration basin and make sure the grading of the piping to the filtration basin is at least 1/4 inch per foot (two percent slope). Provide access for cleaning the sediment trap drain system.

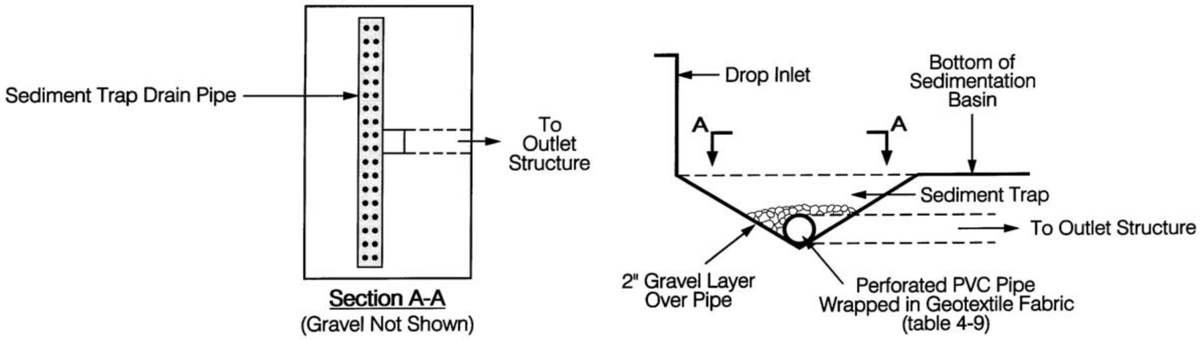


Figure SF-2. Example Sediment Trap Details

Step 9 – Determine Sedimentation Basin Liner Design

If the sedimentation basin is an earthen structure and an impermeable liner is required to protect groundwater quality, the liner shall provide a maximum permeability of 1x10-6 cm/sec (ASTM Method D-2434). If an impermeable liner is not required, then install a geotextile fabric liner that meets the specifications listed in Table SF-3 unless the basin has been excavated to bedrock.

Design Procedure – Filtration Basin

The design procedure and application of design criteria for the Austin Sand Filter Filtration Basin are outlined in the following steps.

Step 1a – Determine Minimum Filtration Basin Storage Volume

The storage capacity of the filtration basin above the surface of the sand filter bed should be greater than or equal to 20 percent of the WQV. This capacity is necessary in order to account for backwater effects resulting from partially clogged filter media.

$$V_{fbs} \geq 0.2 \times WQV$$

Step 1b – SAHM Modeling for Hydromodification Management (If applicable)

Upsize the filtration basin volume as necessary based upon modeling results if implementing as a hydromodification control.

Step 2 – Determine Filter Bed Surface Area

Surface area is the primary design parameter for the filtration basin and is a function of sand permeability, filter bed depth, hydraulic head, and filtration rate. The design filter bed area should be the larger of the minimum area required for storage and the minimum area required for flow.

- Determine minimum filter surface area required for storage (Afbs)

$$A_{fbs} = V_{fbs} / d_{fbs}$$

Where:

V_{fbs} = Storage volume above filter bed, ft^3

A_{fbs} = Filter bed surface area based on storage, ft^2

d_{fbs} = Depth of storage above filter bed, ft (3 ft minimum)

- Determine minimum filter surface area required for flow (A_{ff})

$$A_{ff} = \frac{(WQV)(d_f)}{(k)(d_{fbs} + d_f)(t_f)}$$

Where:

WQV = Design Water Quality Volume, ft^3

A_{ff} = Filter surface area based on flow, ft^2

d_f = Filter bed depth, ft

k = Coefficient of permeability for sand filter, ft/h (0.146 ft/h)

d_{fbs} = Depth of storage above filter bed, ft

t_f = Time required for runoff volume to pass through filter, hrs (48 hrs)

- Use the larger of A_{fbs} and A_{ff} as design value for sand filter bed area

Step 3 – Design Inlet Structure

The inlet structure should spread the flow uniformly across the surface of the sand filter. Flow spreaders, weirs, or multiple orifice openings are recommended. See Figure SF-1 for an example inlet structure design.

Step 4 – Design Filter Bed

The sand filter bed may be either of the two configurations given below. Sand bed depths are final, consolidated depths, so consolidation effects must be taken into account.

- Sand Bed with Gravel Underdrain (Figure SF-3)

  The sand layer shall be a minimum depth of 18 inches and shall consist of 0.02 to 0.04-inch diameter sand. Below the sand is a layer of 0.5 to 2-inch diameter gravel that provides a minimum of two (2) inches of cover over the top of the underdrain lateral pipes. No gravel is required under the lateral pipes. A layer of geotextile fabric meeting the specifications in Table SF-2 must separate the sand and gravel and must be wrapped around the lateral pipes.

Drainage matting meeting the specifications in Table SF-2 should be placed under the laterals to provide for adequate vertical and horizontal hydraulic conductivity to the laterals.

In areas with expected high sediment loads (total suspended solids concentration ≥ 200 mg/L), the two-inch layer of gravel on top of the sand filter should be underlain with Enkadrain 9120™ filter fabric or equivalent meeting the specifications in Table SF-2.

- Sand Bed with Trench Underdrain (Figure SF-4)

  The top layer shall be 12-18 inches of 0.02 to 0.04-inch diameter sand. Laterals shall be placed in trenches with a covering of 0.5 to 2-inch gravel and geotextile fabric (see Table SF-2). The laterals shall be underlain by a layer of drainage matting (see Table SF-2).

  In areas with expected high sediment loads, see the note above about use of Enkadrain filter fabric or equivalent.

Step 5 – Design Underdrain Piping

The underdrain piping consists of the main collector pipe(s) and perforated lateral branch pipes (see plan view in Figure SF-1). The piping should be reinforced to withstand the weight of the overburden. Internal diameters of lateral branch pipes should be six inches or greater and perforations should be 3/8 inch. Each row of perforations should contain at least six holes and the maximum spacing between rows of perforations should not exceed six inches. All piping is to be Schedule 40 polyvinyl chloride (PVC) or greater strength. The minimum slope of piping shall be 1/8 inch per foot (one (1) percent; slopes down to one-half (0.5) percent may be acceptable to the permitting agency). Access for cleaning all underdrain piping is needed.

Sand filter in parking lot.
City of Sacramento Department of Utilities

Note: Unlike the sedimentation basin, the filtration basin does not require a drawdown time for release. Thus, it is not necessary to have a specifically designed orifice for the filtration basin outlet structure.

Step 6 – Design Filtration Basin Liner

If the filtration basin is an earthen structure and an impermeable liner is required to protect groundwater quality, the liner shall provide a maximum permeability of 1x10-6 cm/sec (ASTM Method D-2434). If an impermeable liner is not required, then install a geotextile fabric liner that meets the specifications listed in Table SF-3 unless the basin has been excavated to bedrock.

Table SF-2. Geotextile Fabric and Drainage Matting Specifications for Sand Filters

Property	Test Method	Specifications
Geotextile Fabric		
Material		Non-woven geotextile fabric
Unit Weight		8 oz./yd (minimum)
Filtration Rate		0.08 in/sec (minimum)
Puncture Strength	ASTM D-751 (Modified)	125 lbs (minimum)
Mullen Burst Strength	ASTM D-751	400 psi (minimum)
Tensile Strength	ASTM-D-1682	300 llbs (minimum)
Equivalent Opening Size	US Standard Sieve	No. 80 (minimum)
Drainage Matting		
Material		Non-woven geotextile fabric
Unit Weight		20 oz./yd (minimum)
Flow Rate (fabric)		180 gpm/ft^2 (minimum)
Permeability	ASTM D-2434	12.4 x 10^{-2} cm/sec
Grab Strength	ASTM D-1682	Dry: Lg 90/Wd 70; Wet: Lg 95/Wd 70
Puncture Strength	COE CW-02215	42 lbs (minimum)
Mullen Burst Strength	ASTM-D-1117	400 psi (minimum)
Equivalent Opening Size	ASTM-D-1682	No. 100 (70-120)
Flow Rate (Drainage Core)	Drexel University	14 gpm/ft width
Filter Fabric		
Material		Non-woven geotextile fabric
Unit Weight		4.3 oz./yd (minimum)
Filtration Rate		120 gpm/ft^2 (minimum)
Puncture Strength	ASTM D-751 (Modified)	60 lbs (minimum)
Thickness		0.8 in (minimum)

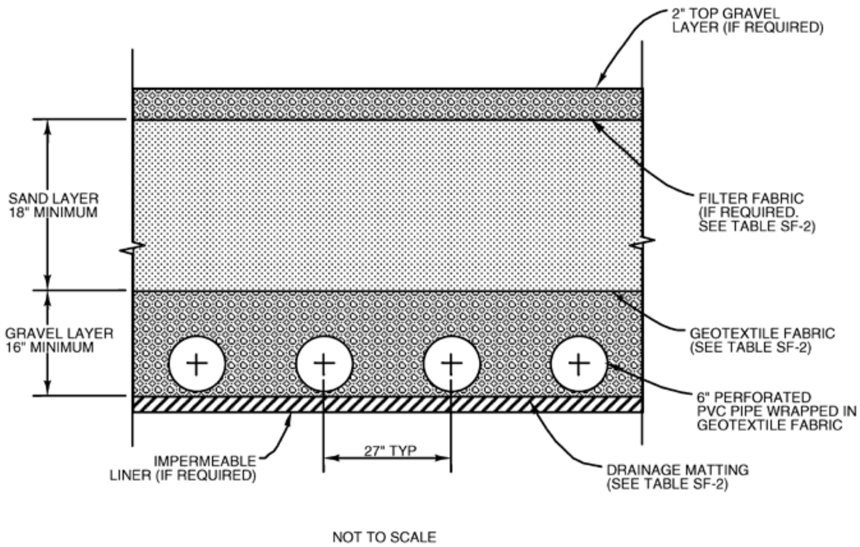


Figure SF-3. Filter Bed with Gravel Underdrain

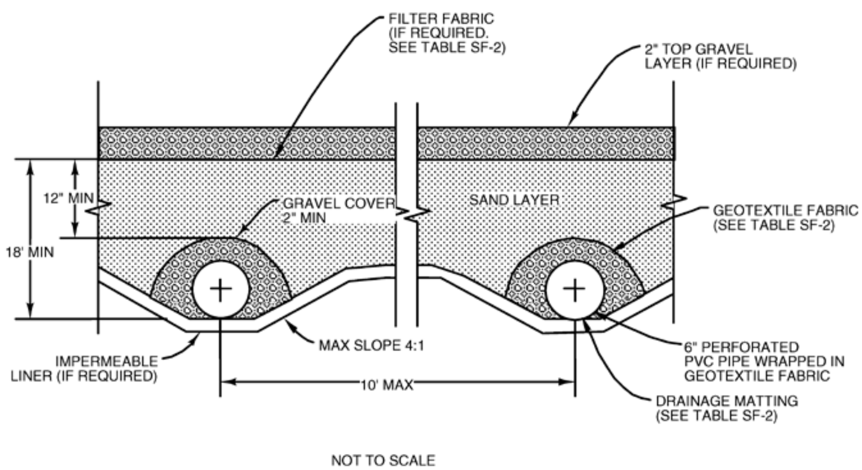


Figure SF-4. Filter Bed with Trench Underdrain

Construction Considerations

- Divert flow around the sand filter to protect it from sediment loads during construction. If sediment does enter the facility during construction, the contractor will be required to remove soil from the unit after the entire site has been stabilized, to the satisfaction of the permitting agency inspector.
- Where underdrains are used, ensure that the minimum slope of the pipe is 0.5 (1/2) percent. Where only gravel filtered water conveyance is provided, slope the filter floor towards the weepholes at a minimum of 0.5 (1/2) percent.
- Ensure that the inverts of the notches, multiple orifices, or weirs dividing the sedimentation chamber from the filtration basin are completely level. Otherwise, water will not arrive at the

filtration basin as sheet flow, and only the downgradient end of the filtration basin will function.

- Inflow grates or slotted curbs may conform to the grade of the completed pavement as long as the filters, notches, multiple orifices, and weirs connecting the sedimentation and filter chambers are completely level.
- Level the top of the sand filter bed in the filtration basin; no slope is allowed.
- If precast concrete lids are used, provide lifting rings or threaded sockets to allow easy removal with standard lifting equipment, considering the party that will be responsible for maintenance.
- Once construction is complete, stabilize the entire contributing drainage area to the filter before allowing runoff to enter the unit.

Long-term Maintenance

The local permitting agencies in the Sacramento area will require execution of a maintenance agreement or permit with the property owner for projects including a sand filter. Check with the local permitting agency about the timing for execution of the agreement. Such agreements will typically include requirements such as those outlined in Table SF-3. The property owner or his/her designee will be responsible for compliance. See Appendix B for additional information about maintenance requirements and sample agreement language.

Table SF-3. Inspection and Maintenance Recommendations for Sand Filters

Activity	Schedule
Remove trash and debris collected in the sedimentation basin inlet area to maintain the inflow capacity of the sand filter and avoid bypassing of the unit.	Before significant storm events during wet season (October 1 – April 30)
Remove cover grates or precast lids on the sedimentation basin and inspect to determine if the system is functioning properly. Inspect for standing water, sediment, grass/vegetative debris, and trash on the trash racks at the outlet pipe or elsewhere in the unit. Schedule removal of observed materials and correct any other observed problems. Sediment removal should be scheduled when the sediment occupies 10 percent of the basin volume.	Inspect quarterly during first year of operation; semiannually after first year of operation Maintain as needed based on observations
Inspect sediment trap (if applicable) and clean when full.	Same as above
Inspect the facility after large rain events to determine whether the facility is draining completely within 48 hours. Look for discoloration of the filter, which may be an indication of clogging.	At least once during the wet season (October 1 – April 30)

Activity	Schedule
If drawdown time exceeds 48 hours, remove top two inches of sand. Restore sand layer depth to 18 inches when overall depth drops to 12 inches.	As required.
Add maintenance recommendations/methods for geotextile fabric, gravel bed, underdrains, as needed.	As needed.
Dispose of sand, gravel, or filter fabric contaminated with petroleum hydrocarbons in accordance with all applicable laws.	As required.
Reconstruct or replace the control measure when it is no longer functioning properly.	See projected lifespan in Appendix B for informational purposes.

References

- California Stormwater Quality Association (CASQA). Stormwater Best Management Practice Handbook – New Development and Redevelopment. January 2003, revised September 2004.
- Urban Drainage and Flood Control District (UDFCD), Denver, Colorado. *Urban Drainage Criteria Manual, Volume 3 – Best Management Practices*. 1999.

Table SF-4. Design Data Summary Sheet for Sand Filter

Designer: ______________________ Date: ____________

Company: ______________________

Project: ______________________

Location: ______________________

1a. Design Water Quality Volume			
a. Contributing drainage area	Area =	______	ft^2
b. Water Quality Volume (based on 48 hr drawdown)	WQV =	______	ft^3
1b. Adjust Volume Up for Hydromodification Management (If Applicable) Based upon SAHM Modeling			
a. Water Quality Volume based on SAHM modeling	V =	______	ft^3
b. SAHM Model Demonstrates Compliance with Flow Duration Standards	(Yes or No)	______	
2. Sedimentation Basin Volume ($V_{sb} \geq$ WQV)	V_{sb} =	______	ft^3
3. Sedimentation Basin Depth (3 ft $\leq d_{sb} \leq$ 10 ft)	d_{sb} =	______	ft
4. Sedimentation Basin Area ($A_{sb} = V_{sb} / d_{sb}$)	A_{sb} =	______	ft^2
5. Sedimentation Basin Shape			
Sedimentation Basin Length (L_{sb})	L_{sb} =	______	ft
Sedimentation Basin Width (W_{sb})	W_{sb} =	______	ft
Sedimentation Basin L:W Ratio (2:1 minimum)	L:W =	______	
6. Filtration Basin Storage Volume ($V_{fbs} \geq$ 0.2 x WQV)	V_{fbs} =	______	ft^3
7. Filter Bed Surface Area			
a. Minimum filter surface area for storage (A_{fbs}) $A_{fbs} = V_{fbs} / d_{fbs}$ Where d_{fbs} = Depth of storage above filter bed (3 ft min.)	A_{fbs} =	______	ft^2
b. Minimum filter surface area for flow (A_{ff})			
Sand Bed Depth ($d_f \geq$ 1.5 ft)	d_f =	______	ft
Coefficient of permeability for sand (k = 0.146 ft/hr)	k =	______	ft/hr
Time required pass through filter (t_f = 40 hr)	t_f =	______	hr
$A_{ff} = \frac{(WQV)(d_f)}{(k)(d_{fbs}+d_f)(t_f)}$	A_{ff} =	______	ft^2
c. Final design filter bed surface area (A_{fb})	A_{fb} =	______	ft^2

8. Filter Bed Design (Check Type Used)

☐ Sand Bed with Gravel Underdrain ☐ Sand Bed with Trench Underdrain

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Underground Storage

Description

Underground storage is a practice of storing stormwater runoff in oversized pipes, detention tanks or vaults for the purpose of mitigating hydromodification impacts, and/or storing runoff for later use for irrigation of landscape areas. In some circumstances water from open bottomed or perforated storage structures can be infiltrated into the ground. Underground storage structures are typically made from concrete, metal or plastic. Many are prefabricated for rapid installation.

Photo source: City of Elk Grove

Pollutant Removal Effectiveness	
Sediment	*N/A
Nutrients	*N/A
Trash	*N/A
Metals	*N/A
Bacteria	*N/A
Oil and Grease	*N/A
Organics	*N/A

**For open bottom facilities refer to pollutant removal effectiveness of other infiltration BMP Fact Sheets within this chapter.*

The following is a partial list of the most common target pollutants for the Sacramento area: copper, lead, mercury, pathogens, diazinon, and chlorpyrifos. For more complete information refer to:

http://www.waterboards.ca.gov/water_issues/programs/tmdl/integrated2010.shtml

Source: *CASQA California Stormwater BMP Handbook, January 2003*

Planning and Siting Considerations

- The maximum recommended area generating stormwater runoff to an underground storage structure is dictated by the available structure volume. The runoff volume needed for either water quality or hydromodification mitigation can be computed using the design procedure within this fact sheet.
- If infiltrating: soil types and the depth to ground water must be investigated. Open bottomed facilities are acceptable only for projects with hydrologic soil group "A" or "B". Additionally, a minimum of 10' must be provided from the bottom of the facility to the seasonal high water table or nearest expected rock layer.
- Permanent structures should not be constructed over the storage system. The access way for maintenance vehicles should also be clear of landscaping and other obstructions.

Advantages

- Useful for any project subject to hydromodification management standards, but unable to comply solely through incorporation of LID measures or Treatment BMPs. Underground storage may also offer LID compliance credits if used as part of a capture and reuse system.

- Useful solution for any project seeking the following:
    - Reduction in stormwater runoff flow rate and (in the case of open bottom systems) volume.
    - Slow, regulated release of collected stormwater.
    - An acceptable option for high density areas seeking to maximize developable area
    - An acceptable alternative to the use of permeable pavement systems in complying with hydromodification management standards
    - Good option for 'use' of stormwater for irrigation of landscape areas.

Limitations

- By themselves, "flow through" storage facilities only mitigate peak flow. Combined with other pretreatment features, limited improvements in water quality improvement can be achieved with flow through systems. This water quality limitation does not apply to systems sized to infiltrate the water quality volume or retain it for later use. Refer to other fact sheets for more information on the water quality benefits of infiltration BMPs.
- Upstream flooding can occur if the system is improperly designed and creates a backwater.
- Cost of storage structures can be relatively high. Tank and vault costs are estimated to range from $10-$15 per cubic foot of storage. Additional design complications can include utility conflicts, increased excavation, and potential temporary dewatering needs.
- Routine maintenance is required to remove sediments and debris that accumulates in the system. These systems must be designed with manhole access to accommodate regular inspection and maintenance.
- Compliance with hydromodification standards may necessitate very small discharge openings to the extent that feasibility is compromised, any orifice opening less than 0.5" is not recommended.

General Maintenance

- Routine sweeping of the impervious drainage areas should reduce sediment loading to the underground storage area.
- During maintenance operation and access into the structure by personnel, confined space work safety procedures must be followed. Refer to: http://www.osha.gov/Publications/osha3138.pdf
- Periodic pumping of sediment and debris is required to have a proper functioning system.
- Sediment clean out should be done mechanically not by flushing.
- Incorporated pretreatment systems will need to be inspected and maintained on a regular basis.

How Does Underground Storage Work?

Underground storage can mitigate the impacts of hydromodification by releasing water at rates low enough to prevent accelerated erosion of downstream channels. Underground storage designed with an open bottom system can permit a portion of annual runoff to infiltrate, which also reduces pollutant load to receiving waters.

Design Criteria

- System volume and sizing of primary discharge outlets is to be confirmed using SAHM or other equivalent continuous simulation tools. The design must be capable of mitigating post development flow duration within the allowable range discussed elsewhere within Chapter 5[1]. In many instances, primary discharge will be dictated heavily by the "low flow threshold[1]" and could necessitate a very small outlet. In such instances, a direct maintenance access should be provided, along with other suitable measures to prevent clogging. Orifice sizes less than 0.5" are not recommended.
- Emergency overflows should be designed into the system to convey or divert excess flow, as well as regulated flow in the event of a system failure. In general emergency overflow devices or diversions should equal or exceed the capacity of inflow pipe(s) and/or contributing surface runoff. At a minimum, emergency overflow or diversions should have adequate capacity to handle the runoff from a 10 year storm, or greater if required by the local agency.

Use the Design Data Summary Sheet provided at the end of this fact sheet (Table US-2) to record design information for the permitting agency's review.

Design Procedure

General Design Issues

- The designer must consider the potential loading from soil weight, vehicles and other live loads on top of the structure
- Pretreatment is recommended at the inlets to treat stormwater runoff to remove floatables and particulates.
- The systems should incorporate water tight gaskets or joints at all structural connection points.
- Maintenance access points (manholes) should be incorporated into the design. In specifying the number and location of manholes, the designer should consider the size of the facility and most likely areas for clogging and deposition of sediment, trash, and debris.
- Metal pipes should only be used in areas where soil chemistry will not negatively impact the structural integrity of the material.

Step 1

Determine suitable location on site for underground storage such that it can effectively capture runoff from newly proposed impervious surface(s). Consider the need and ability to incorporate

[1] Refer to other applicable sections within this chapter as well as Manual Glossary for more information

water quality pretreatment in determining location of underground storage. Allow for maintenance access.

Step 2

Determine if the system can be designed as an "open bottom" facility based upon soil type. Consult with the project geotechnical engineer to determine the need for design details such the incorporation of permeable geotextile fabric or other similar measures that can help ensure proper long term function.

Step 3

Determine system volume, dimensions, and outlet configuration to the extent necessary to satisfy hydromodification requirements using SAHM software or other equivalent method.

Step 4

Select underground storage material based upon dead and live loads, as well as soil chemistry. The designer should consider anticipated elevation (depth) of inflow pipes and outlet connection(s). For situations involving the use of proprietary products, consult with the manufacturer for other potential considerations.

Step 5

Incorporate an emergency overflow into the design using bypass weirs, diversions, etc.

Step 6

Incorporate access ways for pumping and/or mechanical removal of sediment and debris.

Step 7

Incorporate details for water tight joints, gaskets, etc.

Construction Considerations

- Temporary excavation requirements for underground storage can require disturbance considerably larger than the footprint structure. Shoring and bracing may be required.
- If ground water is encountered unexpectedly during construction, that is cause to reconsider use of underground storage as a stormwater management practice. Underground storage is not generally suitable for locations with high groundwater.
- For situations involving the use of proprietary products, consult with the manufacturer for other potential installation and maintenance considerations.

Long-term Maintenance

The local permitting agencies in the Sacramento area require execution of a maintenance agreement or permit with the property owner prior to final acceptance of a private development project that includes an underground vault. Such agreements or permits will typically include requirements such as those outlined in Table US-1. The property owner or his/her designee is responsible for compliance.

Table US-1 Inspection and Maintenance Recommendations for Underground Storage

Activity	Schedule
Sweeping	
Sweep pavement area(s) to reduce inflowing sediment load.	Minimum once annually prior to start of rainy season.
Inspect Storage Chamber	
Visually inspect storage chamber from maintenance access point to identify presence of standing water.	Within 48 to 72 hours after all significant runoff producing events.
Inspect storage chamber and inlet/outlet structure(s) for signs of physical deterioration and perform corrective action or replacement as necessary.	Once per year minimum.
Cleanout of Sediment and Debris	
Remove sediment and debris using mechanical device. Haul and dispose of accumulated sediment and debris at a suitable facility.	As required based upon visual inspection of storage chamber, or once per year minimum.
Pre Treatment Areas (If Applicable)	
(Refer to Other Fact Sheets Based Upon BMP Type)	

Helpful Links

- (Confined Space Information) http://www.osha.gov/Publications/osha3138.pdf

References Used to Develop This Fact Sheet

- Federal Highway Administration, *Environmental Review Toolkit: Fact Sheet – Detention Tanks and Vaults*, http://environment.fhwa.dot.gov/ecosystems/ultraurb/3fs6.asp, accessed 6/3/13.
- LakeSuperiorStreams.org, *Site Design Toolkit: Underground Storage*, http://www.lakesuperiorstreams.org/stormwater/toolkit/underground.html, accessed 6/3/13.
- United States Environmental Protection Agency, *National Menu of Best Management Practices for Storm Water Phase II*, 2002. http://cfpub.epa.gov/npdes/stormwater/menuofbmps/index.cfm

Table US-2. Design Data Summary Sheet for Underground Storage

Designer: ______________________ **Date:** ______________

Company: ______________________

Project: ______________________

Location: ______________________

1. Design Water Quality Volume or Rate for Pre Treatment Area (If Applicable)

(Refer to Applicable Fact Sheet Based Upon BMP Type)

2. Determine Underlying Soil Type & Ability to Incorporate Infiltration	Hydrologic Soil Type (Specify A, B, C, or D) ________	Specify Design Infiltration Rate inches per hour (If any) ________
3. Storage Dimensions	**PARAMETERS MODELED IN SAHM**	**ACTUAL DESIGN ON PLANS**
Cross Sectional Shape (Circular, Arch, Rectangle, etc)	N/A	
Length (ft)		
Width (ft)		
Height (ft)		
Total Storage Provided (ac-ft)		
Native Infiltration Applied (inches per hour, see above)		N/A
Outlet #1 Description (Specify shape, size, elevation)		
Outlet #2 Description (Specify shape, size, elevation)		
Outlet #3 Description (Specify shape, size, elevation)		
SAHM Model Demonstrates Compliance with Flow Duration Standards	(Yes or No)________	
4. Specify Storage Chamber Material Type	(Specify Concrete, Metal, HDPE, etc) ________________	
5. Emergency Overflow	**MODELED IN SAHM**	**ACTUAL DESIGN ON PLANS**
Cross Sectional Shape (Sharp Crested Weir, Broad Crested Weir, Orifice, etc)	N/A	
Length (ft)		
Width (ft)		
Height (ft)		
Overflow Design Discharge (cfs) ________________	Hydraulic Capacity of Overflow (cfs) ____________	

6. Maintenance Access Incorporated (Yes or No)

7. Water Tight Joints/Gaskets Specified (Yes or No)

Vegetated Filter Strip

Description

A Vegetated Filter Strip is a gently sloped soil surface planted with dense, sod-forming vegetation and designed to receive and treat sheet flow runoff from adjacent surfaces. As the runoff flows through the vegetation and over the soil surface at a shallow depth, pollutants are removed by a variety of physical, chemical, and biological mechanisms, including sedimentation, filtration, adsorption, and microbial degradation and conversion.

Caltrans

POLLUTANT REMOVAL EFFECTIVENESS	
Sediment	Medium
Nutrients	Low
Trash	Low
Metals	Medium
Bacteria	Low
Oil and Grease	Medium
Organics	Medium

The following is a partial list of the most common target pollutants for the Sacramento area: copper, lead, mercury, pathogens, diazinon, and chlorpyrifos. For more complete information refer to:

http://www.waterboards.ca.gov/water_issues/programs/tmdl/integrated2010.shtml

Source: CASQA California Stormwater BMP Handbook, January 2003

Siting Considerations

- Drainage area: 5 acres maximum per filter strip.
- Longitudinal Slope: 1% - 4%
- Terracing may be used for slopes > 4%
- Minimum length in flow direction: 25 ft.
- Minimum depth to groundwater table: 2 ft.
- Maximum ponding depth: 1 ft.
- Type A & B soils only.

Vector Considerations

- Potential for mosquitoes due to standing water will be greatly reduced or eliminated if the strip is properly designed, constructed, and operated.

Advantages

- Relatively inexpensive when used to replace part of a conventional storm drainage system and integrated into site landscaping.
- Attractive.
- Easy to maintain.
- Potential LEED Credits
- Credit 6.1 – Stormwater Design – Quantity Control

Limitations

- Possible conflicts with water conservation ordinances for landscape irrigation requirements.

- Not appropriate for industrial sites or locations where spills may occur.
- Removes high percentage of particulate pollutants, but not soluble pollutants.

General Maintenance Recommendations (Low to Moderate)

- Periodically remove debris and sediment from filter strip surface.
- Repair/replace vegetation as necessary to maintain full cover and prevent erosion.
- See Table VFS-2 for additional vegetation maintenance recommendation.

How Does a Vegetated Filter Strip Work?

A Vegetated Filter Strip is designed to allow dispersal of sheet flow over a gently sloping, densely vegetated surface. Treatment of the runoff occurs through a variety of natural mechanisms as the runoff flows through the vegetation and over the soil surface. To ensure adequate treatment, the vegetation must be dense and strong. Greater surface area and contact time promote greater runoff treatment efficiencies. The volume of runoff can be reduced through infiltration into underlying soils. See Figure VFS-1 for a typical Vegetated Filter Strip configuration.

Other Names: Grass filter strips, Biofilter

Do not confuse a Vegetated Filter Strip with a Vegetated Swale, described elsewhere in this manual, or a Grass Buffer Strip, which is used as a low impact design strategy or for pretreatment. The latter provides only limited pollutant removal because of higher application rates, and it requires downstream treatment controls.

Planning and Siting Considerations

- Select location where site topography allows for the design of filter strips with proper slopes in flow direction.
- Integrate Vegetated Filter Strips into open space buffers, undisturbed natural areas, and other landscape areas when possible.
- For parking lot design, stalls can be shortened if tire curbs are provided around the perimeter of the filter strip and cars are allowed to overhang the filter strip.
- Irrigation is typically required to maintain viability of the filter strip vegetation. Coordinate design of general landscape irrigation system with that of the Vegetated Filter Strip, as applicable.

Design Criteria

Design criteria for Vegetated Filter Strips are listed in Table VFS-1. Use the design data summary sheet (Table VFS-3) provided at the end of this fact sheet to record design information for review by the agency plan reviewer.

Use the design data summary sheet (Table VFS-3) provided at the end of this fact sheet to record design information for review by the agency plan reviewer.

Table VFS-1. Vegetated Filter Strip Design Criteria

Design Parameter	Criteria	Notes
Drainage area	≤ 5 acres	For larger areas, break up into sub-sheds of 5 acres or less with a filter strip for each.
Design flow	WQF	See Appendix E in this Design Manual.
Maximum linear application rate (q_a)	0.005 cfs/ft of width	Rate at which runoff is applied across the top width of filter strip. This rate, combined with design flow, will define the design width of the filter strip.
Minimum slope in flow direction	1%	Gentler slopes are prone to ponding of water on surface.
Maximum slope in flow direction	4%	Steeper slopes are prone to channeling.
Minimum length in flow direction	25 ft	Most treatment occurs in the first 25 feet of flow. Longer lengths will typically provide somewhat higher levels of treatment.
Vegetation height (typical)	2-4 in	Vegetation should be maintained at a height greater than the depth of flow at design flow rate but sufficiently low to prevent lodging or shading.

Design Procedure

Step 1 – Calculate Water Quality Flow (WQF) (Flow-Based Control Measure)

Using the Appendix E in this Design Manual, determine the contributing area and water quality design flow, WQF.

Early Design is Critical!
Vegetated Filter Strips must be located on the site plan at the earliest possible design phase when laying out the building and parking footprints and before the site grading plan is prepared.

Step 2 – Calculate minimum width of Vegetated Filter Strip (W_{VFS})

The design minimum width of the Vegetated Filter Strip (W_{VFS}) normal to flow direction is a determined from the design WQF and the minimum application rate (q_a), as follows:

$$W_{VFS} = (WQF)/(q_a)$$

$$W_{VFS} = (WQF)/0.005 \text{ cfs/ft (minimum)}$$

Step 3 – Determine the minimum length of Vegetated Filter Strip in the flow direction

The length of the filter strip in the flow direction must be a minimum of 25 feet. Greater lengths are desirable, as somewhat better treatment performance can typically be expected.

Step 4 – Determine design slope

Slope of the filter strip surface in the direction of flow should be between one (1) percent and four (4) percent to avoid ponding and channeling of flow. Terracing may be used to maintain a slope of four (4) percent in steeper terrain.

Step 5 – Design inlet flow distribution

Incorporate a device such as slotted curbing, modular block porous pavement, or other spreader devices at the upstream end of the filter strip to evenly distribute flow along the top width. Concentrated flow delivered to the filter strip must be distributed evenly by means of a level spreader as shown in Figure VFS-1.

Step 6 – Select vegetation

A full, dense cover of sod-forming vegetation is necessary for the filter strip to provide adequate treatment.

Select vegetation that:

- Will be dense and strong enough to stay upright, even in flowing water;
- Has minimum need for fertilizers;
- Is not prone to pests and is consistent with IPM practices;
- Will withstand being inundated for periods of time; and
- Is consistent with local water conservation ordinance requirements.

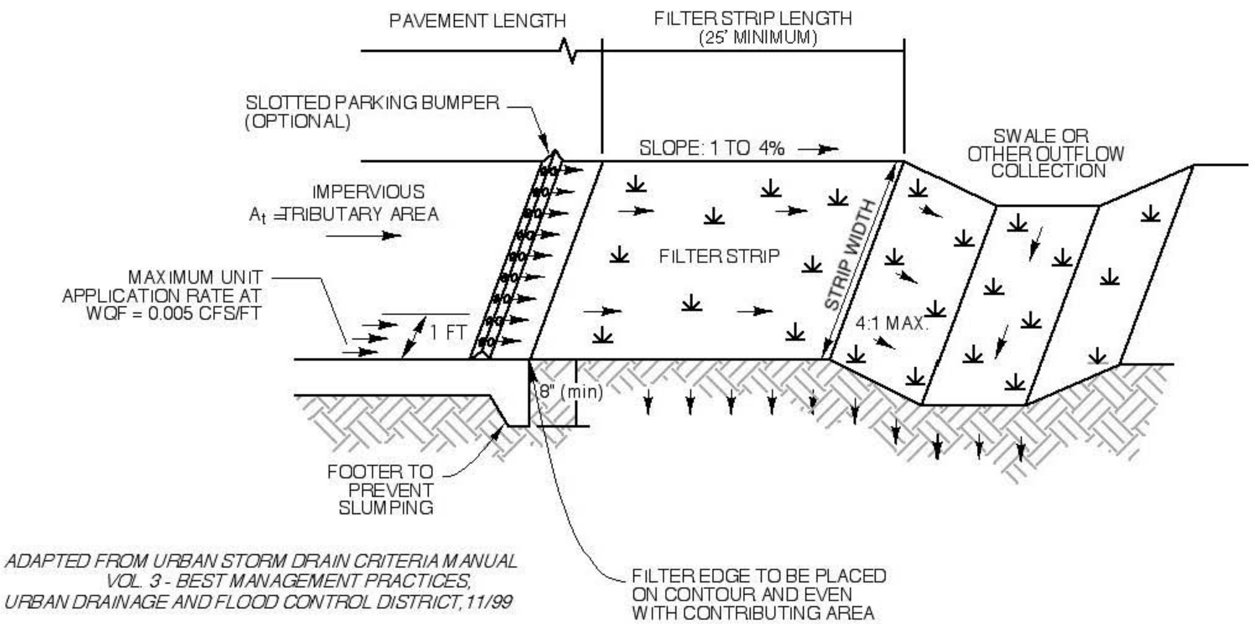
Do not use bark or similar buoyant material in the filter strip or around drain inlets or outlets.

Step 7 – Design outlet flow collection

Provide a means for outflow collection and conveyance (e.g., grass channel/swale, storm drain, gutter).

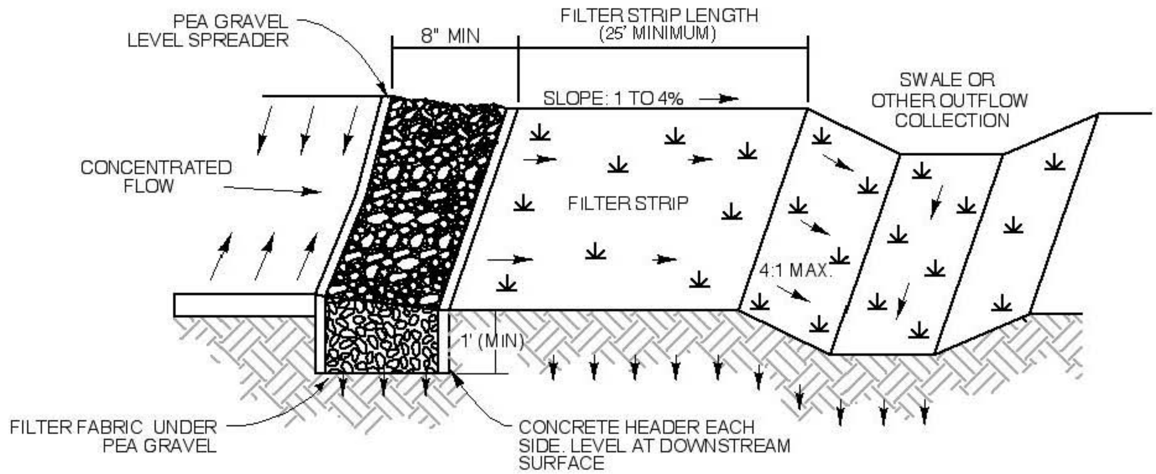
Step 8 – Design irrigation system

Provide an irrigation system to maintain viability of filter strip grass. Refer to the Efficient Irrigation fact sheet elsewhere in this chapter.



SHEET FLOW CONTROL

NOT TO SCALE



CONCENTRATED FLOW CONTROL

NOT TO SCALE

Figure VFS-1. Vegetated Filter Strip

Construction Considerations

- Divert runoff (other than necessary irrigation) during the period of vegetation establishment. Where runoff diversion is not possible, cover graded and seeded areas with suitable erosion control materials.
- Install sediment controls (e.g., staked straw wattles) around the filter strip to prevent high sediment loads from entering the filter strip during ongoing upstream construction activities.
- Repair, seed, or re-plant damaged areas immediately.

Long-term Maintenance

The local permitting agencies in the Sacramento area will require execution of a maintenance agreement or permit with the property owner for projects including a vegetated filter strip. Check with the local permitting agency about the timing for execution of the agreement. Such agreements will typically include requirements such as those outlined in Table VFS-2. The property owner or his/her designee will be responsible for compliance. See Appendix B for additional information about maintenance requirements and sample agreement language.

Table VFS-2. Inspection and Maintenance Recommendations for Vegetated Filter Strips

Activity	Schedule
Mow grass to maintain a height of 2 to 4 inches (typical).	As required.
Use integrated pest management (IPM) techniques to minimize use of fertilizers, pesticides and herbicides.	As required.
Remove trash and debris from the filter strip.	As required.
Inspect filter strip for signs of erosion, vegetation damage/coverage, channel formation problems, debris buildup, and excessive sedimentation on the surface of the strip. Correct problems or remove debris and sediment as soon as possible.	At least twice annually. Schedule one inspection at the end of the wet season so that summer maintenance can be scheduled to prepare filter strip for wet season. Additional inspections after periods of heavy runoff are desirable.
Remove sediment in inlet areas, the channel, culverts, and outlets whenever flow into the filter strip is retarded or blocked.	As required.
Repair ruts or holes in the strip by removing vegetation, adding and tamping suitable soil, and reseeding. Replace damaged vegetation.	As required.
Inspect filter strip for obstructions (e.g., debris accumulation, invasive vegetation) and pools of standing water that can provide mosquito-breeding habitat. Correct observed problems as soon as possible.	At least twice during the wet season after significant storms. Additional inspections after periods of heavy runoff are desirable.
Reconstruct or replace the control measure when it is no longer functioning properly.	See projected lifespan in Appendix B for informational purposes.

Table VFS-3. Design Data Summary Sheet for Vegetated Filter Strip

Designer: ____________________ Date: __________

Company: ____________________

Project: ____________________

Location: ____________________

1. Design Flow: WQF = I x C x A — WQF = ________ cfs

   I = Design Intensity = 0.18 in/hr — I = ________ in/hr

   C = Runoff Coefficient — C = ________

   A = Contributing Drainage Area — A = ________ acres

2. Design Width

   W_{VFS} = (WQF)/0.005 cfs/ft — W_{VFS} = ________ ft

3. Design Length (25 ft minimum) — L_{VFS} = ________ ft

4. Design Slope (1% minimum; 4% maximum) — S_{VFS} = ________ %

5. Flow Distribution (Check type used or describe "Other")

   ☐ Slotted Curbing ☐ Level Spreader ☐ Modular Block Porous Pavement

   ☐ Other ____________________

6. Vegetation (describe): ____________________

   ____

7. Outflow Collection (Check type used or describe "Other")

   ☐ Grass Swale ☐ Street Gutter ☐ Storm Sewer

   ☐ Underdrain Used ☐ Other ____________________

Notes: ____________________

____

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Vegetated Swale

Description

A vegetated swale is a wide, shallow, open channel planted with dense, sod-forming vegetation and designed to accept runoff from adjacent surfaces. As the runoff slows and travels through the vegetation and over the soil surface, pollutants are removed by a variety of physical and chemical mechanisms, including sedimentation, filtration, adsorption, and microbial degradation and conversion.

Photo source unknown

Siting Considerations

- Drainage area: 10 acres maximum per swale.
- Longitudinal Bottom Slope: 0.5%-2.5%
- Underdrains recommended based on feedback from the project geotechnical engineer (typically for slopes less than 1%). For slopes up to 5%, check dams should be used to reduce slopes to 2.5%.
- Minimum Bottom width: 2 ft.
- Side slopes: 3:1 or flatter.
- Liners may be required in areas where swales may be impacted by hazardous materials or where spills may occur (e.g., retail gasoline outlets, auto maintenance businesses, processing/manufacturing areas).
- Surface flow into swale preferred instead of underground conveyance.

Pollutant Removal Effectiveness	
Sediment	Medium
Nutrients	Low
Trash	Low
Metals*	Medium
Bacteria*	Low
Oil and Grease	Medium
Organics*	Medium

The following is a partial list of the most common target pollutants for the Sacramento area: copper, lead, mercury, pathogens, diazinon, and chlorpyrifos. For more complete information refer to:

http://www.waterboards.ca.gov/water_issues/programs/tmdl/integrated2010.shtml

Source: CASQA California Stormwater BMP Handbook, January 2003

Vector Considerations

- Potential for mosquitoes due to standing water will be greatly reduced or eliminated if the swale is properly designed, constructed, and maintained.

Advantages

- Relatively inexpensive when used to replace part of a conventional storm drainage system and integrated into site landscaping.

- Provides both stormwater treatment and conveyance.
- Reduces runoff volume during small storm events.
- Attractive and easy to maintain.
- Potential LEED Credits
  - Credit 6.1 – Stormwater Design – Quantity Control
  - Credit 6.2 – Stormwater Design – Quality Control

Limitations

- May conflict with water conservation ordinances related to landscape irrigation needs.
- May not be appropriate for industrial sites or locations where spills may occur unless liner is used to prevent infiltration.

General Maintenance Recommendations (Low to Moderate)

- Periodically remove debris and sediment from inlets and swale.
- Repair/replace vegetation as necessary to maintain full cover and prevent erosion.
- See Table VS-2 for additional vegetation maintenance recommendation.

How Does a Vegetated Swale Work?

A vegetated swale differs from a conventional drainage channel or roadside ditch due to the incorporation of specific features that enhance stormwater pollutant removal. A vegetated swale is designed to control flow velocities through the vegetation in the swale and to provide sufficient contact time to promote settling and filtering of the runoff flowing through it. Greater surface area and contact time promote greater runoff treatment efficiencies. The volume of runoff can also be reduced through infiltration into underlying soils.

Runoff is treated as it flows through, not over, the vegetation in a vegetated swale. Vegetation can cause considerable turbulence, resulting in energy loss and retardance of flow. To provide adequate treatment, the vegetation must be dense and strong.

Other Names: Grassy swale, bioswale

Alternative vegetation is encouraged but is subject to approval of local permitting agency. Parking lot swale at Elk Grove Marketplace, Elk Grove, California. Photo: CKB Environmental

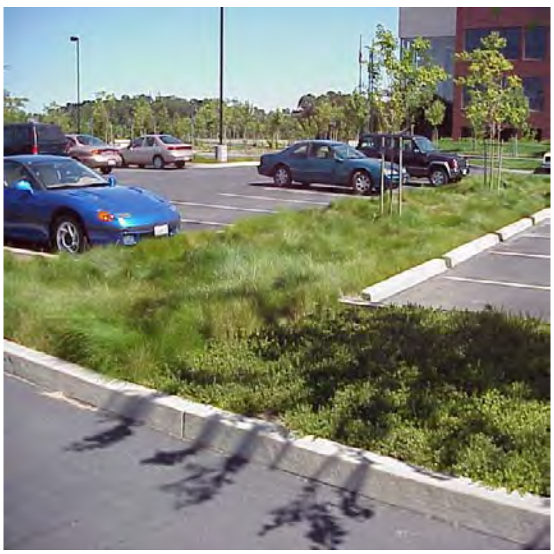
Planning and Siting Considerations

- Select location where site topography allows for the design of a channel with sufficiently mild slope (unless small drop structures are used) and enough surface area to maintain non-erosive velocities in the channel.

- Integrate swales into open space buffers, undisturbed natural areas, and other landscape areas when possible. Do not place in open space or wetland preserve areas where future maintenance could be prohibited.
- For parking lot design, stalls can be shortened if tire curbs are provided around the perimeter of the swale and cars are allowed to overhang the swale (see Farm Bureau photo).

Early Design is Critical!
Vegetated swales must be located on the site plan at the earliest possible design phase when laying out the building and parking footprints and before the site grading plan is prepared.

- In parking lots, plan areas for pedestrians to cross swales without damaging vegetation.
- The required swale length to meet treatment criteria for a 1-acre project site is typically in the range of 75 to 100 feet. The length will vary depending on several variables, including the geometry of the swale and the runoff coefficient for the site.



Vegetated Swale Planted with Native Clump Grasses (note that trees should be located outside of flowline), U.S. Farm Bureau, Sacramento. Photo: City of Sacramento.

Roadside Swale. Photo: City of Spokane

Design Criteria

Design criteria for vegetated swales are listed in Table VS-1. Use the Design Data Summary Sheet provided at the end of this fact sheet (Table VS-3) to record design information for the permitting agency's review.

Table VS-1. Vegetated Swale Design Criteria

Design Parameter	Criteria	Notes
Contributing drainage area	≤ 10 acres	For larger areas, break up into sub-sheds of 10 acres or less, with a swale for each.
Water Quality design flow	WQF	See Appendix E in this Design Manual.
Roughness coefficient (n) for treatment design	0.2	Reflects the roughness associated with shallow flow through dense vegetation.
Roughness coefficient (n) for conveyance design	0.1	Reflects the roughness of swale when depth of flow is above the height of the grass. To be used to determine capacity of swale to convey peak hydraulic flows.
Minimum contact time for treatment of the WQF	7 minutes	Provide sufficient length to yield minimum contact time for the WQF
Minimum bottom width	2 ft	
Maximum bottom width	10 ft	Swales wider than 10 feet must meet additional flow spreading requirements.
Maximum side slopes	3:1	Side slopes must allow for ease of mowing. Steeper slopes may be allowed with adequate slope stabilization
Longitudinal slope	0.5-2.5%	
Check dams	As required	For longitudinal slope > 2.5% but less than 5%, and as a means of promoting more infiltration. Spacing as required to maintain maximum longitudinal bottom slope ≤ 2.5%.
Underdrains	As required	For longitudinal slope < 1.0%
Maximum depth of flow (treatment)	3-5 in	1 inch below top of vegetation
Maximum flow velocity (treatment)	1 ft/sec	Based on Manning's n - 0.20. Concentrated inlet flow must be spread.
Inlet Design/Curb cuts	≥ 12 in wide	To prevent clogging and promote flow spreading, pavement should be slightly higher than swale. Include energy dissipaters/flow spreaders such as cobble, porous concrete, or gravel at inlet.
Trees, shrubs, and plants (if applicable)		Should be located outside of the flow area.

Design Procedure

*Record all of your calculations on the **Vegetated Swale Design Data Summary Sheet** (Table VS-3) at the end of this section. The data sheet will be checked by the agency plan review staff.*

Step 1 – Determine the vegetated swale's function

The vegetated swale can be designed to function as both a treatment control measure for the stormwater quality design flow and as a conveyance system to pass the peak hydraulic design flows, if the swale is located "on-line".

Step 2 – Calculate Water Quality Flow (WQF)

Using Appendix E in this Design Manual, determine the contributing area and stormwater quality design flow, WQF.

Step 3 – Provide for peak hydraulic design flows

Using local hydrologic design criteria, calculate flows greater than WQF to be diverted around or flow through the swale. Design the diversion structure, if needed.

Step 4 – Design the vegetated swale using Manning's Equation

Swales can be trapezoidal or parabolic in shape, as illustrated in Figure VS-1. While trapezoidal channels are the most efficient for conveying flows, parabolic configurations provide good water quality treatment and may be easier to mow since they don't have sharp breaks in slope.

Use a roughness coefficient (n) of 0.20 with Manning's Equation to design the treatment area of a swale to account for the flow through the vegetation. To determine the capacity of the swale to convey peak hydraulic flows (for example, the 10-year event with 1 ft. of freeboard), use a roughness coefficient (n) of 0.10 with Manning's Equation.

Manning's Equation

$$Q = \frac{1.49}{n}\frac{A^{5/3}}{P^{2/3}} \times s^{1/2}$$

Where:

Q = WQF, (cfs)

A = Cross sectional area of flow, (ft2)

P = Wetted perimeter of flow, (ft)

s = Bottom slope in flow direction, (ft/ft)

n = Manning's n (roughness coefficient)

For treatment design, solve Manning's equation by trial and error to determine a bottom width that yields a flow depth of 3 to 5 inches at the design WQF and the swale geometry (i.e., side slope and s value) for the site under design.

Step 5 – Design Inlet Controls

- For flow introduced along the length of the swale through curb cuts, provide minimum curb cut widths of 12 inches and avoid short-circuiting the swale by providing the minimum contact time of 7 minutes.
- For swales that receive direct concentrated runoff at the upstream end, provide an energy dissipater, as appropriate, and a flow spreader such as a pea gravel diaphragm flow spreader at the upstream end of the swale.

Step 6 – Select Vegetation

A full, dense cover of sod-forming vegetation is typically recommended for vegetated swales, since most pollutant removal performance studies are based on use of grass. Alternative vegetation such as trees, shrubs and groundcovers may also be allowed; check with the local permitting agency.

Vegetated swale,
The City of Sacramento

Select vegetation that:

- Will be dense and strong enough to stay upright, even in flowing water and steep slopes;
- Has minimum need for fertilizers;
- Provides shading (if necessary);
- Is not prone to pests and will not require a lot of pesticide/herbicide application, consistent with any integrated pest management (IPM) practices or policies of the local permitting agency;
- Will withstand being inundated for periods of time; and
- Needs little supplemental water, consistent with local water conservation ordinances. Bunch-type grasses or grass mixes are preferred (i.e. Sisyrinchium bellum - blue-eyed grass).

The Alameda Countywide C.3 Stormwater Technical Guidance handbook (https://cleanwaterprogram.org/index.php/resources/recources/development.html) contains a detailed plant list for consideration, although vegetation selection must be approved by the permitting agency. Do not use bark or similar buoyant material in the swale or around drain inlets or outlets.

Construction Considerations

- Divert runoff (other than necessary irrigation) during the period of vegetation establishment. Where runoff diversion is not possible, cover graded and seeded areas with suitable erosion control materials.
- Install sediment controls (e.g., staked straw wattles) around the swale to prevent high sediment loads from entering the swale during ongoing upstream construction activities.
- Repair, seed, or re-plant damaged areas immediately.
- Apply erosion control measures as needed to stabilize side slopes and inlet areas.

Long-term Maintenance

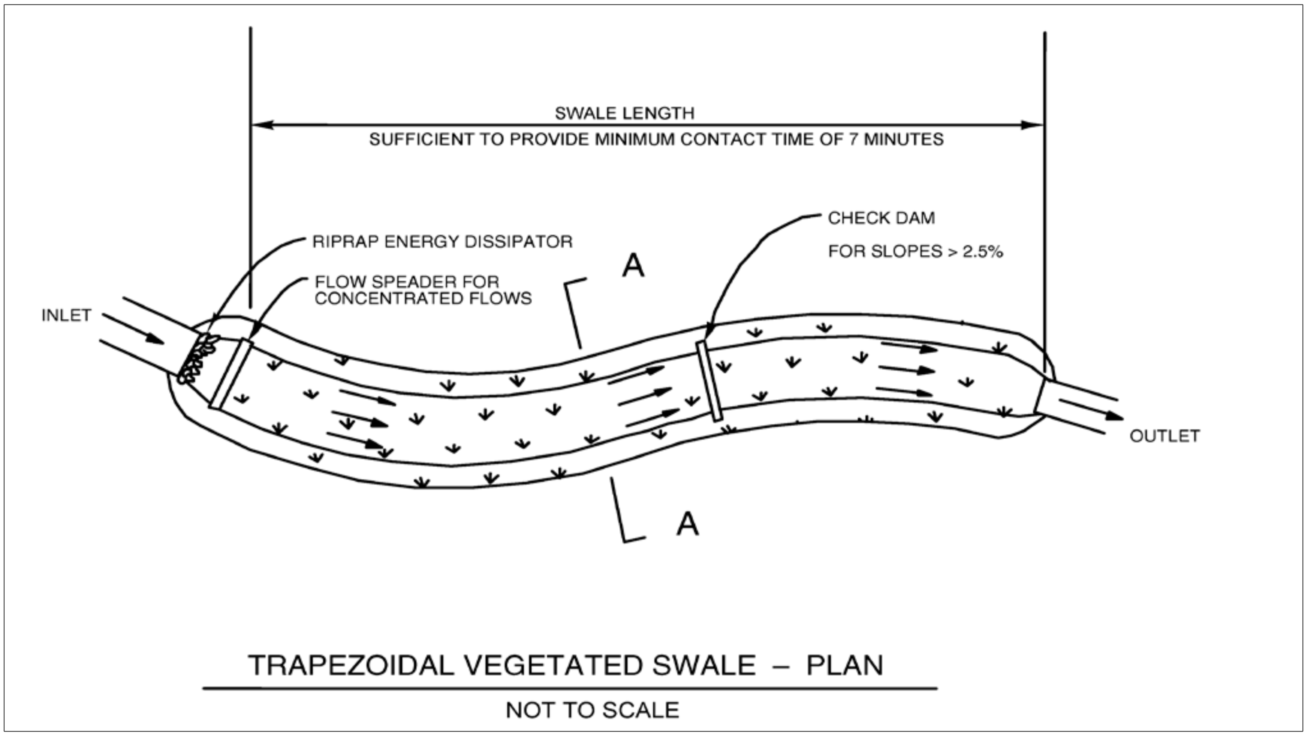
The local permitting agencies in the Sacramento area will require execution of a maintenance agreement or permit with the property owner for projects including a vegetated swale. Check with the local permitting agency about the timing for execution of the agreement. Such agreements will typically include requirements such as those outlined in Table VS-2. The property owner or his/her designee will be responsible for compliance. See Appendix B for additional information about maintenance requirements and sample agreement language.

*Swales with rock in the flowline are **discouraged** due to high maintenance needs (including use of weed killers) and potential for mosquito breeding.*

Table VS-2. Inspection and Maintenance Recommendations for Vegetated Swales

Activity	Schedule
Mow grass to maintain a height of 4 to 6 inches or above depth of flow at WQF.	As needed to maintain optimum grass height
Use integrated pest management (IPM) techniques to minimize use of fertilizers, pesticides and herbicides.	As needed.
Remove trash and debris from the swale (especially at the outlet)	As needed.
Inspect swale for signs of erosion, vegetation damage/coverage, channelization problems, debris build-up and excessive sedimentation in bottom of channel. Correct problems (e.g., remove sediment or stabilize, re-seed eroded areas) as soon as possible.	At least twice annually. Schedule one inspection at the end of the wet season so that summer maintenance can be scheduled to prepare swale for wet season. Additional inspections after periods of heavy runoff are desirable.
Remove sediment in inlet areas, channel, culverts, and outlets whenever flow into the swale is retarded or blocked.	As needed.

Activity	Schedule
Repair ruts or holes in the channel by removing vegetation, adding and tamping suitable soil, and reseeding. Replace damaged vegetation.	As needed.
Inspect swale for obstructions (e.g., debris accumulation, invasive vegetation) and pools of standing water that can provide mosquito breeding habitat. Correct observed problems as soon as possible.	At least twice during the wet season after significant storms. Additional inspections after periods of heavy runoff are desirable.
Reconstruct or replace the control measure when it is no longer functioning properly.	See projected lifespan in Appendix B for informational purposes.



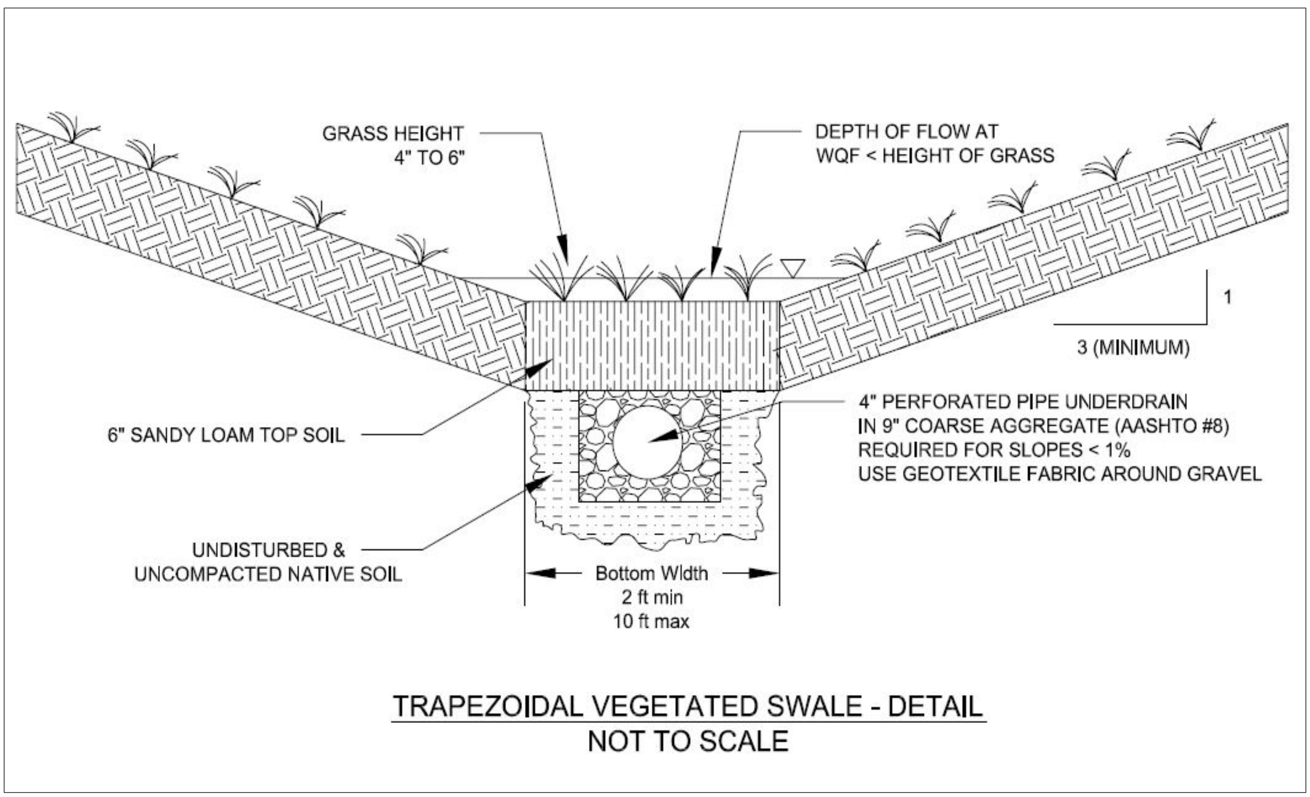


Figure VS-1. Vegetated Swale

Note: 6" sandy loam top soil layer only required if deemed necessary by the project geotechnical engineer to promote the swale's function.

Table VS-3. Design Data Summary Sheet for Vegetated Swale

Designer: ______________________ **Date:** __________

Company: ______________________

Project: ______________________

Location: ______________________

1. Design Flow: WQF = I x C x A	WQF =	______	cfs
I = Design Intensity = 0.18 in/hr	I =	______	in/hr
C = Runoff Coefficient	C =	______	
A = Contributing Drainage Area	A =	______	acres
2. Swale Geometry			
Swale Bottom Width (b)	b =	______	Ft
Side slope (Z)	Z =	______	
3. Depth of flow (d) at WQF (3" to 5" with Manning's n=0.20)	d =	______	in
4. Design Slope			
s = 1% minimum without underdrains, 2.5% maximum without grade controls	s =	______	%
Number of grade controls required		______	
5. Design flow velocity (Manning's n=0.20)	v =	______	ft/sec
6. Contact Time (t_c = 7 minutes maximum)	t_c =	______	Minutes
7. Design Length, L = (t_c) x (flow velocity) x 60	L =	______	ft

8. Vegetation (describe): ______________________

9. Outflow Collection (Check type used or describe "Other")

☐ Grated Inlet ☐ Infiltration Trench ☐ Underdrain Used

☐ Other ______________________

Notes: ______________________

Water Quality Detention Basins

Source: County of Sacramento, Department of Water Resources

Description

A stormwater quality detention basin (also called a water quality basin or extended detention basin) is designed to hold stormwater runoff from small storms and the initial runoff ("first flush") from larger storms for a regulated downstream release. Pollutants are removed from stormwater through gravitational settling and biological processes depending on the type of basin. There are three types of water quality detention basins:

- Wet stormwater quality detention basins (wet basins) that store a permanent pond of water
- Dry extended stormwater quality detention basins (dry-extended basins) that temporarily store stormwater runoff
- Combination (wet/dry) stormwater quality detention basins (combination basins) that combine the wet and dry basin treatment systems

Stormwater quality basins must incorporate features that treat dry-weather flows (such as irrigation runoff). Wet basins and combination basins treat the dry weather flows within the permanent pond (micropool); however, dry basin designs must include an additional feature such as a submerged gravel bed or other agency approved feature.

Pollutant Removal Effectiveness		
	Dry Basin	Wet Basin
Sediment	Medium	High
Nutrients	Low	Medium
Trash	High	High
Metals	Medium	High
Bacteria	Medium	High
Oil and Grease	Medium	High
Organics	Medium	High

The following is a partial list of the most common target pollutants for the Sacramento area: copper, lead, mercury, pathogens, diazinon, and chlorpyrifos. For more complete information refer to:

http://www.waterboards.ca.gov/water_issues/programs/tmdl/integrated2010.shtml

Source: CASQA California Stormwater BMP Handbook, January 2003

Siting Considerations

- Drainage area: typically greater than 20 acres
- Longitudinal bottom slope: At least 2% in dry basins. Can undulate in wet basins.
- Side slopes: 3:1 or flatter for basin; 3:1 or steeper for permanent ponds.
- Impermeable liners may be required in areas with high groundwater.

Vector Considerations

- Potential for mosquitoes due to standing water will be greatly reduced or eliminated if the basins and associated features are properly designed, constructed, operated and maintained.
- Permanent ponds shall be stocked with mosquito fish for vector control.

Advantages

- May provide both stormwater quality treatment and flood control if designed for flood flows.
- Mitigate increased volume and flow impacts caused by development.
- If properly designed, constructed, and maintained, have substantial aesthetic and recreational value and provide wildlife habitat.
- Viewed as a public amenity when integrated into a park or open space setting and properly designed and landscaped.
- Wet basins: Permanent ponds can provide significant water quality improvement across a broad spectrum of constituents including dissolved nutrients.
- Wet basins: Can treat dry weather flows without the need for additional features.
- Dry basins: May be easier to maintain than wet basins.
- Potential LEED Credits
    - Credit 6.2 – Stormwater Design – Quality Control

Photo: Bilby Road, The City of Elk Grove

Limitations

- May pose some safety concerns where there is public access.
- Cannot be placed on steep, unstable slopes.
- Wet basins: Need a supplemental water source to replenish and maintain the permanent pond.
- Wet basins: Are typically not permitted if routine pumping of ground or surface water would be needed to maintain the permanent pond. Check with the local permitting agency.
- Dry basins: May require more land than combination and wet ponds.

How Does a Water Quality Detention Basin Work?

Stormwater quality detention basins allow particles and associated pollutants to settle out. Permanent ponds (micropools) may enhance pollutant removal through biological and chemical processes. The volume of runoff may also be reduced through infiltration and evaporation. Dry basins fill up during a storm event and detain the water quality volume for a period of 48 hours. Wet basins allow stormwater runoff to slowly pass through the pond displacing water from the permanent pond. Combination basins include both a permanent pond and additional storage for detaining a portion of the water quality volume for a period of 48 hours.

Other Names: water quality basin, extended detention basin, dry extended basin, wet ponds, wet extended-detention basins, dry ponds

Planning and Siting Considerations

Photo: Rain Garden, City of Elk Grove

- Plan water quality basins to be aesthetically-pleasing public amenities (see Figure DB-1).
- Where possible, design water quality basins as a joint use with parks (passive recreation), open space, wildlife habitat, aesthetic amenities and/or flood control detention facilities (see Figures DB-1 and DB-2). Generally, the area within the water quality volume (WQV) is not well suited for recreation facilities such as ballparks, picnic areas and restrooms.
- Ponds present special design considerations such as the selection of appropriate vegetation and nuisance abatement in order to function properly as both a water quality control measure and a public amenity.
- Use dry basins if dry weather flows are not sufficient to maintain the permanent pond of wet and combination ponds. See Figure DB-4.
- Wet and combination basins may require a supplemental water source to maintain the permanent pond until the entire drainage shed is built out.
- Wet and combination basins require submitting water balancing calculations to ensure that the permanent pond volume will be maintained in the dry season. Use an evaporation rate of 0.45 in/day for the Sacramento area.
- May be required to include aeration and/or fountains for permanent ponds with depths greater than 6 feet.
- Place top soil within the top 12" of the basin to help support plant growth.
- Consider utilizing trees and shrubs for habitat esthetics, shade, and runoff reduction.
- Refer to the local agency drainage criteria for flood control design.
- Consider re-circulating dry-weather flows in a water feature or as irrigation water to conserve water and benefit water quality.
- Provide vehicle/equipment access for maintenance of the basins and inlet/outlet structures. May be required to include a boat ramp for harvesting of aquatic plants. Refer to the local agency for specific design criteria. Access could be combined with other uses such as walking or bicycle paths.
- Impermeable liners may be required in areas with high groundwater.
- May require approval from State Division of Safety of Dams (http://www.water.ca.gov/damsafety).

Figure DB-1. Park Incorporating Water Quality Detention with Wet Pond

Figure DB-2. Water Quality Detention Pond Incorporating Wet Pond and Natural Contours

Design Criteria

Design criteria for stormwater detention basins are listed in Table DB-1.

Table DB-1. Water Quality Detention Basin Design Criteria

Design Parameter	Criteria for Basin Type			Notes
	Dry	Wet	Combo	
Drainage area	Typically > 20 acres			
Design volume	WQV	1.25 WQV	1.125 WQV	See Figure DB-3 and Appendix E in this manual for details.
	Or as dictated greater by SAHM modeling (for projects with hydromodification requirement)			
Drawdown Time	48 hrs			See Appendix E
Depth of Basin/ Permanent Pond	NA	4 – 8 ft	4 – 8 ft	A 4 ft pond depth ensures an open water area, retards cattail growth, reduces stagnation, and allows for mosquito fish. Water deeper than 4 ft increases the residence time and results in less heating/stagnation in summer.
Basin Shape	Length 3X width (minimum)			Always maximize the distance between the inlet and outlet. Whenever possible, shape the basin to gradually expand from the inlet then gradually contract toward the outlet (e.g., teardrop).
Side slopes (H:V)	3:1 or flatter 3:1 or steeper			Basin side slopes Permanent ponds side slopes
Embankment side slope (H:V)	4:1 or flatter 3:1 or flatter			Inside Outside (without retaining wall)
Longitudinal slope/ bottom surface	Slope at least 2%	Undulate the bottom depth	Undulate the bottom depth	
Basin freeboard	1 ft			
Treatment for dry-weather flows	Submerged gravel bed	Permanent pond	Permanent pond	Other dry weather treatment features for dry basins may be approved by the permitting agency on a case-by-case basis.
Vegetation	Appropriate for extended dry periods	Appropriate for extended wet periods	Appropriate for both wet and dry periods	
Sediment Forebay Volume	5 to 10% maximum of the total design volume			Sediment forebays may not be required; check with the local permitting agency.

Step 1a – Calculate Water Quality Volume (WQV)

Using Appendix E in this manual, determine the stormwater quality design volume, WQV, for the contributing area. See Figure DB-3 and table DB-1 for the volume requirements for dry, combination and wet basins.

Step 1b – SAHM Modeling for Hydromodification Management (If applicable)

Upsize the water quality basin volume as necessary based upon modeling results if implementing as a hydromodification management control.

Step 2 – Design the Basin

Design the basin to:

- Provide the required volume as determined in step 1.
- Meet criteria on Table DB-1 regarding depth, shape, side slope and longitudinal slope
- Incorporate a sediment forebay if required by the local agency. See step 3.
- Maximize residence time by placing the inlet and outlet on opposite ends of the basin. Ensuring the length is at least three times the width, as measured down the center of the flow path. For permanent ponds, incorporate additional features to maximize residence time, such as:
    - Contouring the basin bottom to baffle flows and promote mixing.
    - Using islands or peninsulas.
    - If possible, designing the deepest point to be at least 8 ft. deep.
- Incorporate access. See step 5.
- Incorporate a concrete low flow channel in dry basins (see Figures DB-4 and DB-5).
- Consider an aquatic bench with emergent vegetation around the perimeter of wet ponds and permanent pools to help with water quality and to provide a safety feature.

See Figure DB-4 for an example of a dry extended detention basin.

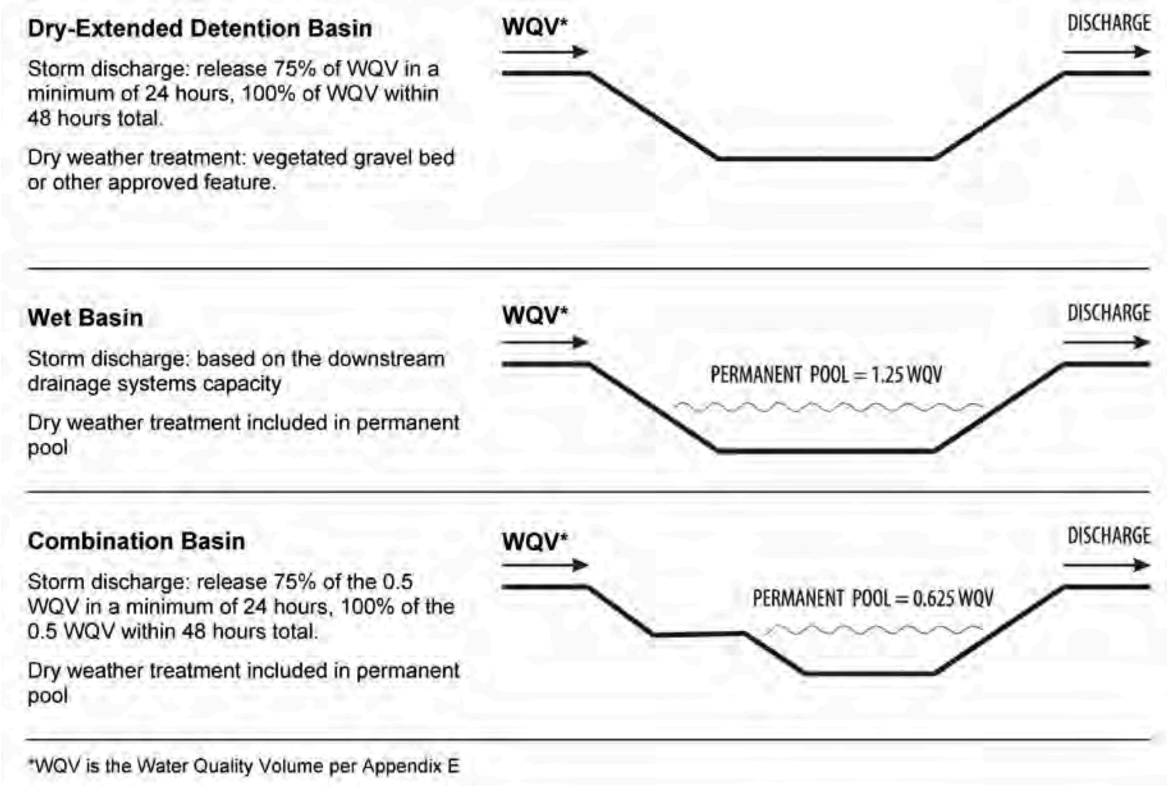


Figure DB-3. Basin Criteria to Control Stormwater Pollution

Step 3 – Sediment Forebay

A sediment forebay may be required (check with local permitting agency) at each inflow point in order to trap sediment where it can be easily cleaned out. The forebay size should be about 5% to 10% maximum of the total design volume and designed to release in 3-5 minutes.

For easy-maintenance, design the sediment forebay(s) to include:

- An access road. See step 5 for detailed information.
- Concrete lining to prevent equipment from sinking during cleaning.
- A concrete wall to separate the forebay from the rest of the water quality basin. The concrete wall should include overflow weir allowing flows to exit at non-erosive velocities during the 2-year and 10-year frequency design storms.

Step 4 - Design the Inlet and Outlet

Inlet Design

Design the inlet structure to:

- Dissipate energy of incoming flows to prevent erosion and prevent resuspension of previously deposited sediment.
- For permanent ponds, set pipe invert approximately two (2) feet from pond bottom above sediment storage.

- Install trash/access control rack. Check with the local agencies details.
- Provide access per Step 5.

Outlet Design

The goal of the outlet design criteria is to detain flows for a sufficient period of time to permit the settling of smaller sized sediments while meeting the release criteria so that storage is available for subsequent storm events. Outlets should be designed in accordance to Figure DB-6 or equal design as approved by the local agency and shall include trash racks to keep debris from clogging the outlet without interfering with the hydraulic capacity. In addition, flap gates should be installed to avoid the effects of backwater in the downstream creek or channel. The release criteria for the basins are as follows:

- Dry Basin - A dry basin is required to release 75 percent of the water quality volume in a minimum of 24 hours and the total design volume over an additional 24 hours for a total release time of 48 hours. The WQV should not be discharged too quickly or pollutant removal will be compromised.
- Wet basins - A wet basin is required to maintain the permanent pond volume while discharging based on the downstream drainage systems capacity.
- Combination basins - A combination basin is required to maintain the permanent pond volume while releasing 75 percent of the 0.5 WQV in a minimum of 24 hours and the remainder 25 percent of the 0.5 WQV over an additional 24 hours for a total release time of 48 hours.

For hydromodification management, outlet design is to be confirmed using SAHM or other equivalent continuous simulation tools

Step 5 – Access Design

Provide a way for maintenance vehicles to access all structures and cells within the basin such as the basin bottom, sediment forebay, inlets and outlets, low flow channels and submerged gravel beds. Design access roads to have an all weather access surface, a width of 15' to 20' (check with the local permitting agency for required width) and a minimum turning radius of 40 feet. Design access ramps to be concrete or other impervious surface (check with local permitting agency) to the basin bottom with a maximum slope of 10% and a width of 15 feet. Place gates across all access ramps to discourage access.

Step 6 – Design for Safety

Incorporate features for safety:

- Consider fencing the facility with post and cable (6" x 6" post minimum) or other approved fencing material to discourage access.
- Hinge and lock gates on structures.
- Provide gates or removable bollards across access roads.

If applicable, design the dam embankment for safety:

- Obtain approval from State Division of Safety of Dams, if required based on the size of the dam/storage volume. If that is not required, nonetheless design the embankment-spillway-outlet system to prevent catastrophic failure.
- Design the embankment not to fail during 100-year and larger storms.
- Create embankment slopes to be 3:1 or flatter for outside slopes and 4:1 or flatter for inside slopes and plant them with turf forming grasses.
- Compact embankment soils in accordance to geotechnical engineer's specifications.
- Design spillway structures and overflows in accordance with local drainage criteria.

Step 7- Incorporate Treatment for Dry-Weather Flows

For wet and combination basins, the permanent pond provides treatment for dry-weather flows. For dry basins, it is necessary to provide dry-weather flow treatment such as a vegetated submerged gravel bed or other equal treatment that is approved by the local permitting agency. See Figure DB-4.

Dry weather flows vary by land use, drainage basin size, soil types and other factors. Determine dry weather design flows, Q, using the values in Table DB-2 or other criteria acceptable to the local agency.

Table DB-2. Dry Weather Design Flows

Basin	Area (acres)	Dry Weather Flow (MGAL/WK)	Land Use	MGAL/WK (per Ac shed)	CFS (per Ac shed)	Ac-ft/day (per Ac shed)
Summary of City of Sacramento Drainage Sump Stations Used						
33	684	1.07	Residential/Commercial	0.0016	0.000354	0.0007
34	687	1.25	Residential	0.0018	0.000398	0.0008
63	481	1.71	Residential	0.0036	0.000796	0.0016
66	443	1.72	Industrial	0.0039	0.000862	0.0017
67	896	3.10	Residential/Commercial	0.0035	0.000774	0.0015
69	1,115	4.50	Residential	0.0040	0.000884	0.0018
96	1,308	1.33	Mix	0.0010	0.000221	0.0004
116	197	0.30	Industrial	0.0015	0.000332	0.0007
129	1,356	3.53	Mix (mostly residential)	0.0026	0.000575	0.0011
132	2,044	8.83	Residential	0.0043	0.000950	0.0019
151	1,058	3.24	Mix	0.0031	0.000685	0.0013
152	1,479	13.60	Mix	0.0092	0.002034	0.0040
154	662	0.92	Commercial/Industrial	0.0014	0.000309	0.0006
159	573	1.48	Residential/Industrial	0.0026	0.000575	0.0011
			Average	0.0032	0.000696	0.0014
			Median	0.0029	0.000630	0.0012

Basin	Area (acres)	Dry Weather Flow (MGAL/WK)	Land Use	MGAL/WK (per Ac shed)	CFS (per Ac shed)	Ac-ft/day (per Ac shed)
Flow data from FY 12, 13, 14, 15 & 16						
Residential and Residential/Other						
33	684	1.07	Residential/Commercial	0.0016	0.000354	0.0007
34	687	1.25	Residential	0.0018	0.000398	0.0008
63	481	1.71	Residential	0.0036	0.000796	0.0016
67	896	3.10	Residential/Commercial	0.0035	0.000774	0.0015
69	1,115	4.50	Residential	0.0040	0.000884	0.0018
129	1,356	3.53	Mix (mostly residential)	0.0026	0.000575	0.0011
132	2,044	8.83	Residential	0.0043	0.000950	0.0019
159	573	1.48	Residential/Industrial	0.0026	0.000575	0.0011
			Average	*0.0030*	*0.000663*	*0.0013*
			Median	*0.0031*	*0.000675*	*0.0013*
Commercial/Industrial/Mix						
66	443	1.72	Industrial	0.0039	0.000860	0.0017
96	1,308	1.33	Mix	0.0010	0.000220	0.0004
116	197	0.30	Industrial	0.0015	0.000330	0.0007
151	1,058	3.24	Mix	0.0031	0.000690	0.0013
152	1,479	13.60	Mix	0.0092	0.002030	0.0040
154	662	0.92	Commercial/Industrial	0.0014	0.000310	0.0006
			Average	*0.0034*	*0.000740*	*0.0015*
			Median	*0.0023*	*0.000510*	*0.0010*
Residential						
34	687	1.25	Residential	0.0018	0.000398	0.0008
63	481	1.71	Residential	0.0036	0.000796	0.0016
69	1,115	4.50	Residential	0.0040	0.000884	0.0018
132	2,044	8.83	Residential	0.0043	0.000950	0.0019
			Average	*0.0034*	*0.000757*	*0.0015*
			Median	*0.0038*	*0.000840*	*0.0017*

Vegetated Submerged Gravel Beds

Vegetated submerged gravel beds can be used to reduce contaminants in dry weather flows within or outside of a dry basin (See Figure DB-4). Design vegetated submerged gravel beds so that:

- Anticipated dry weather flows pass through the gravel bed without overland flow or flooding.

- Anticipated dry weather flows pass through the gravel bed without dry out (excessive dry headspace) at the inlet zone of the bed.
- The bed remains functional in the likely event of changing hydraulic conductivity (As the bed clogs with roots and sediment, it should not flood.)
- Water levels are fully controllable through the use of inlet and outlet structures.
- The system achieves desired removal of contaminants.
- The gravel bed shall be planted with emergent plants (See Table DB-3).
- The top 3" of the gravel bed shall be above the outlet flow line.
- Gravel shall be held to 2" below the outfall flow line within a 4 foot radius of the outfall pipe.

Basin geometry: Choose a length-to-width ratio that results in a sufficient hydraulic gradient to push the water through the gravel bed. A length-to-width ratio of 5 to 10 is common, but other length-to width ratios can be used provided the hydraulic gradient is adequate. (As the length-to-width ratio is increased, the linear velocity of the water passing through the gravel bed increases, the pressure drop increases, and the hydraulic gradient decreases. At some point, the hydraulic gradient is not sufficient to push the water through the gravel bed, resulting in overland flow.)

Design Criteria: Design using the following criteria:

- The gravel media - 1" to 1-1/2" in size.
- The bed depth – d = 2 feet (The depth of media is selected by allowing consideration for bottom sediment buildup and rooting requirements of desired vegetation.)
- The design porosity of the gravel bed - $\varepsilon = 0.3$
- The effective hydraulic conductivity shall be less than 95,000 ft/day.
- Nominal hydraulic detention time through the gravel bed, $\tau = 2$ days.

$$\textbf{Surface Area} = SA = L\,W = (\tau\,Q)\,/\,(d\,\varepsilon) = (2\text{ days})Q/(2\text{ feet})(0.3)(86400\text{ sec/day})$$

Where Q= dry weather design flow rate (cfs)

Step 8 - Prepare a Landscaping Plan

Retain a certified landscape architect or wetland specialist to prepare a landscaping plan that includes:

- a planting layout showing what species to plant where
- plant sizes (e.g. seed, plug, 1-gallon container, etc.)
- planting techniques
- plant spacing
- soil amendments
- hydroseed specifications
- Irrigation specifications (which must conform to applicable local regulations)

Consider the following when choosing plants:

- Do not plant trees at the base of any access ramps, around any inlet, outlet or culvert, or within 5 to 10 feet of a concrete structure or channel.
- Cluster trees and shrubs when possible to make mowing of basin easier.
- Trees may not be allowed on the basin floor (check with local permitting agency).
- Use native plants.
- Choose plants that are adapted to the site conditions, including the expected degree of inundation/soil moisture.
- Incorporate plants known to improve water quality.
- Where possible, specify an array of plant types, including emergent species (in channels/ponds), herbaceous species, and trees and shrubs (along the outer borders). This results in a more natural system and enhances the aesthetic and wildlife value. However, shrubs and trees should not be used for clay-lined permanent ponds or basins.

See Tables DB-3 and DB-4 for a list of suitable plants for different degrees of inundation/soil saturation. These lists are not comprehensive; other plants may be used as deemed suitable by the project's landscape architect.

Table DB-3. Plants for Areas that are Periodically Inundated

Scientific Name	Common Name	Propagation Method			Notes
		PLUG	CONTAINER STICK	SEED	
Emergent species					
Carex densa	Dense sedge	✓	✓		Best where soil is saturated for greater duration
Carex barbarae	Santa Barbara sedge	✓	✓		
Cyperus eragrostis	Tall faltsedge	✓	✓		
Eleocharis macrostachya	Creeping spikerush	✓	✓		
Juncus balitcus	Baltic rush	✓	✓		
Juncus xiphioides	Irish-leaved rush	✓	✓		
Grasses					
Hordeum brachyantherum	Meadow barley			✓	
Leptochloa fascicularis	Bearded sprangle-top			✓	
Muhlenbergia rigens	Deergrass			✓	
Paspalum distichum	Paspalum			✓	
Phalaris arundinaceae	Reed canary grass			✓	
Phalaris lemmonii	Lemmon's canary grassed			✓	
Herbaceous species					
Polygonum lapathifolium	Willow weed	✓	✓		Locate where soil is most apt to be saturated
Polygonum punctatum	Dotted smartweed	✓	✓		
Verbena hastate	Blue vervain		✓	✓	Locate near borders where soil dries out first

Table DB-4. Plants to Use In/Adjacent to a Permanent Pond

Scientific Name	Common Name	Propagation Method: PLUG	CONTAINER STICK	POLE CUTTINGS	TUBER	SEED	Notes
Aquatic species							
Ceratophyllum demersum	Hornwort	✓	✓				
Elodea canadensis	Common waterweed	✓	✓				
Potomogeton pectinatus	Sago pondweed				✓		
Emergent species							
Carex barbarae	Santa Barbara sedge	✓	✓				Best at pond border where soils are saturated/ periodically inundated
Juncus balitcus	Baltic rush	✓	✓				
Juncus effuses	Soft rush	✓	✓				
Scirpus acutus var. *Occidentalis*	Hard-stem bulrush	✓	✓				Adapted to water levels up to 3 feet
Scirpus americanus	Three square	✓	✓				Best at pond border
Grasses							
Hordeum brachyantherum	Meadow barley					✓	Adjacent to pond, where soils are saturated to the surface but not inundated
Leptochloa fascicularis	Bearded sprangle-top					✓	
Paspalum distichum	Paspalum					✓	
Herbaceous species							
Baccharis douglasii	Marsh baccharis	✓	✓				
Euthamia occidentalis	Western goldenrod	✓	✓				
Polygonum lapathifolium	Willow weed	✓	✓				Can be grown along the pond borders where soils are saturated to the surface
Polygonum punctatum	Dotted smartweed	✓	✓				
Sagittaria latifolia	Broad-leaf arrowhead	✓	✓				
Shrubs (may not be appropriate if pond is clay lined)							
Baccharis salicifolia	Mule fat		✓				
Cephalanthus occidentalis	Common buttonbush		✓				Can be grown on the pond banks; accepts greater soil saturation than the California rose

Scientific Name	Common Name	Propagation Method: PLUG	CONTAINER STICK	POLE CUTTINGS	TUBER	SEED	Notes
Rosa californica	California rose		✓				Can be grown on the pond banks, ideally where there is minimal surface soil saturation
Trees (should not be used for clay-lined permanent ponds)							
Alnus rhombifolia	White alder		✓				Can be grown on pond berms/ borders
Populus fremontii	Fremont's cottonwood		✓	✓			
Salix exigua	Sandbar willow		✓	✓			
Salix gooddingii	Goodding's black willow		✓	✓			
Salix lasiolepis	Arroyo willow		✓	✓			
Salix laevigata	Red willow		✓	✓			
Salix lucida var. *lasiandra*	Shining willow		✓	✓			

Construction Considerations

- Before acceptance of the basin by the local agency, the accumulated sediment must be removed.
- See "Recommended Planting Guidelines" later in this fact sheet for information on planting techniques and recommended planting times.
- Take steps to ensure plants become established:
    - Plant emergent species bordering the permanent pond in saturated soil, so the plants will become established. Maintain the water level in the pond to allow for soil saturation or shallow inundation around the base of the plants, but avoid significant flooding and inundation of stems and leaves during the first year. Tall plugs and plantings can tolerate greater depths of inundation as long as a significant portion of the stems and leaves of the plantings remain above the water surface.
    - Provide drip irrigation for plantings in areas that will not be saturated to the surface or inundated. Irrigate as needed at least during the first two years--until the plants can survive on annual rainfall and/or groundwater.
    - Irrigate hydroseeded areas only if needed for plant establishment. Hydroseeded portions of the bank do not need irrigation in years of normal rainfall. If a period of drought occurs after hydroseeding, supplemental watering may be needed to establish germination in the first year.

Long-term Maintenance

Regional detention basins usually will be maintained by the local agency. A long-term maintenance plan (i.e., adaptive management plan) shall be prepared by the developer/owner and approved by the local agency prior to acceptance of the basin.

If the basin will be privately maintained, the local agencies will require execution of a maintenance agreement with the property owner prior to final acceptance of a private development project, including acceptance of the water quality basin. Check with the local permitting agency about the timing for execution of the agreement. The maintenance agreement will typically include requirements such as those in Table DB-5. The property owner or his/her designee will be responsible for compliance. See Appendix B for additional information about maintenance requirements and sample agreement language.

Table DB-5. Inspection and Maintenance Recommendations for Water Quality Detention Basins

Activity	Schedule
Inspect the facility for needed maintenance.	Twice a year.
Remove trash and debris.	At least twice a year.
Remove sediment, debris and litter that accumulates in the sediment forebay (To clean the sediment-collection area for a wet basin, it may be necessary to drain, pump or partially drawdown the pond area.)	Every 3 to 5 years or when 6 to 12 inches have accumulated, whichever comes first. Cleanout stakes or permanent markers are recommended to track accumulation.
Remove sediment that accumulates in the concrete low flow channel (if applicable).	Annually.
Control weeds and invasive plant species. Carefully weed areas to avoid removing the native species.	Regularly during the first 2 years and then as needed.
Use integrated pest management (IPM).Refer to Landscaping fact sheet elsewhere in this chapter.	As needed.
Irrigate plants. Refer to Efficient Irrigation fact sheet elsewhere in this chapter.	As needed during the establishment period (see Construction Considerations) and during periods of drought.
Replant any bare areas. Investigate why the die-off occurred and take remedial action to correct the problem.	In the event of extensive die-off.
Harvest vegetation around the perimeter of permanent ponds so that mosquito fish are not impeded by thick vegetation.	Each summer. More frequently if required by local vector control agencies.
Harvest vegetation in channels.	As needed.
Where permitted by the Department of Fish and Game or other agency regulations, stock wet ponds with mosquito fish (Gambusia spp.) to enhance natural mosquito and midge control.	As needed.
Control any erosion by redirecting or dissipating the water source. If necessary, recontour, mulch, and/or reseed.	When there are signs of erosion, including gullies, rills, and evidence of sheet erosion.
Reconstruct or replace the control measure when it is no longer functioning properly.	See projected lifespan in Appendix B for informational purposes.
Prune trees (if applicable).	Every 3-5 years.

Recommended Planting Guidelines

Propagation Methods

Plugs. Plugs are clumps of plant roots, rhizomes or tubers combined with associated soil. To propagate plants with plugs, follow these guidelines:

- Plant plugs during the fall dormant period, preferably between October 1 and November 15.
- Collect plugs from a suitable collection site in the vicinity of the constructed basins, using a qualified botanist or nursery staff. Plugs can be removed manually or salvaged with an excavator or backhoe. Collect plugs from healthy specimens free of insects, weeds and disease. Use either whole plants or plant divisions. The minimum recommended size is 1 foot x 1 foot.
- When possible, plant plugs immediately after collection. When necessary, plugs can be stored in a cool, moist, shaded location for a maximum of one day.
- Space plugs 1 foot to 6 feet apart, depending on the size of the plug. Smaller plugs can be planted at the minimum distance to promote faster spreading and cover. Plant larger plugs from cattail and bulrush species at 3 foot to 6 foot intervals.
- Prepare a hole slightly larger than the diameter of each plug and place the root system of the plug into the hole. Use a breaking bar or similar technique to create the planting hole. Manual planting with a spade is recommended for wet soils. Power augers can be used to create holes in dry soils. Alternatively, in lieu of individual holes, create a trench along the narrow axis of the pond; manually place plants at specified elevations in relation to the proximity of permanently saturated soils as shown on the planting plan.
- If the plug has an established root system, make sure the base of the stem and top of the root collar are level with the ground surface. Secure tubers to prevent floating. Place rhizomes in the soil with a slight upward angle.
- Backfill the hole or trench containing the plug(s) with soil and tamp it down to assure good soil contact and secure the plug.
- Cut back the vegetative portion of the plant to prevent water loss and wilting, and encourage the growth of roots and new shoots. Plugs of wetland plants should be grown in saturated soil.
- For wetland plants, the soil should not be allowed to dry out after planting.

Container Stock. When planting using container stock, follow these guidelines:

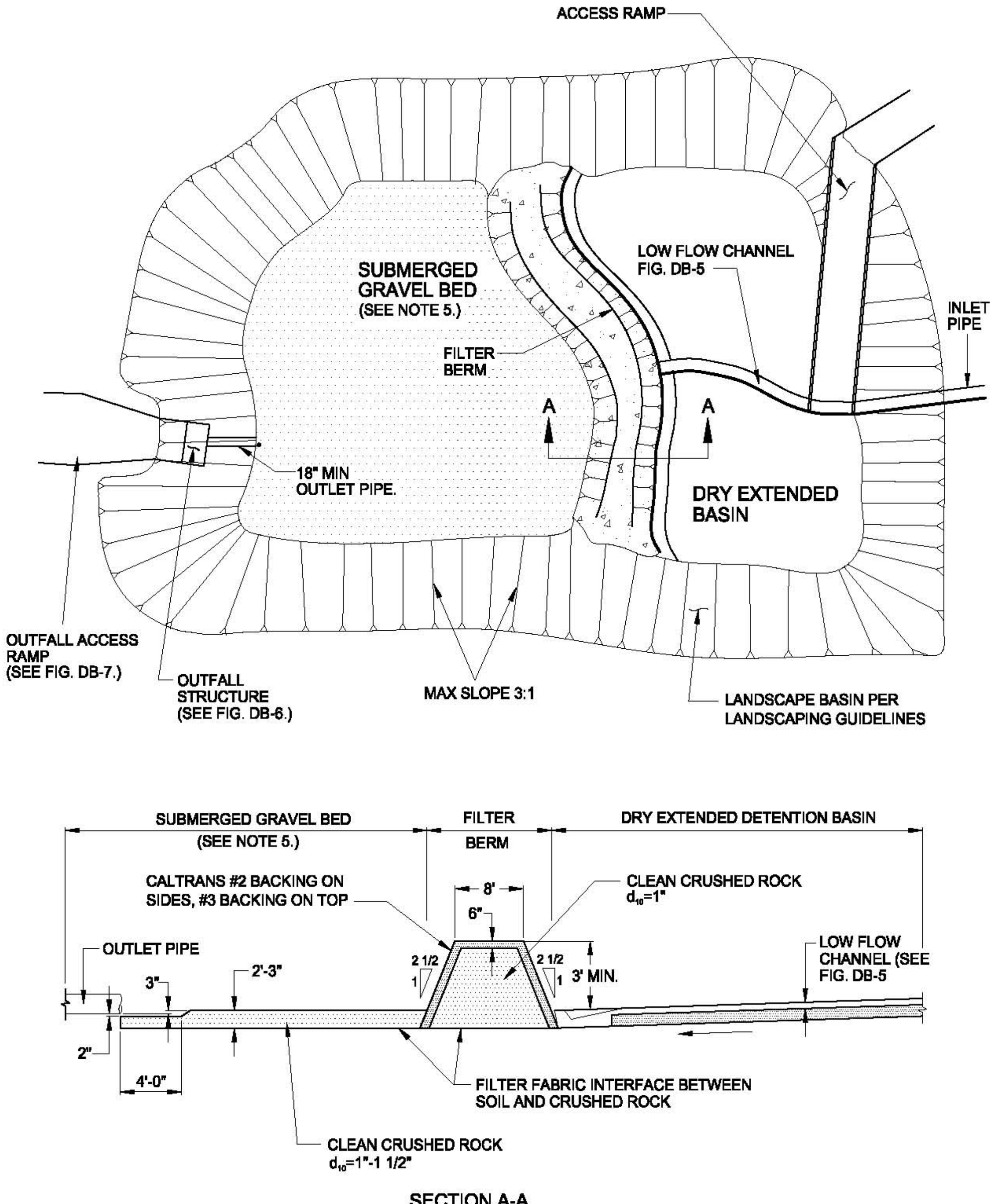
- Dig planting holes twice as wide and deep as the container size. It is recommended that container plantings receive a balanced time released fertilizer tablet that is placed at the bottom of the planting hole prior to installation of the plant.
- Space plants as shown on the planting plan.
- When planting, make sure the root collar and base of the stem are level with the adjacent soil surface. Berms for water retention and mulch can be used enhance plant establishment.
- Backfill the soil and tamp it down to assure contact with the roots. Promptly water to promote the settling of soil.

Pole Cuttings. Follow these guidelines when using pole cuttings:

- Collect pole cuttings from the young wood of dormant trees that are healthy and free of diseases.
- Size pole cuttings to have at least five viable nodes; to have a diameter at the base between 1/2 and 2 inches (1 inch is optimum); and to be between 2 and 4 feet long.
- Collect pole cuttings no more than 10 days prior to planting. Place them in cool water to promote swelling of the nodes, and keep the water fresh by aeration and/or by daily replacement.
- Following the production of the nodes (2-5 days), plant the pole cuttings in a rich organic medium mixed with native soil to encourage the production of a fibrous root system.
- Place pole cuttings in a hole approximately 3 feet deep (as determined by the length of the cutting--generally 75 percent of the length of the cutting should be planted beneath the soil surface). Backfill with native soil, or a rich organic medium mixed with native soil. Tamp down the soil to remove air pockets and assure soil contact with the cutting.

Seeds. Follow these guidelines when seeding:

- Plant seeds in the fall, preferably during the early portion of the dormant season. Time seeding to occur after plugs, container stock and pole cuttings are installed.
- Scarify the soil surface with a rake prior to seeding, taking care not to damage previously planted vegetation.
- Plant seeds at the ratios and rates specified by the supplier. The certified germination percentage should be provided by the supplier. Use seeds free of weeds and diseases.
- Broadcast seeds over the scarified planting area, using a hand-held spreader. Seed can be mixed with a slow-released fertilizer (16-20-0).
- Rake the surface to cover the seeds with about one eighth to one quarter inch of soil.



NOTES:

1.- ALL GRAVEL-SOIL INTERFACES MUST BE LINED WITH MIRAFI 400 GEOFILTER OR APPROVED EQUAL.
2.- TOP 3" OF SUBMERGED GRAVEL BED SHALL BE ABOVE THE OUTLET FLOW LINE.
3.- WITHIN A 4' RADIUS OF THE OUTFALL PIPE, GRAVEL SHALL BE HELD TO 2" BELOW OUTFALL FLOW LINE.
4.- CLEAN CRUSHED ROCK TO BE PLACE NO SOONER THAN 2 WEEKS PRIOR TO ACCEPTANCE BY LOCAL AGENCY.
5.- DRY BASINS SHALL INCLUDE AN ADDITIONAL FEATURE TO TREAT DRY WEATHER FLOWS SUCH AS A SUBMERGED GRAVEL BED. CHECK WITH YOUR LOCAL PERMITTING AGENCY FOR ALLOWED DRY WEATHER TREATMENT FEATURES.

DATE: MAY 2007

Figure DB-4. Dry Extended Stormwater Quality Detention Basin

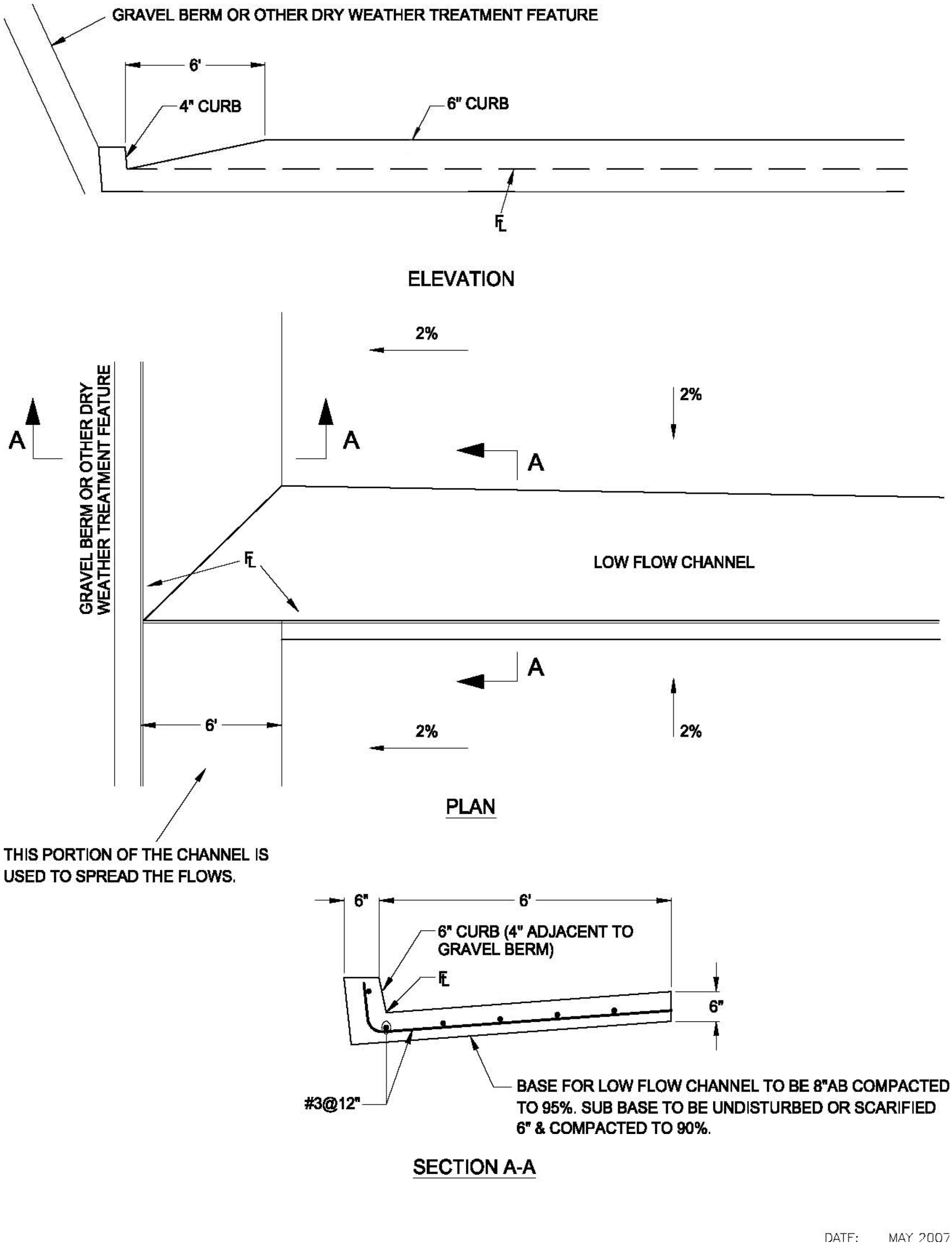


Figure DB-5. Low Flow Channel

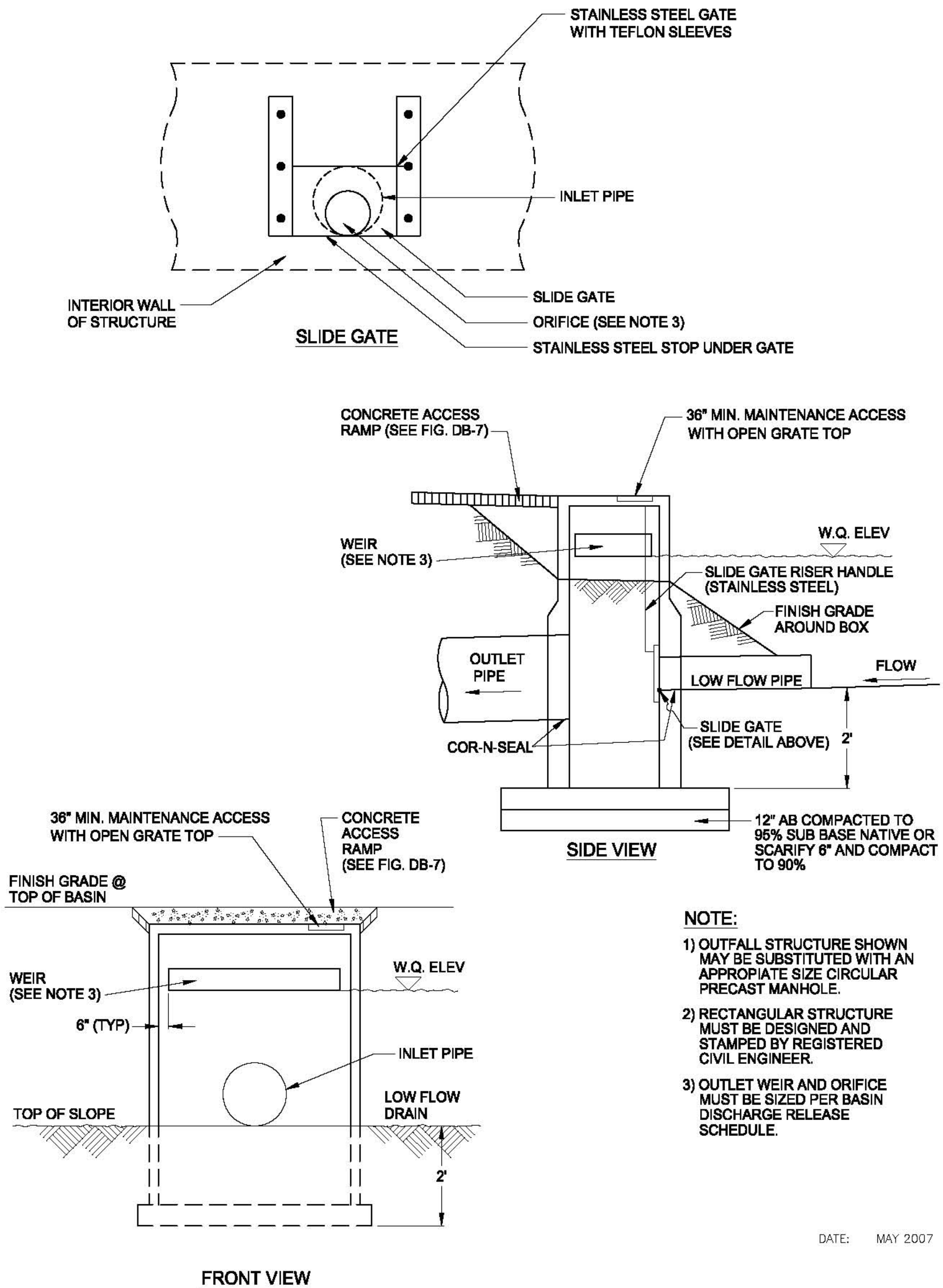


Figure DB-6. Outfall Structure

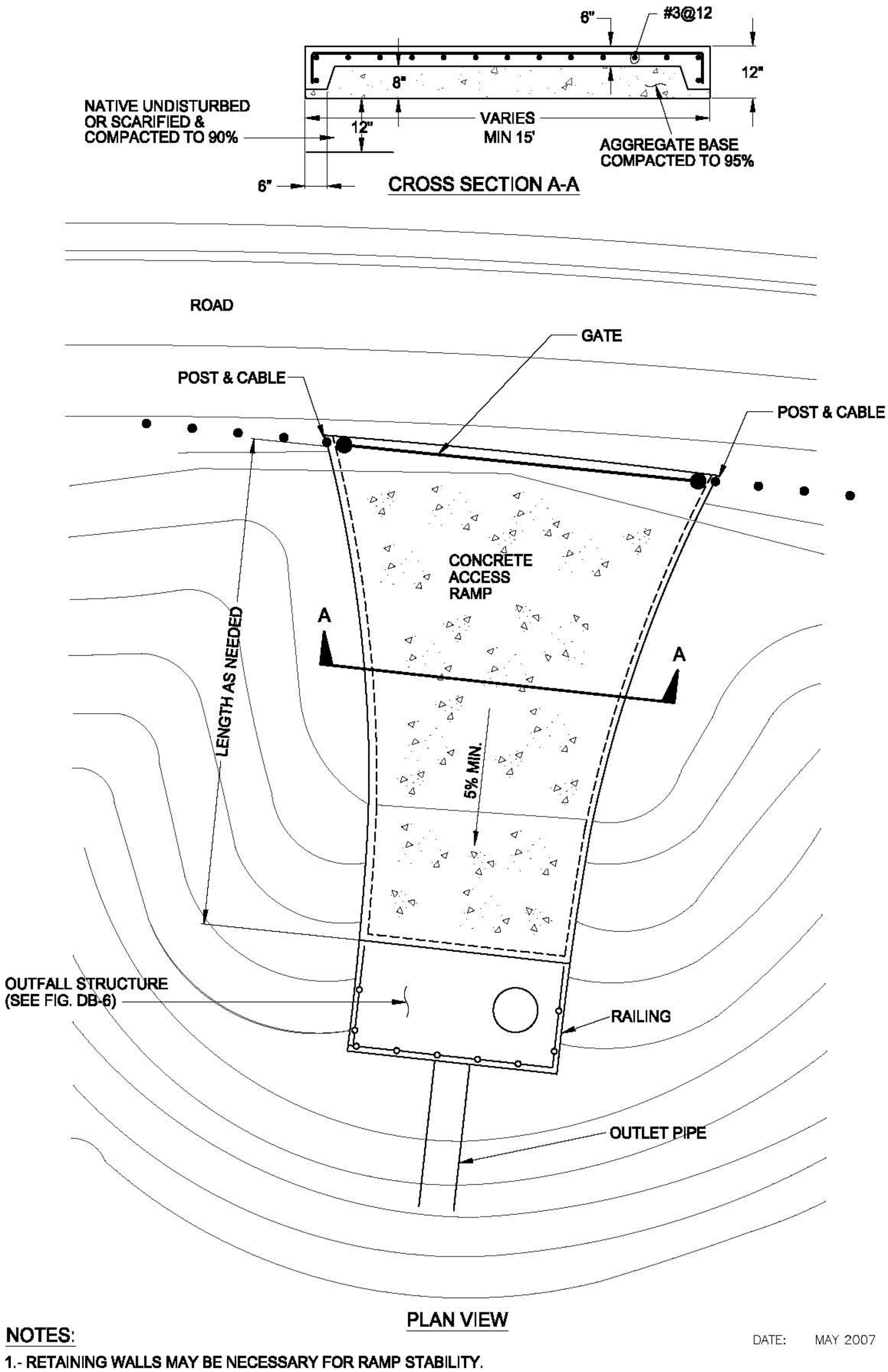


Figure DB-7. Outfall Structure Access Ramp

Table DB-6. Design Data Summary Sheet for Water Quality Detention Basin

Designer:		**Date:**	
Company:			
Project:			
Location:			

1a. Design Water Quality Volume			
a. Tributary drainage area	Area =		ft^2
b. Water Quality Volume	WQV =		ft^3
1b. Adjust Volume Up for Hydromodification Management (If Applicable) Based upon SAHM Modeling			
a. Water Quality Volume based on SAHM modeling	V =		ft^3
b. SAHM Model Demonstrates Compliance with Flow Duration Standards	(Yes or No)		
2. Basin Depths and Water Surface Areas	**ACTUAL DESIGN**		
a. For Wet and Combination Basins			
Permanent pool volume (Vol_{pp})	Vol_{pp} =		acre-ft
Average depth of permanent pool (D_{avg}) (4-8 ft)	D_{avg} =		ft
Water surface area of permanent pool (A_{pp})	A_{pp} =		ft^2
Water surface elevation of permanent pool (WS $Elev_{pp}$)	WS $Elev_{pp}$ =		ft
b. Forebay			
Depth range = 2-4 ft	Depth =		ft
Volume range = 5-10% of WQV	Volume =		acre-ft
Water surface area range	WS Area =		ft^2
3. Depth of WQV and Max WS Elevation			
a. Maximum water surface area with WQV (A_{WQV})	A_{WQV} =		ft^2
b. Maximum water surface elevation with WQV (WS $Elev_{WQV}$)	WS $Elev_{WQV}$ =		ft
4. For Wet and Combo Basins: Determine maximum dry season inflow to maintain permanent pond in the dry season. Use Table DB-2 and an evaporation rate of 0.45 in/day for the Sacramento area.	Q_{E-P} =		acre-ft/mo
$Q_{inflow} = - Q_{E-P} + Q_{seepage}$	$Q_{seepage}$ =		acre-ft/mo
	Q_{inflow} =		acre-ft/mo
5. Outlet			
a. Outlet Type:			
b. Drawdown Time	Time =		Hours

Design Data Summary Sheet for Water Quality Detention Basin (Page 2 of 2)

Project: ______________________________

6. Basin Shape

Length-Width Ratio (2:1 minimum)	Ratio =	______	L:W

7. Embankment Side Slope

a. Interior Side Slope (4:1 or flatter)	Slope =	______	H:V
b. Exterior Side Slope (3:1 or flatter)	Slope =	______	H:V

8. Maintenance Access Ramp

a. Slope (10% maximum)	Slope =	______	%
b. Width (15 to 20 feet)	Width =	______	ft

9. Vegetation (describe)

Native Grasses ______________________________

Irrigated Turf ______________________________

Trees ______________________________

Emergent Aquatic Plants (specify type/density) ______________________________

____

Other ______________________________

Notes: ______________________________

____