APPENDIX F

Alternative Stormwater Treatment Control Measure Fact Sheets

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LID-1: Infiltration Basin

Description

An infiltration basin is a shallow earthen basin constructed in naturally permeable soil designed for retaining and infiltrating stormwater runoff into the underlying soils and the groundwater table. The bottoms of the basins are typically vegetated with dry-land grasses or irrigated turf grass. Infiltration basins can provide stormwater runoff treatment through a variety of natural mechanisms (i.e., filtration, adsorption, biological degradation) as water flows through the soil profile.

Because stormwater runoff is infiltrated into an infiltration basin, the potential for groundwater contamination or mobilization of existing soil or groundwater contamination must be carefully considered. Infiltration basins are typically not suitable for sites that use or store chemicals or hazardous materials, unless these materials are prevented from entering the basin, or un-remediated “brownfield sites” where there is known groundwater or soil contamination.

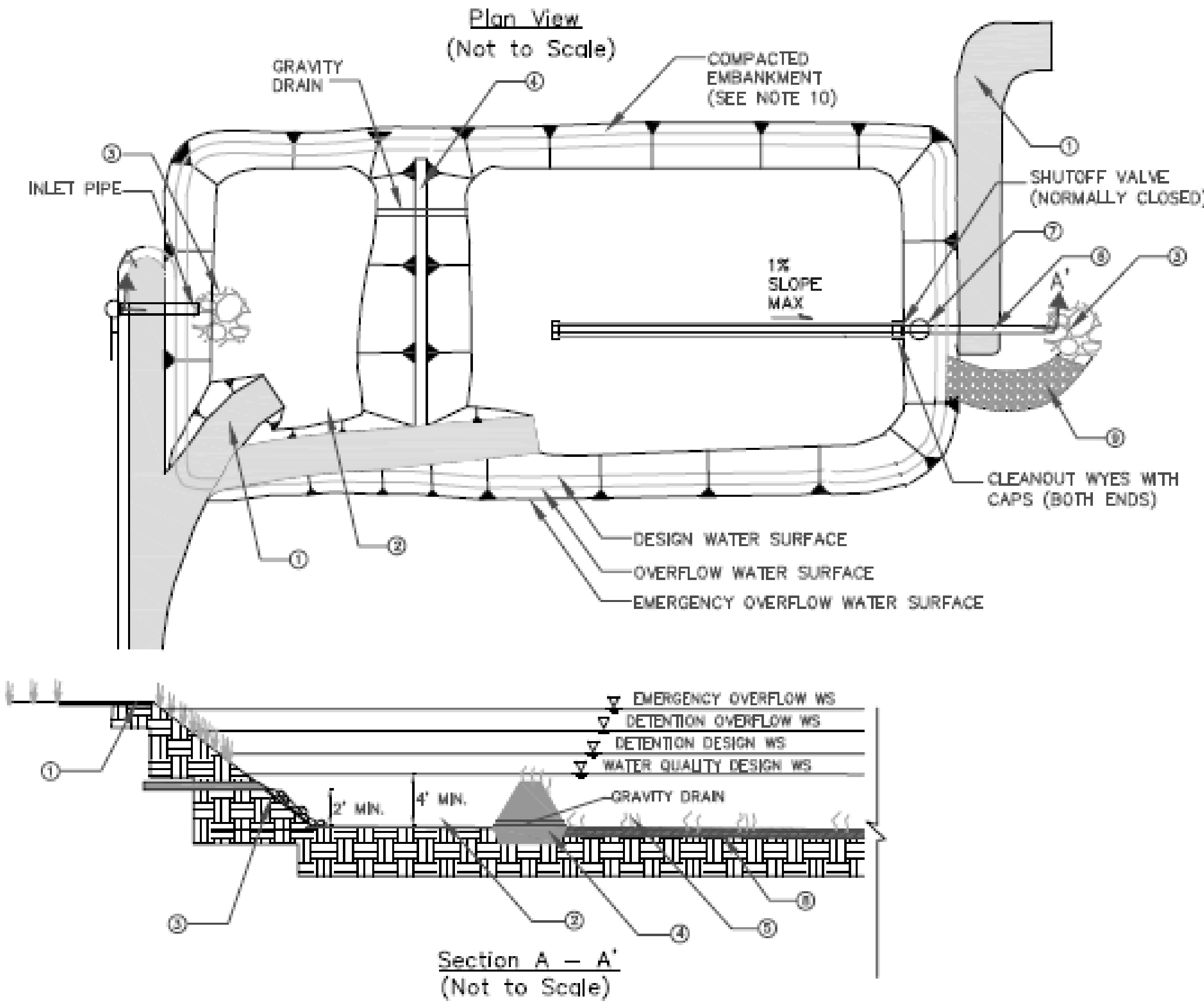
An example schematic of a typical infiltration basin is presented in **Figure F-1**.

Use and Applicability

The Phase II Permit (Provision E.12.e.(f)) identifies bioretention as the standard stormwater treatment control measure unless (1) it is determined to be infeasible and an alternative stormwater treatment control measure that is equivalent to bioretention is proposed and demonstrated (Provision E.12.e.(g)), or (2) a specific exemption applies (Provision E.12.e.(i)). An infiltration basin can be proposed as an alternative to bioretention if it meets all of the following measures of equivalent effectiveness:

- Equal or greater amount of stormwater runoff infiltrated or evapotranspired;
- Equal or lower pollutant concentrations in stormwater runoff that is discharged after biotreatment;
- Equal or greater protection against shock loadings and spills; and
- Equal or greater accessibility and ease of inspection and maintenance.

An infiltration basin, which is designed to infiltrate stormwater runoff, is an acceptable alternative to bioretention.



NOTES:

1. MAINTENANCE RAMP SHOULD BE PAVED. SLOPE SHOULD NOT EXCEED 12%. MAINTENANCE RAMP SHOULD PROVIDE ACCESS TO BOTH THE FIRST CELL AND MAIN BASIN.
2. UPSTREAM PRETREATMENT SHALL BE PROVIDED. SEDIMENT FOREBAY WITH VOLUME EQUAL TO 25% OF TOTAL INFILTRATION BASIN VOLUME MAY BE USED IN LIEU OF UPSTREAM PRETREATMENT. DEPTH SHALL BE 4' MIN TO 8' MAX PLUS AN ADDITIONAL 1 FOOT MIN SEDIMENT STORAGE DEPTH.
3. RIP RAP APRON OR OTHER ENERGY DISSIPATION.
4. EXTEND EARTHEN BERM ACROSS ENTIRE WIDTH OF THE INFILTRATION BASIN.
5. INFILTRATION BASIN BOTTOM AND SIDE SLOPES SHALL BE PLANTED WITH DROUGHT TOLERANT VEGETATION. DEEP ROOTED VEGETATION PREFERRED FOR BASIN BOTTOM. NO TOPSOIL SHALL BE ADDED TO INFILTRATION BASIN BED.
6. SIZE OUTLET PIPE FOR FLOOD CONTROL FLOW
7. WATER QUALITY OUTLET STRUCTURE.
8. OVER EXCAVATE BASIN BOTTOM 1 FOOT. RE–PLACE EXCAVATED MATERIAL UNIFORMLY WITHOUT COMPACTION. AMENDING EXCAVATED MATERIAL WITH 2" – 4" OF COARSE SAND IS RECOMMENDED FOR SOILS WITH BORDER LINE INFILTRATION CAPACITY.
9. INSTALL EMERGENCY OVERFLOW SPILLWAY AS NEEDED. SEE FIGURE 2–4 FOR DETAILS
10. EMBANKMENT SIDE SLOPES SHALL BE NO STEEPER THAN 3H:1V BOTH OUTSIDE AND INSIDE.

Figure F-1. Example Infiltration Basin Schematic

Design Specifications

The following sections provide design specifications for infiltration basins.

Geotechnical

Due to the potential to contaminate groundwater and/or soils, cause slope instability, impact surrounding structures, and potential for insufficient infiltration capacity, a geotechnical investigation must be conducted during the site assessment process to verify the site suitability for infiltration. It is critical to understand how stormwater runoff will move through the soil (horizontally and vertically) and if there are any geological conditions that may inhibit the movement of water. Soil infiltration rates and the depth to the groundwater table must be evaluated to ensure that conditions are satisfactory for proper operation of an infiltration basin. Infiltration basins cannot be located on sites with a slope greater than 10 percent in order to promote infiltration and uniform ponding. A Site Conditions Report summarizing the relevant findings from the geotechnical investigation must be submitted with the Project Stormwater Plan.

Setbacks

Applicable setbacks must be implemented when siting an infiltration basin.

Pretreatment

Pretreatment, which refers to design features that provide settling of large particles before stormwater runoff enters a stormwater treatment control measure, is important to ensure proper operation of an infiltration basin and reduce the long-term maintenance burden. Pretreatment (e.g., vegetated swales, proprietary devices) must be provided to reduce the sediment load entering an infiltration basin in order to prevent the underlying soils from being occluded prematurely and maintain the infiltration rate of the infiltration basin. Additionally for sites with high infiltration rates, pretreatment is required to protect groundwater quality.

An alternative design for an infiltration basin can include a sediment forebay to remove sediment from stormwater runoff. The sediment forebay must be separated from the infiltration basin by a berm or similar feature, and must be equal to 25 percent of the total infiltration basin volume. The sediment forebay must be designed with a minimum length-to-width ratio of 2:1 and must completely drain to the main infiltration basin through an eight-inch (minimum) low-flow outlet. All inlets must enter the sediment forebay. If there are multiple inlets into the sediment forebay, the length-to-width ratio is based on the average flow path length for all inlets.

Flow Entrance and Energy Dissipation

The drainage management area(s) (DMA[s]) tributary to the infiltration basin must be graded to minimize erosion as stormwater runoff enters the basin or by providing energy dissipation devices at the inlet. Piped entrances must include rock, splash blocks, or other erosion controls at the entrance to dissipate energy and disperse flows. If a sediment forebay is included in the design, the energy dissipation devices must be installed at the inlet to the sediment forebay. Flow velocity into the sediment forebay must be 4 ft/s or less.

Drainage

Infiltration basins provide stormwater runoff storage above ground and must completely drain within 48 hours. The underlying soils must be allowed to dry out periodically in order to restore hydraulic capacity to receive stormwater runoff from subsequent storm events, maintain infiltration rates, maintain adequate soil oxygen levels for healthy soil biota and vegetation, and provide proper soil conditions for biodegradation and retention of pollutants. The use of vertical piping, either for distribution or infiltration enhancement, is prohibited. This application may be classified as a Class V Injection Well per 40 CFR Part 146.5(e)(4).

Sizing

Step 1: Determine the SDV_{adj}

Infiltration basins are designed to capture and retain the SDV_{adj}, which is the difference between the SDV (Section 5.2) and the volume of stormwater runoff managed through site design measures (Section 5.5), for the tributary DMA(s).

Step 2: Determine the design infiltration rate

Determine the in-situ infiltration rate of the underlying soil using the Double-Ring Infiltrometer standard (ASTM D3385). Apply a safety factor to the in-situ infiltration rate to determine the design infiltration rate (f_{design}). A typical safety factor of 4 can be used (i.e., multiply in-situ infiltration rate by 0.25). The design infiltration rate must be between 0.5 and 5.0 in/hr. Soil amendments may be used to improve the flow of stormwater runoff into the underlying soil if the design infiltration rate is less than 0.5 in/hr. The infiltration rate will decline between maintenance cycles as the surface of the infiltration basin becomes occluded and particulates accumulate in the infiltrative layer.

Step 3: Calculate the surface area of the infiltration basin

Determine the required size of the infiltration surface by assuming the SDV_{adj} will fill the available ponding depth. The maximum depth of stormwater runoff that can be infiltrated within the maximum drawdown time (48 hrs) is calculated using the following equation:

$$d_{max} = \frac{f_{design}}{12} \times t$$

Where:

d_{max} = Maximum depth of water that can be infiltrated within the required drawdown time [ft];
f_{design} = Design infiltration rate [in/hr]; and
t = Maximum drawdown time (max 48 hrs) [hr].

Select the ponding depth (d_p) such that:

$$d_{max} \geq d_p$$

Where:

d_{max} = Maximum depth of water that can be infiltrated within the maximum drawdown time [ft]; and
d_p = Ponding depth [ft].

Calculate the infiltrating surface area (bottom of the infiltration basin) required:

$$A = \frac{SDV_{adj}}{\frac{f_{design}}{12} \times T + d_p}$$

Where:

A = Surface area of the bottom of the infiltration basin [ft^2];
SDV_{adj} = Adjusted stormwater design volume [ft^3];
f_{design} = Design infiltration rate [in/hr];
T = Time to fill infiltration basin (use 2 hrs) [hr]; and
d_p = Ponding depth [ft].

The bottom of infiltration basin must be the underlying soil that is over-excavated at least one foot in depth with the soil replaced uniformly without compaction. Amending excavated soil with 2 to 4 inches of coarse sand (~15 to 30 percent porosity) is recommended.

Overflow Device

An overflow device is required at the ponding depth near the inlet of the infiltration basin to divert stormwater runoff in excess of the design capacity of the infiltration basin. The following, or equivalent, must be provided:

- A vertical PVC pipe (SDR 26) to act as an overflow riser.
- The overflow riser(s) should be at least eight inches in diameter so it can be cleaned without damage to the pipe.
- The inlet to the overflow riser must be at the ponding depth and capped with a spider cap to exclude floating debris. Spider caps must be screwed on and include a locking mechanism. The overflow device must convey stormwater

runoff in excess of the design capacity of the infiltration basin to an approved discharge location (e.g., another stormwater treatment control measure, storm drain system, receiving water).

Embankments

Embankments are earthen slopes or berms used to detain or redirect the flow of water. For infiltration basins, the embankments must be design with the following specifications:

- All earthworks must be conducted in accordance with the Agency's Standard Specifications.
- The side slopes must be no steeper than 3:1 (H:V).
- The minimum top width of all berm embankments must be 20 feet, unless otherwise approved by the Agency.
- Berm embankments must be constructed on the consolidated underlying soil or adequately compacted and stable fill soils approved by a licensed geotechnical engineer. The soils must be free of loose surface soil materials, roots, and other organic debris.
- Berm embankments must be constructed of compacted soil (95 percent minimum dry density, Modified Proctor method per ASTM D1557) and placed in 6-inch lifts.
- Berm embankments greater than 4 feet in height must be constructed by excavating a key equal to 50 percent of the berm embankment cross-sectional height and width. This requirement may be waived if specifically recommended by a licensed geotechnical engineer.
- Low growing, climate-appropriate grasses must be planted on downstream embankment slopes.

Vegetation and Landscaping

- A thick mat of climate-appropriate grass must be established on the infiltration basin floor and embankment side slopes following construction. Grasses help prevent erosion and increase evapotranspiration, and their rhizomes discourage compaction within the root zone to help maintain infiltration rates. Additionally, active growing vegetation helps break up surface crusts that accumulate from sedimentation of fine particulates. Note that grass may need to be irrigated during the establishment period.
- Landscaping outside of the infiltration basin, but within the easement/right-of-way, may be included as long as it does not hinder maintenance access and operations.
- Trees or shrubs must not be planted within 10 feet of inlet or outlet pipes or manmade drainage structures such as spillways, flow spreaders, or earthen embankments. Species with roots that seek water (e.g., willow, poplar) may not

be planted within 50 feet of pipes or manmade structures. Weeping willow (*Salix babylonica*) may not be planted in or near infiltration basins.

- Plant species that are not climate-appropriate are not permitted. A sample list of suitable vegetation species is included in Appendix H. Prior to installation, a landscape architect must certify that all proposed vegetation is appropriate for the project site.

Maintenance Access

Maintenance access must be provided to the structures associated with the infiltration basin (e.g., pretreatment, inlet, overflow devices) if it is publicly-maintained. Manhole and catch basin lids must be in or at the edge of the access road. An access ramp to the infiltration basin bottom is required to facilitate the entry of sediment removal and vegetation maintenance equipment without compacting the bottom and side slopes of the infiltration basin.

Unless otherwise required by the Agency, access roads must meet the following design specifications:

- All access ramps and roads must be paved with a minimum of six inches of concrete over three inches of crushed aggregate base material. This requirement may be modified depending on the soil conditions and intended use of the road at the discretion of the Agency.
- The maximum grade is 12 percent unless otherwise approved by the Agency.
- Centerline turning radius must be a minimum of 40 feet.
- Access roads less than 500 feet long must have a 12-foot wide pavement within a minimum 15-foot wide bench. Access roads greater than 500 feet long must have a 16-foot wide pavement within a minimum 20-foot wide bench.
- All access roads must terminate with turnaround areas of 40-feet by 40-feet. A hammer type turnaround area or a circle drive around the top of the infiltration basin is also acceptable.
- Adequate double-drive gates and commercial driveways are required at street crossings. Gates must be located a minimum of 25 feet from the street curb except in residential areas where the gates may be located along the property line provided there is adequate sight distance to see oncoming vehicles at the posted speed limit.

Restricted Construction Materials

Use of pressure-treated wood or galvanized metal at or around an infiltration basin is prohibited.

Construction Considerations

As part of the site planning process, the areas designated for an infiltration basin must be identified. Compaction of underlying soils near and at the infiltration basin at the project site must be avoided. Establish protective perimeters to prevent inadvertent compaction by construction activities. The equipment used to construct an infiltration basin should have extra-wide, low-pressure tires and must not enter the infiltration basin.

The area identified for an infiltration basin must be protected from construction-related sediment loads. During construction activities if possible, divert all flows around the areas intended for the infiltration basin. Sediment control measures should also be implemented to prevent sediment from impacting the areas identified for an infiltration basin. If the underlying soils are compacted or the area identified for an infiltration basin is occluded, ripping or loosening the top two inches of the underlying soils prior to construction of the infiltration basin may be needed to improve infiltration. Final grading must produce a level basin bottom without low spots or depressions. After construction is completed, the entire tributary area to the infiltration basin must be stabilized before allowing stormwater runoff to enter it.

Maintenance Requirements

Maintenance and regular inspections must be conducted to ensure proper function of an infiltration basin. The following activities must be conducted to maintain infiltration basin:

- Conduct regular inspection and routine maintenance of pretreatment device(s).
- If a sediment forebay is included, remove sediment buildup exceeding 50 percent of the sediment storage capacity, as indicated by the steel markers. Remove sediment from the rest of the infiltration basin when it accumulates six inches. Test removed sediments for toxic substance accumulation in compliance with current disposal requirements if visual or olfactory indications of pollution are noticed. If toxic substances are detected at concentrations exceeding thresholds of Title 22, Section 66261 of the California Code of Regulations, dispose of the sediment in a hazardous waste landfill and investigate and mitigate the source of the contaminated sediments to the maximum extent possible.
- Remove and dispose of trash and debris, as needed, but at least prior to the beginning of the wet season.
- Inspect infiltration basin frequently to ensure that water infiltrates into the subsurface completely within the maximum drawdown time. If water is present in the infiltration basin more than 48 hours after a storm, the infiltration basin may be clogged. Maintenance activities triggered by a clogged basin include:
    - Check for debris/sediment accumulation, rake surface and remove sediment (if any), and evaluate potential sources of sediment and

vegetative or other debris. If suspected upstream sources are outside of the Agency's jurisdiction, additional pretreatment may be necessary.
  - Determine if it is necessary to remove the top layer of the underlying soils to restore infiltrative capacity.
- Eliminate standing water to prevent vector breeding.
- Maintain vegetation as needed to sustain the aesthetic appearance of the site, and as follows:
  - Prune and/or remove vegetation, large shrubs, or trees that limit access or interfere with operation of the infiltration basin.
  - Mow grass to four to nine inches high and remove grass clippings.
  - Rake and remove fallen leaves and debris from deciduous plant foliage.
  - Remove invasive, poisonous, nuisance, or noxious vegetation and replace with climate-appropriate vegetation.
  - Remove dead vegetation if it exceeds 10 percent of area coverage. Replace vegetation immediately to maintain cover density and control erosion where soils are exposed.
  - Do not use herbicides or other chemicals to control vegetation
  - Re-establish vegetation, which may require replanting and/or reseeding, following sediment removal activities.
- Inspect inlet structure for erosion and re-grade if necessary.
- Inspect overflow devices for obstructions or debris, which should be removed immediately. Repair or replace damaged pipes upon discovery.

The Agencies require execution of a Maintenance Access Agreement to be recorded by the property owner for the on-going operation and maintenance of all privately-maintained stormwater treatment control measures. The property owner is responsible for compliance with the Maintenance Access Agreement. An example Maintenance Access Agreement is presented in Appendix G.

LID-2: Infiltration Trench

Description

An infiltration trench is a narrow trench constructed in naturally pervious soils designed for retaining and infiltrating stormwater runoff into the underlying soils and groundwater table. Infiltration trenches, which are typically filled with gravel and sand, provide stormwater runoff treatment through various natural mechanisms (i.e., filtration, adsorption, biological degradation) as water flows through the soil profile.

An infiltration trench differs from an infiltration basin in that the former is used for small drainage areas and stores stormwater runoff underground within the void spaces of rocks or stones while the latter is used for larger drainage areas and stormwater runoff is stored within a visible ponded surface.

Because stormwater runoff is infiltrated into an infiltration trench, the potential for groundwater contamination or mobilization of existing soil or groundwater contamination must be carefully considered. Infiltration trenches are typically not suitable for sites that use or store chemicals or hazardous materials, unless they are prevent from entering the trench, or un-remediated "brownfield sites" where it is known groundwater or soil contamination.

An example schematic of a typical infiltration trench is presented in **Figure F-2**.

Use and Applicability

The Phase II Permit (Provision E.12.e.(f)) identifies bioretention as the standard stormwater treatment control measure unless (1) it is determined to be infeasible and an alternative stormwater treatment control measure that is equivalent to bioretention is proposed and demonstrated (Provision E.12.e.(g)), or (2) a specific exemption applies (Provision E.12.e.(i)). An infiltration trench can be proposed as an alternative to bioretention if it meets all of the following measures of equivalent effectiveness:

- Equal or greater amount of stormwater runoff infiltrated or evapotranspired;
- Equal or lower pollutant concentrations in stormwater runoff that is discharged after biotreatment;
- Equal or greater protection against shock loadings and spills; and
- Equal or greater accessibility and ease of inspection and maintenance.

An infiltration trench, which is designed to infiltrate stormwater runoff, is an acceptable alternative to bioretention.

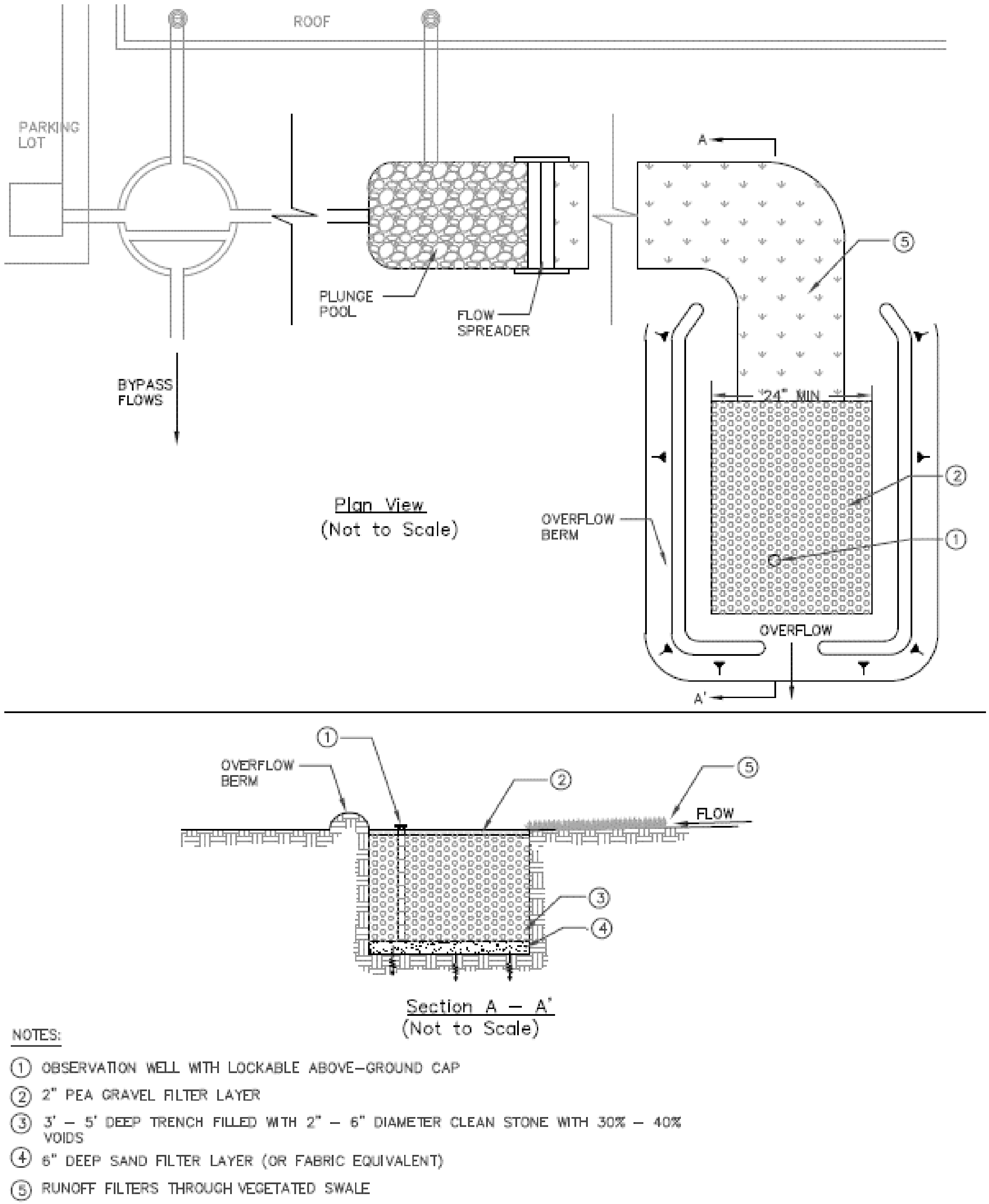


Figure F-2. Example Infiltration Trench Schematic

Design Specifications

The following sections provide design specifications for infiltration trenches.

Geotechnical

Due to the potential to contaminate groundwater and/or soils, cause slope instability, impact surrounding structures, and potential for insufficient infiltration capacity, a geotechnical investigation must be conducted during the site assessment process to verify the site suitability for infiltration. It is critical to understand how stormwater runoff will move through the soil (horizontally and vertically) and if there are any geological conditions that may inhibit the movement of water. Soil infiltration rates and the depth to the groundwater table must be evaluated to ensure that conditions are satisfactory for proper operation of an infiltration trench. Infiltration trenches cannot be located on sites with a slope greater than 15 percent. A Site Conditions Report summarizing relevant findings from the geotechnical investigation must be submitted with the Project Stormwater Plan.

Setbacks

Applicable setbacks must be implemented when siting an infiltration trench.

Pretreatment

Pretreatment, which refers to design features that provide settling of large particles before stormwater runoff enters a stormwater treatment control measure, is important to ensure proper operation of an infiltration trench and reduce the long-term maintenance burden. Pretreatment (e.g., vegetated swales, proprietary devices) must be provided to reduce the sediment load entering an infiltration trench in order to prevent the underlying soils from being occluded prematurely and maintain the infiltration rate of the infiltration trench. Additionally for sites with high infiltration rates, pretreatment is required to protect groundwater quality.

Flow Entrance and Energy Dissipation

The drainage management area(s) (DMA[s]) tributary to the infiltration trench must be graded to minimize erosion as stormwater runoff enters the trench by creating sheet flow conditions rather than a concentrated stream condition or by providing energy dissipation devices at the inlet. Typically, a minimum slope of 1 percent for pervious surfaces and 0.5 percent for impervious surfaces to the inlet of the infiltration trench should be maintained. The following types of flow entrances can be used for infiltration trenches:

- Level spreaders (e.g., slotted curbs) can be used to facilitate sheet flow.

- Dispersed low velocity flow across a landscape area. Dispersed flow may not be possible given space limitations or if the infiltration trench is controlling roadway or parking lot flows where curbs are mandatory.
- Dispersed flow across pavement or gravel and past wheel stops for parking areas.
- Flow spreading trench around perimeter of infiltration trench that may be filled with pea gravel or vegetated with 3:1 side slopes.
- Curb cuts for roadside or parking lot areas. Curb cuts must include rock or other erosion controls in the channel entrance to dissipate energy. The flow entrance should drop two to three inches from the curb line and provide an area for settling and periodic removal of sediment and coarse material before flow disperses to the remainder of the infiltration trench.
- Piped entrances that must include rock, splash blocks, or other erosion controls at the entrance to dissipate energy and disperse flows.

Drainage

Infiltration trenches provide stormwater runoff storage in the voids of the rock fill and must completely drain within 48 hours. The underlying soils must be allowed to dry out periodically in order to restore hydraulic capacity to receive stormwater runoff from subsequent storm events, maintain infiltration rates, and provide proper soil conditions for biodegradation and retention of pollutants. The use of vertical piping, either for distribution or infiltration enhancement, is prohibited. This application may be classified as a Class V Injection Well per 40 CFR Part 146.5(e)(4).

Sizing

Step 1: Determine the SDV_{adj}

Infiltration trenches are designed to capture and retain the SDV_{adj}, which is the difference between the SDV (Section 5.2) and the volume of stormwater runoff managed through site design measures (Section 5.5), for the tributary DMA(s).

Step 2: Determine the design infiltration rate

Determine the in-situ infiltration rate of the underlying soil using the Double-Ring Infiltrometer standard (ASTM D3385). Apply a safety factor to the in-situ infiltration rate to determine the design infiltration rate (f_{design}). A typical safety factor of 4 can be used (i.e., multiply in-situ infiltration rate by 0.25). The design infiltration rate must be between 0.5 and 5.0 in/hr. Soil amendments may be used to improve the flow of stormwater runoff into the underlying soil if the design infiltration rate is less than 0.5 in/hr. The infiltration rate will decline between maintenance cycles as the surface of the infiltration trench becomes occluded and particulates accumulate in the infiltrative layer.

Step 3: Calculate the surface area

Determine the size of the required infiltration surface by assuming the SDV_{adj} will fill the available void spaces in the media layers. The maximum depth of stormwater runoff that can be infiltrated within the maximum drawdown time (48 hrs) is calculated using the following equation:

$$d_{max} = \frac{f_{design}}{12} \times t$$

Where:

d_{max} = Maximum depth of water that can be infiltrated within the maximum drawdown time [ft];
f_{design} = Design infiltration rate [in/hr]; and
t = Maximum drawdown time (max 48 hrs) [hr].

The maximum depth of water that can be infiltrated within the maximum drawdown time is constrained by the following equation:

$$d_{max} \geq n_t \times d_t$$

Where:

d_{max} = Maximum depth of water that can be infiltrated within the maximum drawdown time [ft];
n_t = Infiltration trench media layer porosity; and
d_t = Depth of infiltration trench fill [ft].

Calculate the infiltrating surface area (bottom of the infiltration trench) required:

$$A = \frac{SDV_{adj}}{\frac{f_{design}}{12} \times T + n_t \times d_t}$$

Where:

A = Surface area of the bottom of the infiltration trench [ft^2];
SDV_{adj} = Adjusted stormwater design volume [ft^3];
f_{design} = Design infiltration rate [in/hr];
T = Time to fill the infiltration trench (use 2 hrs) [hr];
n_t = Infiltration trench fill porosity; and
d_t = Depth of infiltration trench fill [ft].

Infiltration trenches must be designed and constructed to be at least 24 inches wide and 3 to 5 feet deep with a longitudinal slope not to exceed 3 percent. The media layers must have the following composition and thickness:

- Top layer: 2 inches of pea gravel

- Middle layer: 3 to 5 feet of washed 2- to 6-inch gravel with void spaces of approximately 30 to 40 percent
- Bottom layer: 6 inches of sand or hydraulic restriction layer.

The bottom of infiltration trench, below the media layers, must be the underlying soils that is over-excavated at least one foot in depth with the soil replaced uniformly without compaction. Amending the excavated soil with 2 to 4 inches of coarse sand (~15 to 30 percent porosity) is recommended.

Hydraulic Restriction Layer

The entire infiltrative area, including the side slopes must be lined with a hydraulic restriction layer to prevent soil from migrating into the top layer and reducing the infiltration capacity. If a hydraulic restriction layer is used in lieu of six inches of sand, it should be installed at the bottom of the infiltration trench prior to placing the media layers. The hydraulic restriction layer should be installed generously with overlapping seams. The specifications of the hydraulic restriction layer are presented in **Table F-1**.

Table F-1. Hydraulic Restriction Layer Specifications for Infiltration Trenches

Parameter	Test Method	Specifications
Material		Nonwoven geomembrane liner
Unit weight		8 oz/yd^3 (minimum)
Filtration rate		0.08 in/sec (minimum)
Puncture strength	ASTM D-751 (Modified)	125 lbs (minimum)
Mullen burst strength	ASTM D-751	400 lb/in^2 (minimum)
Tensile strength	AST D-1682	300 lbs (minimum)
Equiv. opening size	US Standard Sieve	No. 80 (minimum)

Observation Well

An observation well must be installed to check water levels, drawdown time, and evidence of clogging. The observation well is a vertical section of perforated PVC pipe, four- to six-inch diameter, installed flush with the top of the infiltration trench on a footplate and with a locking, removable cap.

Overflow Device

An overflow device is required near the inlet of the infiltration trench to divert stormwater runoff in excess of the design capacity of the infiltration trench. For rooftop drainage, the distance between the downspouts and the overflow device should be maximized in order to increase the opportunity for stormwater runoff retention and infiltration. The following, or equivalent, must be provided:

- A vertical PVC pipe (SDR 26) to act as an overflow riser.

- The overflow riser(s) should be at least eight inches in diameter so it can be cleaned without damage to the pipe.
- The inlet to the overflow riser must be at the top of the infiltration trench with a spider cap to exclude floating debris. Spider caps must be screwed and include a locking mechanism. The overflow device must convey stormwater runoff in excess of the design capacity of the infiltration basin to an approved discharge location (e.g., another stormwater treatment control measure, storm drain system, receiving water).

Vegetation

Infiltration trenches must be kept free of vegetation. Trees and other large vegetation must be planted away from infiltration trenches such that drip lines do not overhang the infiltration area.

Maintenance Access

The infiltration trench must be safely accessible during wet and dry weather conditions if it is publicly-maintained. An access road along the entire length of the infiltration trench is required unless the trench is located along an existing road or parking lot that can be safely used for maintenance access. If the infiltration trench becomes plugged and fails, access is needed to excavate the infiltration trench and replace the media layers. When rehabilitating an infiltration trench, all dimensions of the infiltration trench must be increased by a minimum of two inches to provide a fresh surface for infiltration. To prevent damage and compaction, access must able to accommodate a backhoe working at “arm’s length” from the infiltration trench.

Restricted Construction Materials

Use of pressure-treated wood or galvanized metal at or around an infiltration trench is prohibited.

Construction Considerations

As part of the site planning process, the areas designated for an infiltration trench must be identified. Compaction of underlying soils near and at the infiltration trench at the project site must be avoided. Establish protective perimeters to prevent inadvertent compaction by construction activities. The equipment used to construct an infiltration trench should have extra-wide, low-pressure tires and must not enter the infiltration trench.

The area identified for an infiltration trench must be protected from construction-related sediment loads. During construction activities if possible, divert all flows around the areas intended for the infiltration trench. Sediment control measures should also be implemented to prevent sediment from impacting the areas identified for an infiltration trench. If the underlying soils are compacted or the area identified for an infiltration trench is occluded, ripping or loosening the top two inches of the underlying soils prior to construction of the infiltration trench may be needed to improve infiltration. Final grading must produce a level bottom without low spots or depressions. Clean, washed gravel should be placed in the excavated trench in lifts and lightly compacted with a plate compactor. Unwashed gravel can result in clogging. After construction is completed, the entire tributary area to the infiltration trench must be stabilized before allowing stormwater runoff to enter it.

Maintenance Requirements

Maintenance and regular inspections must be conducted to ensure proper function of an infiltration trench. The following activities must be conducted to maintain an infiltration trench:

- Conduct regular inspection and routine maintenance for pretreatment device(s).
- Inspect infiltration trench and its observation well frequently to ensure that water infiltrates into the subsurface completely within the maximum drawdown time. If water is present in the observation well more than 48 hours after a storm, the infiltration trench may be clogged. Maintenance activities triggered by a potentially clogged facility include:
  - Check for debris/sediment accumulation, rake surface and remove sediment (if any), and evaluate potential sources of sediment and vegetative or other debris. If suspected upstream sources are outside of the Agency's jurisdiction, additional pretreatment may be necessary.
  - Assess the condition of the top layer for sediment buildup and crusting. Remove the top layer of pea gravel and replace. If slow draining conditions persist, the entire infiltration trench may need to be excavated and replaced.
- Eliminate standing water to prevent vector breeding.
- Remove and dispose of trash and debris as needed, but at least prior to the beginning of the wet season.
- Inspect inlet structure for erosion and re-grade if necessary.
- Inspect overflow devices for obstructions or debris, which should be removed immediately. Repair or replace damaged pipes upon discovery.

The Agencies require execution of a Maintenance Access Agreement to be recorded by the property owner for the on-going operation and maintenance of all privately-maintained stormwater treatment control measures. The property owner is responsible for compliance with the Maintenance Access Agreement. An example Maintenance Access Agreement is presented in Appendix G.

LID-3: Dry Well

Description

A dry well is a bored, drilled, or driven shaft or hole whose depth is greater than its width. A dry well may either be a small excavated pit filled with aggregate or a prefabricated storage chamber or pipe segment. Dry well design and function are similar to infiltration trenches in that they are designed to temporarily store and subsequently infiltrate stormwater runoff. In particular, dry wells can be used to reduce the volume of stormwater runoff from building roofs. While generally not a significant source of pollution, roofs are one of the most important sources of new or increased stormwater runoff volume from land development sites. Dry wells can be used to indirectly enhance water quality by reducing the volume of stormwater runoff to be treated by other downstream stormwater treatment control measures.

Because stormwater runoff is infiltrated into by a dry well, the potential for groundwater contamination or mobilization of existing groundwater or soil contamination must be carefully considered. Dry wells are typically not suitable for sites that use or store chemicals or hazardous materials, unless they are prevent from entering the well, or un-remediated “brownfield sites” where it is known groundwater or soil contamination.

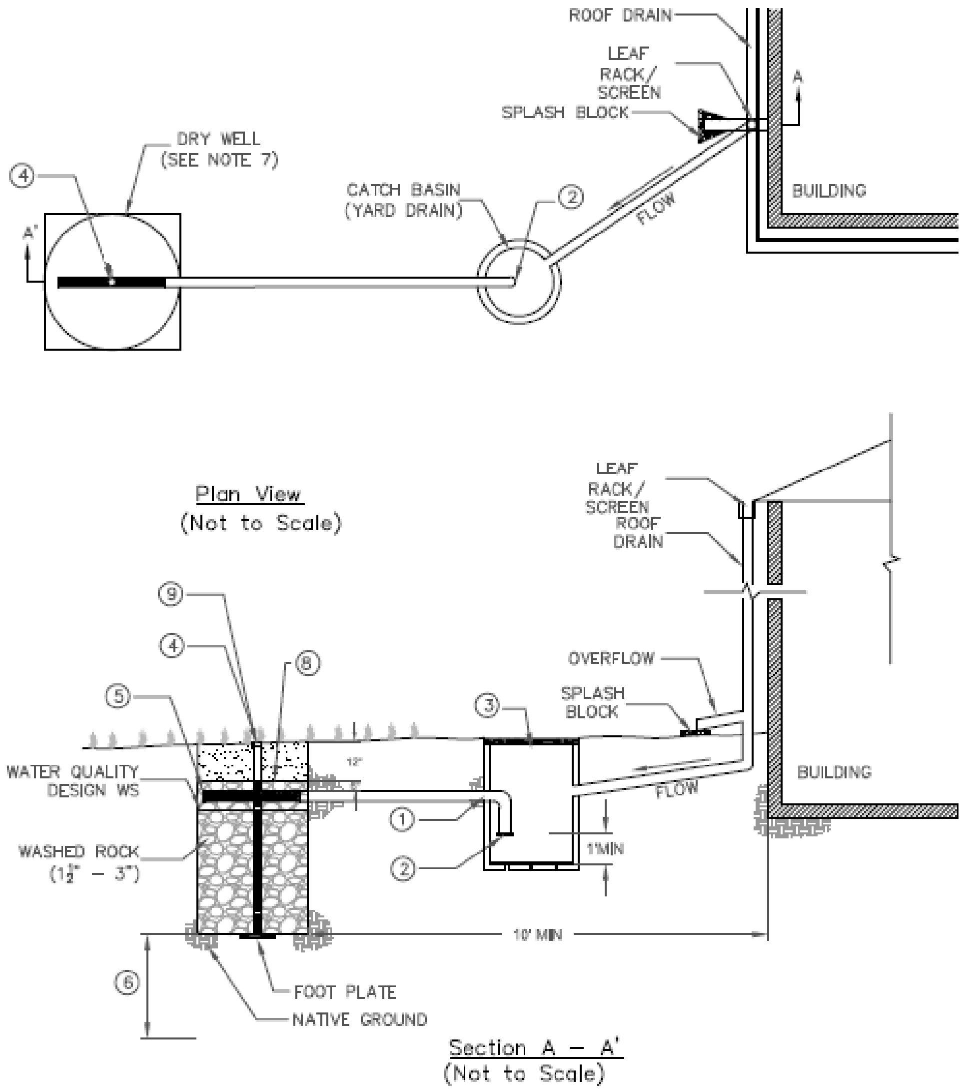
An example schematic of a typical dry well is presented in **Figure F-3**.

Use and Applicability

The Phase II Permit (Provision E.12.e.(f)) identifies bioretention as the standard stormwater treatment control measure unless (1) it is determined to be infeasible and an alternative stormwater treatment control measure that is equivalent to bioretention is proposed and demonstrated (Provision E.12.e.(g)), or (2) a specific exemption applies (Provision E.12.e.(i)). A dry well can be proposed as an alternative to bioretention if it meets <u>all</u> of the following measures of equivalent effectiveness:

- Equal or greater amount of stormwater runoff infiltrated or evapotranspired;
- Equal or lower pollutant concentrations in stormwater runoff that is discharged after biotreatment;
- Equal or greater protection against shock loadings and spills; and
- Equal or greater accessibility and ease of inspection and maintenance.

A dry well, which is designed to infiltrate stormwater runoff, is an acceptable alternative to bioretention.



NOTES:

① MINIMUM 4" – 6" DIAMETER PVC PIPE. INSTALL AT FLAT SLOPE.

② INSTALL FINE MESH SCREEN AT INLET TO DRY WELL. SET INLET ELEVATION AT 1' MINIMUM ABOVE CATCH BASIN BOTTOM.

③ CATCH BASIN (YARD DRAIN) INSTALLED WITH A SOLID LID FLUSH WITH GROUND SURFACE.

④ 4–6" VERTICAL PERFORATED PVC INSPECTION WELL WITH SCREW LID (NUT DOWN) FLUSH WITH GROUND SURFACE.

⑤ CAP END OF 4–6" HORZONTAL PERFORATED PVC DISPERSION PIPE.

⑥ MINIMUM 10' ABOVE SEASONAL HIGH GROUNDWATER TABLE AND 3' ABOVE BEDROCK.

⑦ DRY WELL CONFIGURATION MAY VARY (E.G. PRE–FAB MAY BE CIRCULAR).

⑧ CHOKING STONE LAYER SHALL BE PLACED ON TOP OF THE DRY WELL TO SEPARATE IT FROM THE TOPSOIL AND PREVENT CLOGGING.

Figure F-3. Dry Well Schematic

Design Specifications

The following sections provide design specifications for dry wells.

Geotechnical

Due to the potential to contaminate groundwater and/or soils, cause slope instability, impact surrounding structures, and potential for insufficient infiltration capacity, a geotechnical investigation must be conducted during the site assessment process to verify the site suitability for infiltration. It is critical to understand how stormwater runoff will move through the soil (horizontally and vertically) and if there are any geological conditions that may inhibit the movement of water. Soil infiltration rates and the depth to the groundwater table must be evaluated to ensure that conditions are satisfactory for proper operation of a dry well. Dry wells cannot be located on sites with a slope greater than 15 percent. A Site Conditions Report summarizing the relevant findings from the geotechnical investigation must be submitted with the Project Stormwater Plan.

Setbacks

Applicable setbacks must be implemented when siting a dry well.

Pretreatment

Pretreatment, which refers to design features that provide settling of large particles before stormwater runoff enters a stormwater treatment control measure, is important to ensure proper operation of a dry well and reduce the long-term maintenance burden. If dry wells are used to manage stormwater runoff from rooftops that drain directly to the dry well, pretreatment may not be necessary because stormwater runoff from rooftops are not expected to have large particles. For other applications of a dry well, pretreatment (e.g., vegetated swales, proprietary devices) is required to be provided to reduce the sediment load entering a dry well in order to prevent the underlying soils from being occluded prematurely and maintain the infiltration rate of the dry well. Additionally for sites with high infiltration rates, pretreatment is required to protect groundwater quality.

Flow Entrance and Energy Dissipation

The drainage management area(s) (DMA[s]) tributary to a dry well must be graded to minimize erosion as stormwater runoff enters the dry well by creating sheet flow conditions rather than a concentrated stream condition or by providing energy dissipation devices at the inlet. Typically, maintain a minimum slope of 1 percent for pervious surfaces and 0.5 percent for impervious surfaces to the inlet of the dry well. The following types of flow entrances can be used for dry wells:

- Level spreaders (e.g., slotted curbs) can be used to facilitate sheet flow.

- Dispersed low velocity flow across a landscape area. Dispersed flow may not be possible given space limitations or if the dry well is controlling roadway or parking lot flows where curbs are mandatory.
- Dispersed flow across pavement or gravel and past wheel stops for parking areas.
- Curb cuts for roadside or parking lot areas. Curb cuts must include rock or other erosion controls in the channel entrance to dissipate energy. The flow entrance should drop two to three inches from the curb line and provide an area for settling and periodic removal of sediment and coarse material before flow disperses to the remainder of the dry well.
- Flow spreading trench around perimeter of dry well that may be filled with pea gravel or vegetated with 3:1 side slopes.
- Piped entrances that must include rock, splash blocks, or other erosion controls at the entrance to dissipate energy and disperse flows.

If a dry well receives stormwater runoff from an underground pipe (i.e., stormwater runoff does not enter the top of the dry well from the ground surface), a fine mesh screen must be installed at the inlet. The inlet elevation should be 18 inches below the ground surface (i.e., below 12 inches of surface soil and 6 inches of dry well media).

Drainage

Dry wells provide stormwater runoff storage in the voids of the media layers and must completely drain within 48 hours. Soils must be allowed to dry out periodically in order to restore hydraulic capacity to receive stormwater runoff from subsequent storm events, maintain infiltration rates, and provide proper soil conditions for biodegradation and retention of pollutants. The use of vertical piping, either for distribution or infiltration enhancement, is prohibited. This application may be classified as a Class V Injection Well per 40 CFR Part 146.5(e)(4).

Sizing

Step 1: Determine the SDV_{adj}

Dry wells are designed to capture and retain the SDV_{adj}, which is the difference between the SDV (Section 5.2) and the volume of stormwater runoff managed through site design measures (Section 5.5), for the tributary DMA(s).

Step 2: Determine the design infiltration rate

Determine the in-situ infiltration rate of the underlying soil using the Double-Ring Infiltrometer standard (ASTM D3385). Apply a safety factor to the in-situ infiltration rate to determine the design infiltration rate (f_{design}). A typical safety factor of 4 can be used (i.e., multiply in-situ infiltration rate by 0.25). The design infiltration rate must be between 0.5 and 5.0 in/hr. Soil amendments may be used to improve the flow of stormwater runoff into the underlying soil if the design infiltration rate is less than 0.5 in/hr. The infiltration rate will decline between maintenance cycles as the surface of the dry well becomes occluded and particulates accumulate in the infiltrative layer.

Step 3: Calculate the surface area

Determine the required size of the infiltration surface by assuming the SDV_{adj} will fill the available void spaces of the media layers. The maximum depth of stormwater runoff that can be infiltrated within the maximum drawdown time of 48 hours is calculated using the following equation:

$$d_{max} = \frac{f_{design}}{12} \times t$$

Where:

d_{max} = Maximum depth of water that can be infiltrated within the required drawdown time [ft];
f_{design} = Design infiltration rate [in/hr]; and
t = Maximum drawdown time (max 48 hrs) [hr].

The maximum depth of water that can be infiltrated within the maximum drawdown time is constrained by the following equation:

$$d_{max} \geq n_t \times d_t$$

Where:

d_{max} = Maximum depth of water that can be infiltrated within the maximum drawdown time [ft];
n_t = Dry well media porosity; and
d_t = Depth of dry well media [ft].

Calculate the infiltrating surface area (bottom of the dry well) required:

$$A = \frac{SDV_{adj}}{\frac{f_{design}}{12} \times T + n_t \times d_t}$$

Where:

A = Surface area of the bottom of the dry well [ft^2];
SDV_{adj} = Adjusted stormwater design volume [ft^3];
f_{design} = Design infiltration rate [in/hr];
T = Time to fill stormwater treatment control measure (use 2 hrs) [hr];
n_t = Dry well media porosity; and
d_t = Depth of dry well media [ft].

Dry well configurations vary, but generally have length and width top dimensions close to a square. The media layers must have the following composition and thickness, unless they are prefabricated dry wells:

- Top layer: 2 inches of pea gravel
- Middle layer: 3 to 5 feet of washed 2- to 6-inch gravel; void spaces should be approximately 30 to 40 percent
- Bottom layer: 6 inches of sand or hydraulic restriction layer.

Prefabricated dry wells are often circular with porosities of 80 to 95 percent.

The bottom of dry well must be the underlying soils that is over-excavated at least one foot in depth with the soil replaced uniformly without compaction. Amending the excavated soil with two to four inches of coarse sand is (~15 to 30 percent porosity) recommended.

Hydraulic Restriction Layer

The entire infiltrative area, including the side slopes must be lined with a hydraulic restriction layer to prevent soil from migrating into the top layer and reducing the infiltration capacity. If a hydraulic restriction layer is used in lieu of six inches of sand, it must be installed at the bottom of the dry well prior to placing the media layers. The hydraulic restriction layer should be installed generously with overlapping seams. The specifications of the hydraulic restriction layer are presented in **Table F-2**.

Table F-2. Hydraulic Restriction Layer Specifications for Dry Wells

Parameter	Test Method	Specifications
Material		Nonwoven geomembrane liner
Unit weight		8 oz/yd^3 (minimum)
Filtration rate		0.08 in/sec (minimum)
Puncture strength	ASTM D-751 (Modified)	125 lbs (minimum)
Mullen burst strength	ASTM D-751	400 lb/in^2 (minimum)
Tensile strength	AST D-1682	300 lbs (minimum)
Equiv. opening size	US Standard Sieve	No. 80 (minimum)

Observation Well

An observation well must be installed to check water levels, drawdown time, and evidence of clogging. The observation well is a vertical section of perforated PVC pipe, four- to six-inch diameter, installed flush with the top of the dry well on a footplate and with a locking, removable cap.

Overflow Device

An overflow device is required near the inlet of the dry well to divert stormwater runoff in excess of the design capacity of the dry well. The following, or equivalent, must be provided:

- A vertical PVC pipe (SDR 26) to act as an overflow riser.
- The overflow riser(s) should be at least eight inches in diameter so it can be cleaned without damage to the pipe.
- The inlet to the overflow riser must be at the top of the dry well with a spider cap to exclude floating debris. Spider caps must be screwed on and include a locking mechanism. The overflow device must convey stormwater runoff in excess of the design capacity of the infiltration basin to an approved discharge location (e.g., another stormwater treatment control measure, storm drain system, receiving water).

Vegetation

Dry wells must be kept free of vegetation. Trees and other large vegetation should be planted away from dry wells such that drip lines do not overhang the dry well.

Maintenance Access

The dry well must be safely accessible during wet and dry weather conditions if it is publicly-maintained. If the dry well becomes plugged and fails, access is needed to excavate the dry well and replace the media layers. To prevent damage and compaction, access must able to accommodate a backhoe working at “arm’s length” from the dry well.

Restricted Construction Materials

Use of pressure-treated wood or galvanized metal at or around a dry well is prohibited.

Construction Considerations

As part of the site planning process, the areas designated for a dry well must be identified. Compaction of underlying soils near and at the dry well at the project site must be avoided. Establish protective perimeters to prevent inadvertent compaction by construction activities. The equipment used to construct a dry well should have extra-wide, low-pressure tires and must not enter the dry well.

The area identified for a dry well must be protected from construction-related sediment loads. During construction activities if possible, divert all flows around the areas intended for the dry well. Sediment control measures should also be implemented to prevent sediment from impacting the areas identified for a dry well. If the underlying soils are compacted or the area identified for a dry well is occluded, ripping or loosening the top two inches of the underlying soils prior to construction of the dry well may be needed to improve infiltration. Final grading must produce a level bottom without low spots or depressions. Clean, washed gravel should be placed in the excavated dry well in lifts and lightly compacted with a plate compactor. Unwashed gravel can result in clogging. After construction is completed, the entire tributary area to the dry well must be stabilized before allowing stormwater runoff to enter it.

Maintenance Requirements

Maintenance and regular inspections are required to ensure proper function of a dry well. The following activities must be conducted to maintain a dry well:

- Conduct regular inspection and routine maintenance for pretreatment device(s).
- Inspect dry well and its observation well frequently to ensure that water infiltrates into the subsurface completely within maximum drawdown time. If water is present in the observation well more than 48 hours after a storm, the dry well may be clogged. Maintenance activities triggered by a potentially clogged facility include:
    - Check for debris/sediment accumulation and remove sediment (if any) and evaluate potential sources of sediment and vegetative or other debris. If suspected upstream sources are outside of the Agency’s jurisdiction, additional pretreatment operations may be necessary.
    - Assess the condition of the top layer for sediment buildup and crusting. Remove the top layer of pea gravel and replace. If slow draining conditions persist, the entire dry well may need to be excavated and replaced.
- Eliminate standing water to prevent vector breeding.
- Remove and dispose of trash and debris as needed, but at least prior to the beginning of the wet season.
- Inspect inlet structure for erosion and re-grade if necessary.

The Agencies require execution of a Maintenance Access Agreement to be recorded by the property owner for the on-going operation and maintenance of all privately-maintained stormwater treatment control measures. The property owner is responsible for compliance with the Maintenance Access Agreement. An example Maintenance Access Agreement is presented in Appendix G.

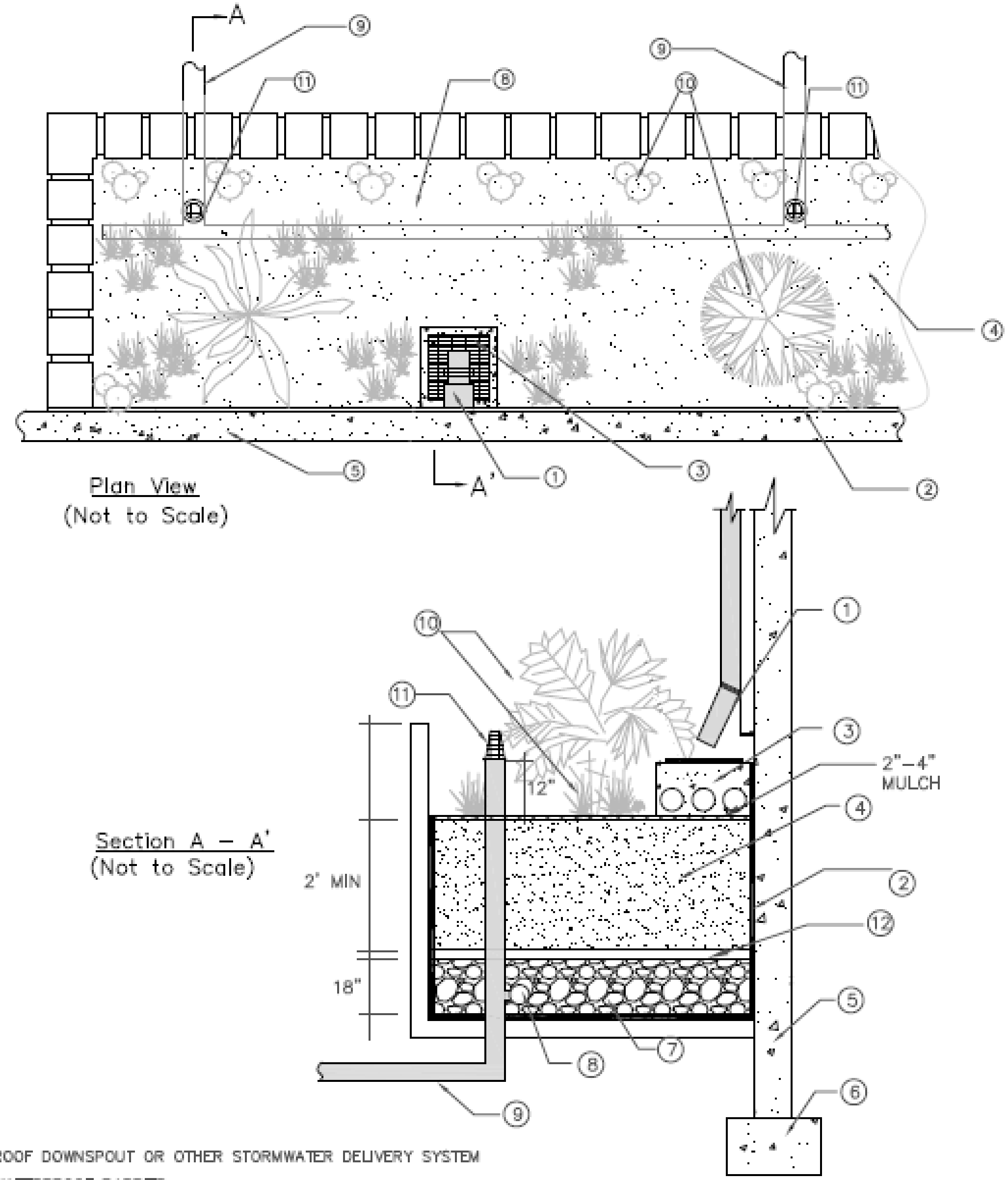
T-1: Stormwater Planter

Description

A stormwater planter, or a flow-through planter, is a stormwater treatment control measure that is completely contained within an impermeable structure with an underdrain. Stormwater planters are similar to bioretention facilities and function as a soil- and plant-based filtration device that remove pollutants though a variety of physical, biological, and chemical treatment processes. A stormwater planter consists of a ponding area, mulch layer, planting media, plants, and an underdrain within the planter box. As stormwater runoff passes through the planting media, pollutants are filtered, adsorbed, and biodegraded by the soil and plants. Stormwater planters contain climate-appropriate vegetation that does not require fertilizers and can withstand wet soils for at least 48 hours. Stormwater planters are only capable of treating stormwater runoff from smaller areas (up to 15,000 square feet of impervious surfaces).

Stormwater planters may be placed adjacent to or near buildings, other structures, or sidewalks. Stormwater planters used directly adjacent to buildings beneath downspouts, which will disconnect the downspout, must be properly lined on the building side, and the overflow outlet discharges away from the building to ensure water does not percolate into footings or foundations. They can also be placed further away from buildings by conveying roof runoff in shallow engineered open conveyances, shallow pipes, or other drainage structures.

An example schematic of a typical stormwater planter is presented in **Figure F-4**.



NOTES:

1. ROOF DOWNSPOUT OR OTHER STORMWATER DELIVERY SYSTEM
2. WATERPROOF BARRIER
3. SHALLOW ENERGY DISSIPATOR BASIN DISPERSES FLOW AT SOIL SURFACE
4. SOIL MIX (SEE PLANTING MEDIA SECTION)
5. BUILDING
6. FOUNDATION. INSTALL FOUNDATION DRAINS AS NEEDED
7. GRAVEL BEDDING (SEE UNDERDRAIN)
8. PERFORATED PIPE SHALL RUN ENTIRE LENGTH OF PLANTER
9. CONNECTION TO DOWNSTREAM CONVEYANCE SYSTEM
10. PLANTS
11. SET OVERFLOW 2" BELOW THE TOP OF THE PLANTER
12. OPTIONAL CHOKING GRAVEL LAYER

Figure F-4. Example Stormwater Planter Schematic

Use and Applicability

The Phase II Permit (Provision E.12.e.(f)) identifies bioretention as the standard stormwater treatment control measure unless (1) it is determined to be infeasible and an alternative treatment control measure that is equivalent to bioretention is proposed and justified (Provision E.12.e.(g)), or (2) a specific exemption applies (Provision E.12.e.(i)). Stormwater planters can be proposed as an alternative to bioretention if it meets all of the following measures of equivalent effectiveness:

- Equal or greater amount of stormwater runoff infiltrated or evapotranspired;
- Equal or lower pollutant concentrations in stormwater runoff that is discharged after biotreatment;
- Equal or greater protection against shock loadings and spills; and
- Equal or greater accessibility and ease of inspection and maintenance.

The Phase II Permit (Provision E.12.e.(h)) allows the use of stormwater planters in project areas with documented high concentrations of pollutants in the underlying soil or groundwater, where infiltration may contribute to a geotechnical hazard, and that are located on elevated plazas or adjacent to structures. Under these allowed variations for site-specific conditions, a hydraulic restriction layer may be incorporated or the underdrain may be located at the bottom of the gravel layer.

The Phase II Permit (Provision E.12.e.(i)) also allows the use of stormwater planters in project areas for the following types of Regulated Projects:

- Projects creating or replacing an acre or less of impervious area, and located in a designated pedestrian-oriented commercial district (i.e., smart growth projects), and having at least 85 percent of the entire project site covered by permanent structures;
- Facilities receiving runoff solely from existing (pre-project) impervious areas; and
- Historic sites, structures, or landscapes that cannot alter their original configuration in order to maintain their historic integrity.

Design Specifications

The following sections provide design specifications for stormwater planters.

Geotechnical

Due to the potential to contaminate groundwater and/or soils, cause slope instability, impact surrounding structures, and potential for insufficient infiltration capacity, a geotechnical investigation must be conducted during the site assessment process to verify the site suitability for a stormwater planter. It is critical to understand how stormwater runoff will move through the soil (horizontally and vertically) and if there are any geological conditions that may inhibit the movement of water. Soil infiltration rates and the depth to the groundwater table must be evaluated to ensure that conditions are satisfactory for proper operation of a stormwater planter. Stormwater planters can only be located on sites with a slope of less than 10 percent. A Site Conditions Report summarizing the relevant findings from the geotechnical investigation must be submitted with the Project Stormwater Plan.

Setbacks

Applicable setbacks must be implemented when siting a stormwater planter.

Pretreatment

Pretreatment, which refers to design features that provide settling of large particles before stormwater runoff enters a stormwater treatment control measure, is important to ensure proper operation of a stormwater planter and reduce the long-term maintenance burden. If stormwater planters are used to manage stormwater runoff from rooftops that drain directly to the planter, pretreatment may not be necessary because stormwater runoff from rooftops are not expected to have large particles. For other applications of a stormwater planter, pretreatment (e.g., vegetated swales, proprietary devices) is required to be provided to reduce the sediment load entering a stormwater planter in order to prevent the underlying soils from being occluded prematurely and maintain the infiltration rate of the stormwater planter.

Flow Entrance and Energy Dissipation

The drainage management area(s) (DMA[s]) tributary to a stormwater planter must be graded to minimize erosion as stormwater runoff enters the planter by creating sheet flow conditions rather than a concentrated stream condition or by providing energy dissipation devices at the inlet. Typically, a minimum slope of 1 percent for pervious surfaces and 0.5 percent for impervious surfaces to the inlet of the stormwater planter should be maintained. The following types of flow entrances can be used for a stormwater planter:

- Level spreaders (e.g., slotted curbs) can be used to facilitate sheet flow.
- Dispersed low velocity flow across a landscaped area. Dispersed flow may not be possible given space limitations or if the stormwater planter controls roadway or parking lot flows where curbs are mandatory.
- Dispersed flow across pavement or gravel and past wheel stops for parking areas.
- Flow spreading trench around perimeter of the stormwater planter that may be filled with pea gravel or vegetated with 3:1 side slopes.
- Curb cuts for roadside or parking lot areas. Curb cuts must include rock or other erosion controls in the channel entrance to dissipate energy. The flow entrance should drop two to three inches from curb line and provide an area for settling

and periodic removal of sediment and coarse material before flow disperses to the remainder of the stormwater planter.

- Piped entrances, such as roof downspouts, must include rock, splash blocks, or other erosion controls at the entrance to dissipate energy and disperse flows.

Drainage

Stormwater planters provide stormwater runoff storage in the ponding zone and in the voids of the planting media and gravel layers and must completely drain within 48 hours. The planting media and gravel layers must be allowed to dry out periodically in order to restore hydraulic capacity to receive stormwater runoff from subsequent storm events, maintain infiltration rates, maintain adequate soil oxygen levels for healthy soil biota and vegetation, and provide proper soil conditions for biodegradation and retention of pollutants.

Sizing

Step 1: Determine the Adjusted SDV (SDV_{adj})

Stormwater planters are designed to capture and retain the SDV_{adj}, which is the difference between the SDV (Section 5.2) and the volume of stormwater runoff managed through site design measures (Section 5.5), for the tributary DMA(s).

Step 2: Determine size of stormwater planter design layers

Stormwater planters consist of several layers that are designed to retain stormwater runoff. The design depths, which are used to size the stormwater planter, are presented in **Table F-3**. Other design parameters for these layers are discussed in further detail in the following sections.

Table F-3. Design Depths of Stormwater Planter Layers

Stormwater Planter Layer	Design depth
Ponding zone	0.5-1.0 ft
Planting media (excluding the mulch layer, if provided)	1.5-3.0 ft
Planting media/gravel layer separation zone (1)	2-4 in
Gravel	1 ft (min)
Hydraulic restriction layer	n/a

(1) In calculating the required bottom surface area of the stormwater planter, the planting media/ gravel layer separation zone is not considered because it is designed primarily to separate the planting media and gravel layer and not to retain stormwater runoff.

Step 3: Calculate the bottom surface area of the stormwater planter

Determine the bottom surface area (surface area at the base of side slopes, not at the top of side slopes) of the stormwater planter using the following equation:

$$A = \frac{SDV_{adj}}{d_{pz} + (\eta_{pm} \times d_{pm}) + (\eta_{gl} \times d_{gl})}$$

Where:

A = bottom surface area of stormwater planter [ft^2];
SDV_{adj} = adjusted stormwater design volume [ft^3];
d_{pz} = depth of ponding zone (0.5-1.0 ft) [ft];
η_{pm} = porosity of planting media [unitless];
d_{pm} = depth of planting media (min 1.5 ft) [ft];
η_{gl} = porosity of gravel layer [unitless]; and
d_{gl} = depth of gravel layer (min 1 ft) [ft].

Any stormwater planter shape configuration is possible as long as the other design specifications are met. The minimum stormwater planter width is 30 inches.

Stormwater Planter Walls

Stormwater planter walls must be made of stone, concrete, brick, clay, plastic, wood, or other stable, permanent material. The use of pressure-treated wood or galvanized metal at or around a stormwater planter is prohibited.

Planting Media Layer

Because stormwater planters are a variation of bioretention facilities, the Phase II Permit requires that the planting media layer:

- Have a minimum depth of 1.5 feet, excluding the mulch layer, if provided;
- Achieve a long-term, in-place minimum infiltration rate of at least 5 in/hr to support maximum stormwater runoff retention and pollutant removal; and
- Consist of 60 to 70 percent sand meeting the specifications of the American Society for Testing and Materials (ASTM) C33 and 30 to 40 percent compost.

Compost must be a well-decomposed, stable, weed-free organic matter source derived from waste materials including yard debris, wood wastes, or other organic material and not including manure or biosolids meeting standards developed by the US Composting Council (USCC). The product must be certified through the USCC Seal of Testing Assurance (STA) Program (a compost testing and information disclosure program).

Mulch is recommended for the purpose of retaining moisture, preventing erosion, and minimizing weed growth. Projects subject to the California Model Water Efficiency Landscaping Ordinance (or comparable local ordinance) will be required to provide at least two inches of mulch. Aged mulch, also called compost mulch, reduces the ability of weeds to establish, keeps soil moist, and replenishes soil nutrients. If mulch is used for a stormwater planter, two to four inches (average three inches) of mulch should be used at the initiation of the planter. Annual placement (preferably in June after weeding) of one to two inches of mulch beneath plants will maintain the mulch layer.

Planting Media/Gravel Layer Separation Zone

The planting media and gravel layer must be separated by a permeable 2-4 inch layer of sand and stone that meets the grading requirements in **Table F-4**.

Table F-4. Planting Media/Gravel Layer Separation Layer Grading Requirements

Sieve Size	Percent Passing
1”	100
3/4”	90-100
3/8”	40-100
No. 4	25-100
No. 8	18-33
No. 30	5-15
No. 50	0-7
No. 200	0-3

Source: Caltrans Standard Specifications (2010) Class 2 Permeable Material

Gravel Layer

The gravel layer must consist of washed 1- to 2.5-inch diameter stone with a minimum 1-foot depth.

Hydraulic Restriction Layer

The hydraulic restriction layer, which can be a 60-mil PVC or 30-mil polyethylene pond liner with bentonite clay mats, must be placed below the gravel layer to prevent infiltration of stormwater runoff below the stormwater planter. If the stormwater planter is located near structures, the hydraulic restriction layer must also be applied along the walls of the stormwater planter to prevent stormwater runoff from percolating to these structures. The hydraulic restriction layer should be installed generously with overlapping seams prior to constructing the layers of the stormwater planter.

Underdrain

Stormwater planters require an underdrain to collect and discharge stormwater runoff that has been filtered through the planting media, but not infiltrated, to another stormwater treatment control measure, storm drain system, or receiving water. The underdrain must have a discharge elevation at the bottom of the gravel layer and a mainline diameter of six inches using slotted PVC SDR 26 or C900. Slotted PVC allows for pressure cleaning and root cutting, if necessary. The slotted pipe should have two to four rows of slots cut perpendicular to the axis of the pipe or at right angles to the pitch of corrugations. Slots should be 0.04 to 0.1 inches wide with a length of 1 to 1.25 inches. Slots should be longitudinally-spaced such that the pipe has a minimum of one square inch opening per lineal foot and should face down. Underdrains should be sloped at a minimum of 0.5 percent in order to drain freely to an approved location.

Observation Well

A rigid non-perforated observation pipe with a diameter equal to the underdrain diameter must be connected to the underdrain to provide a clean-out port as well as an observation well to monitor infiltration rates. The wells/clean-out port must be connected to the slotted underdrain with the appropriate manufactured connections. The wells/clean-outs must extend six inches above the top elevation of the stormwater planter mulch and be capped with a lockable screw cap. The ends of the underdrain pipes not terminating in an observation well/clean-out port must also be capped.

Vegetation

It is recommended that a minimum of three climate-appropriate types of tree, shrub, and/or herbaceous groundcover species be incorporated in a stormwater planter to protect against failure due to disease and insect infestations of a single species. Select vegetation that:

- Can tolerate summer drought, ponding fluctuations, and saturated soil conditions for up to 48 hours.
- Will be dense and strong enough to stay upright, even in flowing water;
- Does not require fertilizers;
- Is not prone to pests and is consistent with Integrated Pest Management practices (IPM); and
- Is consistent with local water conservation ordinance requirements.

A sample list of suitable vegetation species is included in Appendix H. Prior to installation, a landscape architect must certify that all proposed vegetation is appropriate for the project site. Stormwater runoff must be diverted around the stormwater planter during the period of vegetation establishment.

Irrigation System

Provide an irrigation system to maintain viability of vegetation, if necessary. If possible, the general landscape irrigation system should incorporate the stormwater planter. The irrigation system must be designed to local code or ordinance specifications and must comply with the requirements of Section 4. Supplemental irrigation may be required for the establishment period even if it is not needed later.

Overflow Device

An overflow device is required at the ponding depth near the inlet of the stormwater planter to divert stormwater runoff in excess of the design capacity of the stormwater planter. For rooftop drainage, the distance between the downspouts and the overflow outlet should be maximized in order to increase the opportunity for stormwater runoff retention and filtration. The following, or equivalent, must be provided:

- A vertical PVC pipe (SDR 26) to act as an overflow riser.
- The overflow riser(s) should be eight inches or greater in diameter so it can be cleaned without damage to the pipe.
- The inlet to the riser should be at the ponding depth and capped with a spider cap to exclude floating mulch and debris. Spider caps must be screwed on and include a locking mechanism. The overflow device must convey stormwater runoff in excess of the design capacity of the stormwater planter to an approved discharge location (e.g., another stormwater treatment control measure, storm drain system, receiving water).

Construction Considerations

As part of the site planning process, the areas designated for a stormwater planter must be identified. The area identified for a stormwater planter must be protected from construction-related sediment loads. During construction activities if possible, divert all flows around the areas intended for the stormwater planter. Sediment control measures should also be implemented to prevent sediment from impacting the areas identified for a stormwater planter. Final grading must produce a level bottom without low spots or depressions. After construction is completed, the entire tributary area to the stormwater planter must be stabilized before allowing stormwater runoff to enter it.

Maintenance Requirements

Maintenance and regular inspections must be conducted to ensure proper function of a stormwater planter. A stormwater planter requires annual plant, soil, and mulch layer maintenance to ensure optimal infiltration, storage, and pollutant removal capabilities. Stormwater planter maintenance requirements, which consist primarily of landscape care procedures, include:

- Irrigate vegetation as needed during prolonged dry periods. In general, climate-appropriate vegetation will not require irrigation after establishment (two to three years). Regularly inspect the irrigation system, if provided, for clogs or broken pipes and repair as necessary.
- Inspect flow entrances, ponding area, and surface overflow areas periodically, and replace soil, vegetation, and/or mulch layer in areas if erosion has occurred. Properly-designed facilities with appropriate flow velocities should not cause erosion except potentially during in extreme events. If erosion occurs, the flow

velocities and gradients within the stormwater planter and energy dissipation and erosion protection strategies in the pretreatment area, if provided, or flow entrance should be reassessed. If sediment is deposited in the stormwater planter, identify the source of the sediment within the tributary area, stabilize the source, and remove excess surface deposits.

- Prune and remove dead vegetation as needed. Replace all dead vegetation, and if specific plants have a high mortality rate, assess the cause and, if necessary, replace with more appropriate species. Repair, seed, and re-plant damaged areas immediately.
- Remove weeds and other invasive, poisonous, nuisance, or noxious vegetation as needed until the vegetation is established. Weed removal should become less frequent if the appropriate species are used and planting density is attained.
- Remove and properly dispose of trash and other litter.
- Eliminate standing water to prevent vector breeding. If standing water is observed more than 48 hours after a storm event, it may be necessary to remove and replace the planting media and/or gravel layer to restore functionality of the stormwater planter.
- Inspect, and clean if necessary, the underdrain and observation well/clean-out port. Inspect overflow devices for obstructions or debris, which should be removed immediately. Repair or replace damaged pipes upon discovery.
- Repair structural deficiencies to the stormwater planter including rot, cracks, and failure.
- Implement IPM practices if pests are present in the stormwater planter.

The Agencies require execution of a Maintenance Access Agreement to be recorded by the property owner for the on-going operation and maintenance of all privately-maintained stormwater treatment control measures. The property owner is responsible for compliance with the Maintenance Access Agreement. An example Maintenance Access Agreement is presented in Appendix G.

T-2: Tree-Well Filter

Description

A tree-well filter is similar to a stormwater planter and consists of one or multiple chambered pre-cast concrete boxes with a small tree or shrub planted in a bed filled with planting media. Tree-well filters are typically installed along the edge of a parking lot or roadway, where a street tree might normally be planted, and is designed to receive, retain, and infiltrate stormwater runoff from adjoining paved areas. During storm events, stormwater runoff enters the chamber and gradually infiltrates and filters through the planting media into the underlying soil, or collected by an underdrain system.

Source: Low Impact Development Center (top) and University of New Hampshire Stormwater Center (bottom)

Treatment occurs through a variety of natural mechanisms as the stormwater runoff filters through the root zone of the vegetation and during detention of the stormwater runoff in the pore space of the planting media. A portion of stormwater runoff held in the root zone of the soil media is returned to the atmosphere through transpiration by the vegetation. Stormwater runoff that reaches the bottom of the tree-well filter and does not infiltrate into underlying soils is collected and discharged through an underdrain.

Tree-well filters are ideally suited for small areas such as parking lot islands, perimeter building planters, street medians, roadside swale features, and site entrance or buffer features. Tree-well filters can be integrated into other landscape areas. The maximum tributary area of a tree-well filter is one acre.

An example schematic of a typical tree-well filter is presented in **Figure F-5**.

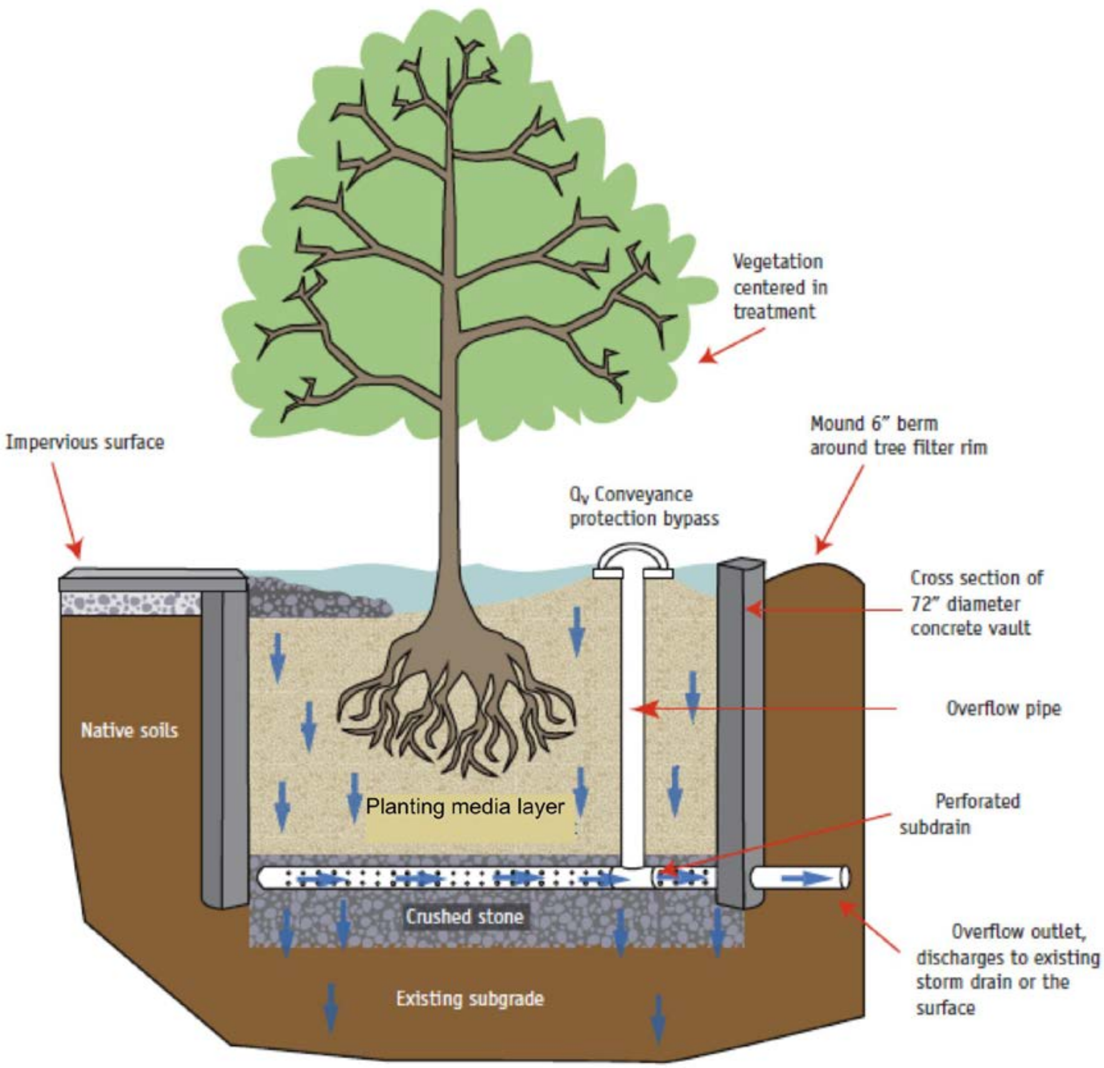


Figure F-5. Example Tree-Well Filter Schematic

Use and Applicability

The Phase II Permit (Provision E.12.e.(f)) identifies bioretention as the standard stormwater treatment control measure unless (1) it is determined to be infeasible and an alternative treatment control measure that is equivalent to bioretention is proposed and justified (Provision E.12.e.(g)), or (2) a specific exemption applies (Provision E.12.e.(i)). Tree-well filters can be proposed as an alternative to bioretention if it meets all of the following measures of equivalent effectiveness:

- Equal or greater amount of stormwater runoff infiltrated or evapotranspired;
- Equal or lower pollutant concentrations in stormwater runoff that is discharged after biotreatment;
- Equal or greater protection against shock loadings and spills; and

- Equal or greater accessibility and ease of inspection and maintenance.

The Phase II Permit (Provision E.12.e.(h)) allows the use of tree-well filters in project areas with documented high concentrations of pollutants in the underlying soil or groundwater, where infiltration may contribute to a geotechnical hazard, and that are located on elevated plazas or adjacent to structures. Under these allowed variations for site-specific conditions, a hydraulic restriction layer may be incorporated or the underdrain may be located at the bottom of the gravel layer.

The Phase II Permit (Provision E.12.e.(i)) also allows the use of tree-well filters in project areas for the following types of Regulated Projects:

- Projects creating or replacing an acre or less of impervious area, and located in a designated pedestrian-oriented commercial district (i.e., smart growth projects), and having at least 85 percent of the entire project site covered by permanent structures;
- Facilities receiving runoff solely from existing (pre-project) impervious areas; and
- Historic sites, structures, or landscapes that cannot alter their original configuration in order to maintain their historic integrity.

Design Specifications

The following sections provide design specifications for tree-well filters.

Geotechnical

Due to the potential to contaminate groundwater and/or soils, cause slope instability, impact surrounding structures, and potential for insufficient infiltration capacity, a geotechnical investigation must be conducted during the site assessment process to identify potential geotechnical hazards. It is critical to understand how stormwater runoff will move through the soil (horizontally and vertically) and if there are any geological conditions that may inhibit the movement of water. Soil infiltration rates and the depth to the groundwater table must be evaluated to ensure that conditions are satisfactory for proper operation of a tree-well filter. Tree-well filters can only be located on sites with a slope of less than 10 percent. A Site Conditions Report summarizing the relevant findings from the geotechnical investigation must be submitted with the Project Stormwater Plan.

Pretreatment

Pretreatment, which refers to design features that provide settling of large particles before stormwater runoff enters a stormwater treatment control measure, is important to ensure proper operation of a tree-well filter and reduce the long-term maintenance burden. If tree-well filters are used to manage stormwater runoff from rooftops that drain directly to the filter, pretreatment may not be necessary because stormwater runoff from rooftops are not expected to have large particles. For other applications of a stormwater planter, pretreatment (e.g., vegetated swales, proprietary devices) is required to be provided to reduce the sediment load entering a tree-well filter in order to prevent the underlying soils from being occluded prematurely and maintain the infiltration rate of the tree-well filter.

Flow Entrance and Energy Dissipation

The drainage management area(s) (DMA[s]) tributary to a tree-well filter must be graded to minimize erosion as stormwater runoff enters the filter by creating sheet flow conditions rather than a concentrated stream condition or by providing energy dissipation devices at the inlet. Typically, a minimum slope of 1 percent for pervious surfaces and 0.5 percent for impervious surfaces to the inlet of the tree-well filter should be maintained. The following types of flow entrances can be used for a tree-well filter:

- Level spreaders (e.g., slotted curbs) can be used to facilitate sheet flow.
- Dispersed low velocity flow across a landscaped area. Dispersed flow may not be possible given space limitations or if the tree-well filter controls roadway or parking lot flows where curbs are mandatory.
- Dispersed flow across pavement or gravel and past wheel stops for parking areas.
- Curb cuts for roadside or parking lot areas. Curb cuts must include rock or other erosion controls in the channel entrance to dissipate energy. The flow entrance should drop two to three inches from curb line and provide an area for settling and periodic removal of sediment and coarse material before flow disperses to the remainder of the tree-well filter.
- Piped entrances, such as roof downspouts, must include rock, splash blocks, or other erosion controls at the entrance to dissipate energy and disperse flows.

Drainage

Tree-well filters provide stormwater runoff storage in the ponding zone and in the voids of the planting media and gravel layers and must completely drain within 48 hours. The planting media and gravel layers must be allowed to dry out periodically in order to restore hydraulic capacity to receive stormwater runoff from subsequent storm events, maintain infiltration rates, maintain adequate soil oxygen levels for healthy soil biota and vegetation, and provide proper soil conditions for biodegradation and retention of pollutants.

Sizing

<u>Step 1: Determine the Adjusted SDV (SDV_{adj})</u>

Tree-well filters are designed to capture and retain the SDV_{adj}, which is the difference between the SDV (Section 5.2) and the volume of stormwater runoff managed through site design measures (Section 5.5), for the tributary DMA(s).

Step 2: Determine size of tree-well filter design layers

Tree-well filters consist of several layers that are designed to retain stormwater runoff. The design depths, which are used to size the tree-well filter, are presented in **Table F-5**. Other design parameters for these layers are discussed in further detail in the following sections.

Table F-5. Design Depths of Tree-Well Filter Layers

Tree-Well Filter Layer	Design depth
Ponding zone	0.5-1.0 ft
Planting media (excluding the mulch layer, if provided)	1.5-3.0 ft
Planting media/gravel layer separation zone (1)	2-4 in
Gravel	1 ft (min)
Hydraulic restriction layer	n/a

(1) In calculating the required bottom surface area of the tree-well filter, the planting media/gravel layer separation zone is not considered because it is designed primarily to separate the planting media and gravel layer and not to retain stormwater runoff.

Step 3: Calculate the bottom surface area of the tree-well filter

Determine the bottom surface area (surface area at the base of side slopes, not at the top of side slopes) of the tree-well filter using the following equation:

$$A = \frac{SDV_{adj}}{d_{pz} + (\eta_{pm} \times d_{pm}) + (\eta_{gl} \times d_{gl})}$$

Where:

A = bottom surface area of tree-well filter [ft^2];
SDV_{adj} = adjusted stormwater design volume [ft^3];
d_{pz} = depth of ponding zone (0.5-1.0 ft) [ft];
η_{pm} = porosity of planting media [unitless];
d_{pm} = depth of planting media (min 1.5 ft) [ft];
η_{gl} = porosity of gravel layer [unitless]; and
d_{gl} = depth of gravel layer (min 1 ft) [ft].

Tree-well filters can have a non-rectangular footprint to fit site landscape design.

Planting Media Layer

Because tree-well filters are a variation of bioretention facilities, the Phase II Permit requires that the planting media layer:

- Have a minimum depth of 1.5 feet, excluding the mulch layer, if provided;

- Achieve a long-term, in-place minimum infiltration rate of at least 5 in/hr to support maximum stormwater runoff retention and pollutant removal; and
- Consist of 60 to 70 percent sand meeting the specifications of the American Society for Testing and Materials (ASTM) C33 and 30 to 40 percent compost.

Compost must be a well-decomposed, stable, weed-free organic matter source derived from waste materials including yard debris, wood wastes, or other organic material and not including manure or biosolids meeting standards developed by the US Composting Council (USCC). The product must be certified through the USCC Seal of Testing Assurance (STA) Program (a compost testing and information disclosure program).

Mulch is recommended for the purpose of retaining moisture, preventing erosion, and minimizing weed growth. Projects subject to the California Model Water Efficiency Landscaping Ordinance (or comparable local ordinance) will be required to provide at least two inches of mulch. Aged mulch, also called compost mulch, reduces the ability of weeds to establish, keeps soil moist, and replenishes soil nutrients. If mulch is used for a tree-well filter, two to four inches (average three inches) of mulch should be used at the initiation of the filter. Annual placement (preferably in June after weeding) of one to two inches of mulch beneath plants will maintain the mulch layer.

Planting Media/Gravel Layer Separation Zone

The planting media and gravel layer must be separated by a permeable 2-4 inch layer of sand and stone that meets the grading requirements in **Table F-6**.

Table F-6. Planting Media/Gravel Layer Separation Layer Grading Requirements

Sieve Size	Percent Passing
1”	100
3/4”	90-100
3/8”	40-100
No. 4	25-100
No. 8	18-33
No. 30	5-15
No. 50	0-7
No. 200	0-3

Source: Caltrans Standard Specifications (2010) Class 2 Permeable Material

Gravel Layer

The gravel layer must consist of washed 1- to 2.5-inch diameter stone with a minimum 1-foot depth.

Hydraulic Restriction Layer

The hydraulic restriction layer, which can be a 60-mil PVC or 30-mil polyethylene pond liner with bentonite clay mats, must be placed below the gravel layer to prevent infiltration of stormwater runoff below the tree-well filter. If the tree-well filter is located near structures, the hydraulic restriction layer must also be applied along the walls of the tree-well filter to prevent stormwater runoff from percolating to these structures. The hydraulic restriction layer should be installed generously with overlapping seams prior to constructing the layers of the tree-well filter.

Underdrain

Tree-well filters require an underdrain to collect and discharge stormwater runoff that has been filtered through the planting media, but not infiltrated, to another stormwater treatment control measure, storm drain system, or receiving water. The underdrain must have a discharge elevation at the bottom of the gravel layer and a mainline diameter of six inches using slotted PVC SDR 26 or C900. Slotted PVC allows for pressure cleaning and root cutting, if necessary. The slotted pipe should have two to four rows of slots cut perpendicular to the axis of the pipe or at right angles to the pitch of corrugations. Slots should be 0.04 to 0.1 inches wide with a length of 1 to 1.25 inches. Slots should be longitudinally-spaced such that the pipe has a minimum of one square inch opening per lineal foot and should face down. Underdrains should be sloped at a minimum of 0.5 percent in order to drain freely to an approved location.

Observation Well

A rigid non-perforated observation pipe with a diameter equal to the underdrain diameter must be connected to the underdrain to provide a clean-out port as well as an observation well to monitor infiltration rates. The wells/clean-out port must be connected to the slotted underdrain with the appropriate manufactured connections. The wells/clean-outs must extend six inches above the top elevation of the tree-well filter mulch and be capped with a lockable screw cap. The ends of the underdrain pipes not terminating in an observation well/clean-out port must also be capped.

Vegetation

Select a tree that:

- Can tolerate summer drought, ponding fluctuations, and saturated soil conditions for up to 48 hours;
- Is suited to well-drained soil;
- Will be dense and strong enough to stay upright, even in flowing water;
- Does not require fertilizers;
- Is not prone to pests and is consistent with Integrated Pest Management (IPM) practices; and

- Is consistent with local water conservation ordinance requirements.

A sample list of suitable tree species is included in Appendix H. Prior to installation, a landscape architect must certify that proposed trees are appropriate for the project site.

Irrigation System

Provide an irrigation system to maintain viability of tree, if necessary. If possible, the general landscape irrigation system should incorporate the tree-well filter. The irrigation system must be designed to local code or ordinance specifications and must comply with the requirements of Section 4. Supplemental irrigation may be required for the establishment period even if it is not needed later.

Overflow Device

An overflow device is required at the ponding depth of the tree-well filter to divert stormwater runoff in excess of the design capacity of the tree-well filter. For rooftop drainage, the distance between the downspouts and the overflow outlet should be maximized in order to increase the opportunity for stormwater runoff filtration through the planting media. The following, or equivalent, must be provided:

- A vertical PVC pipe (SDR 26) to act as an overflow riser.
- The overflow riser(s) should be eight inches or greater in diameter so it can be cleaned without damage to the pipe.
- The inlet to the riser should be at the ponding depth and capped with a spider cap to exclude floating mulch and debris. Spider caps must be screwed on and include a locking mechanism. The overflow device should convey stormwater runoff in excess of the design capacity of the tree-well filter to an approved discharge location (e.g., another stormwater treatment control measure, storm drain system, receiving water).

Construction Considerations

As part of the site planning process, the areas designated for a tree-well filter must be identified. The area identified for a tree-well filter must be protected from construction-related sediment loads. During construction activities if possible, divert all flows around the areas intended for the tree-well filter. Sediment control measures should also be implemented to prevent sediment from impacting the areas identified for a tree-well filter. Final grading must produce a level bottom without low spots or depressions. After construction is completed, the entire tributary area to the tree-well filter must be stabilized before allowing stormwater runoff to enter it.

Maintenance Requirements

Maintenance and regular inspections must be conducted to ensure proper function of a tree-well filter. In general, tree-well filter maintenance requirements are typical landscape care procedures and include:

- Irrigate tree as needed during prolonged dry periods. In general, climate-appropriate trees will not require significant irrigation. Regularly inspect the irrigation system, if provided, for clogs or broken pipes and repair as necessary.
- Inspect flow entrances, ponding area, and surface overflow areas periodically, and replace planting media and/or mulch layer in areas if erosion has occurred. Properly designed facilities with appropriate flow velocities should not cause erosion except potentially during in extreme events. If erosion occurs, the flow velocities and gradients within the tree-well filter and flow dissipation and erosion protection strategies in the flow entrance should be reassessed. If sediment is deposited in the tree-well filter, identify the source of the sediment within the tributary area, stabilize the source, and remove excess surface deposits.
- Prune the tree as needed.
- Repair, seed, and re-plant damaged areas immediately.
- Remove weeds and other invasive, poisonous, nuisance, or noxious vegetation as needed until the vegetation is established. Weed removal should become less frequent if the appropriate species are used and planting density is attained.
- Eliminate standing water to prevent vector breeding. If standing water is observed more than 48 hours after a storm event, it may be necessary to remove and replace the planting media and/or gravel layer to restore functionality of the tree-well filter.
- Inspect, and clean if necessary, the underdrain and observation well/clean-out port. Inspect overflow devices for obstructions or debris, which should be removed immediately. Repair or replace damaged pipes upon discovery.
- Implement IPM practices if pests are present in the tree-well filter.

The Agencies require execution of a Maintenance Access Agreement to be recorded by the property owner for the on-going operation and maintenance of all privately-maintained stormwater treatment control measures. The property owner is responsible for compliance with the Maintenance Access Agreement. An example Maintenance Access Agreement is presented in Appendix G.

T-3: Sand Filter

Description

A sand filter operates similar to a stormwater planter; however, instead of filtering stormwater runoff through engineered planting media, stormwater runoff is filtered through a constructed sand bed with an underdrain system. Stormwater runoff enters a sand filter and spreads over the surface. As flows increase, water backs up on the surface of the filter where it is held until it can percolate through the sand. The treatment pathway is vertical (downward through the sand). High flows in excess of the design volume are diverted to prevent overloading of the filter. Stormwater runoff that percolates through the sand is collected with an underdrain that conveys it to another stormwater treatment control measure, storm drain system, or receiving water. As stormwater runoff passes through the sand, pollutants are trapped in the pore spaces between sand grains or adsorbed to the sand surface.

Sand filters can be placed underground and have the capability of reducing the peak stormwater runoff flow for small storms.

An example schematic of a typical sand filter is presented in **Figure F-6**.

Use and Applicability

The Phase II Permit (Provision E.12.e.(f)) identifies bioretention as the standard stormwater treatment control measure unless (1) it is determined to be infeasible and an alternative treatment control measure that is equivalent to bioretention is proposed and demonstrated (Provision E.12.e.(g)), or (2) a specific exemption applies (Provision E.12.e.(i)). An alternative to bioretention can be proposed if it meets <u>all</u> of the following measures of equivalent effectiveness:

- Equal or greater amount of stormwater runoff infiltrated or evapotranspired;
- Equal or lower pollutant concentrations in stormwater runoff that is discharged after biotreatment;
- Equal or greater protection against shock loadings and spills; and
- Equal or greater accessibility and ease of inspection and maintenance.

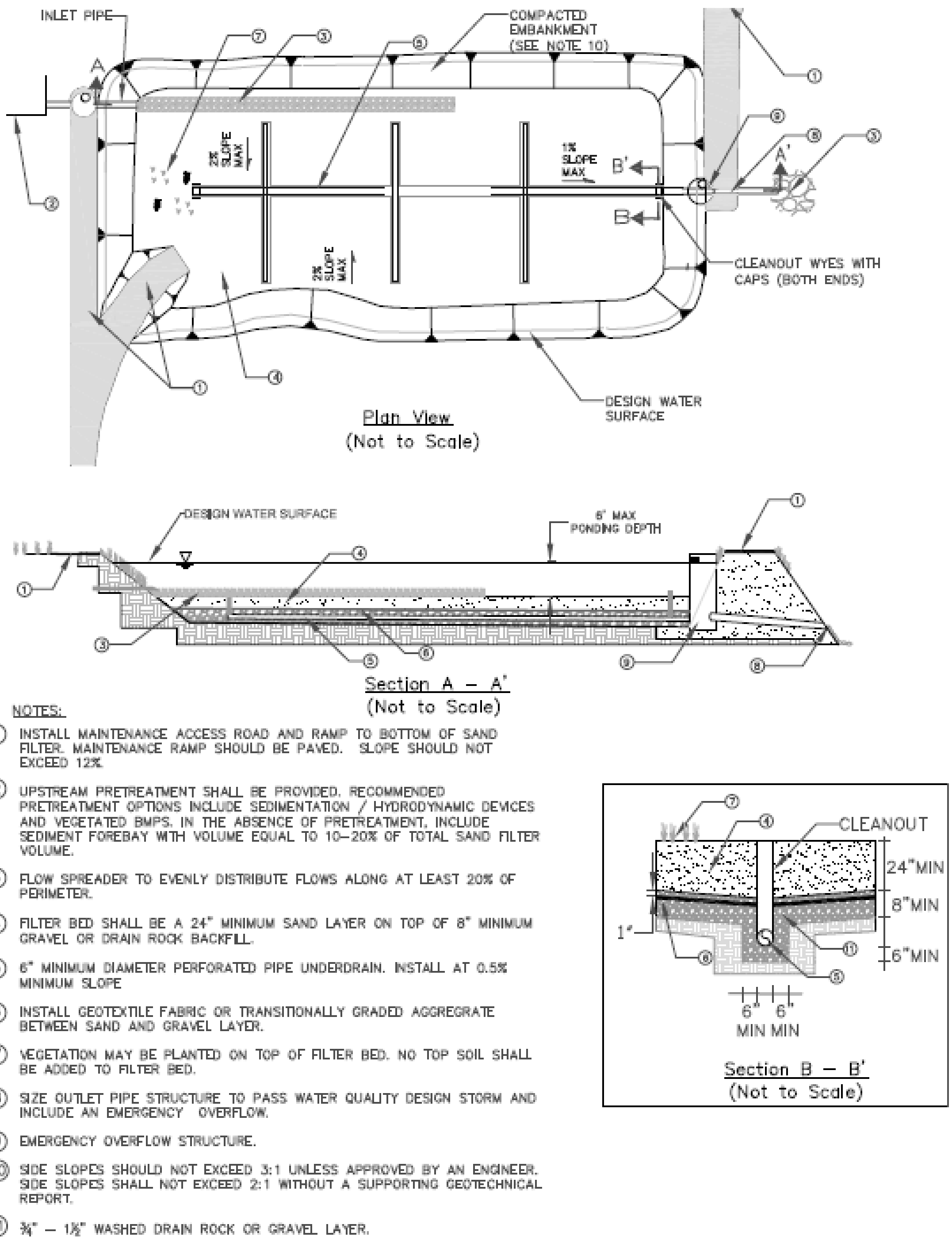


Figure F-6. Example Sand Filter Schematic

However, sand filters are unable to infiltrate or evapotranspire an equivalent amount of stormwater runoff when compared to bioretention. While sand filters cannot be used as an alternative to bioretention, there are two specific situations where they may be implemented as part of the stormwater management strategy at a project site. For project sites that have high-risk areas, such as fueling stations, truck stops, auto repairs, and heavy industrial sites, additional treatment may be required to address pollutants of concern unless these areas are isolated from stormwater runoff with little chance of spill migration.

The Phase II Permit (Provision E.12.e.(i)) also allows the use of sand filters in project areas for the following types of Regulated Projects:

- Projects creating or replacing an acre or less of impervious area, and located in a designated pedestrian-oriented commercial district (i.e., smart growth projects), and having at least 85 percent of the entire project site covered by permanent structures;
- Facilities receiving runoff solely from existing (pre-project) impervious areas; and
- Historic sites, structures, or landscapes that cannot alter their original configuration in order to maintain their historic integrity.

Design Specifications

The following sections provide design specifications for sand filters.

Setbacks

Applicable setbacks must be implemented when siting a sand filter.

Pretreatment

The primary challenge associated with sand filters is maintaining the filtration capacity, which is critical to its performance. If the flow entering the sand filter has high sediment concentrations, clogging of the sand filter is likely. Contribution of eroded soils or leaf litter may also reduce the filtration and associated treatment capacity of the sand filter.

Pretreatment, which refers to design features that provide settling of large particles before stormwater runoff enters a stormwater treatment control measure, is important to ensure proper operation of a sand filter and reduce the long-term maintenance burden. Pretreatment (e.g., vegetated swales, proprietary devices) must be provided to reduce the sediment load entering a sand filter in order to prevent the filtration media from being occluded prematurely and maintain the filtration capacity of the sand filter.

An alternative design for a sand filter can include a sediment forebay to remove sediment from stormwater runoff. The sediment forebay must be separated from the san filter by a berm or similar feature, which may be constructed out of earthen embankment material, grouted riprap, or other structurally-sound material, and must be equal to 10 to 20 percent of the total sand filter volume. A gravity drain outlet (minimum four-inch diameter) from the forebay must extend the entire width of the internal berm. The forebay outlet to the sand filter must be off-set from the inlet flow line to prevent short-circuiting. Permanent steel post depth markers must be placed in the forebay to identify the settled sediment removal limits at 50 and 100 percent of the forebay sediment storage depth.

Flow Entrance and Energy Dissipation

Sand filters must be placed off-line to prevent scouring of the filter bed by high flows. The drainage management area(s) (DMA[s]) tributary to the sand filter must be graded to minimize erosion as stormwater runoff enters the filter by creating sheet flow conditions rather than a concentrated stream condition. A flow spreader must be installed at the inlet along one side of the sand filter to evenly distribute stormwater runoff across the entire width of the sand filter and to prevent erosion of the filter surface. The flow spreader must be provided for a minimum of 20 percent of the filter perimeter. If the length-to-width ratio of the filter is 2:1 or greater, the flow spreader must be located on the longer side and for a minimum length of 20 percent of the perimeter of the sand filter. Erosion protection must be provided along the first foot of the sand filter bed adjacent to the flow spreader.

Drainage

Sand filters provide stormwater runoff storage in the ponding zone and in the voids of the sand media and must completely drain within 48 hours. The sand filter must be allowed to dry out periodically in order to restore hydraulic capacity to receive stormwater from subsequent storm events, maintain filtration rates, and provide proper conditions retention of pollutants.

Sizing

<u>Step 1: Determine the Adjusted SDV (SDV_{adj})</u>

Sand filters are designed to capture and retain the SDV_{adj}, which is the difference between the SDV (Section 5.2) and the volume of stormwater runoff managed through site design measures (Section 5.5), for the tributary DMA(s).

<u>Step 2: Determine maximum ponding depth</u>

Determine the maximum ponding depth (d_{pz}) above the sand filter. Aside from providing temporary storage of stormwater runoff, the ponding zone determines the hydraulic head over the filter bed surface, which increases the flow rate through the sand. This depth is defined as the depth at which water begins to overflow the reservoir above the sand filter and depends on the site topography and hydraulic constraints. The maximum ponding depth is six feet. There must also be a minimum freeboard of one foot.

<u>Step 3: Determine sand filter bed depth</u>

The depth of the sand filter bed (D) must be at least two feet, but three feet is preferred.

Step 4: Determine the design hydraulic conductivity

Determine the design saturated hydraulic conductivity (K) of the sand conditioned rather than clean. This approach represents the average sand bed condition as silt is captured and held in the sand bed instead of clean sand that will become occluded during the first use of the sand filter.

Step 5: Calculate the sand filter surface area

Determine the surface of the sand filter area using the following equation:

$$A_{sf} = \frac{SDV_{adj} \times R \times D}{K \times t \times (h + D)}$$

Where:

A_{sf} = surface area of the sand filter bed [ft^2];
SDV_{adj} = adjusted stormwater design volume [ft^3];
R = adjustment factor [use R=0.7];
D = sand filter bed depth (maximum 3 ft) [ft];
K = Design hydraulic conductivity [use 3 ft/day];
t = Maximum drawdown time [use 48 hours]; and
h = Average depth of ponding zone [ft, use $d_{pz}/2$].

The size of the sand filter is determined by assuming that the inflow is immediately discharged through the filter as if there was no ponding zone. An adjustment factor (0.7) is applied to compensate for the greater filter size resulting from this method.

Sand filters may be designed in any geometric configuration, but rectangular with a 1.5:1 length-to-width ratio or greater is preferred.

Sand Filter Walls

The walls of the sand filter may be vertical retaining walls, provided: (a) they are constructed of reinforced concrete; (b) a fence, which prevents access, is provided along the top of the wall (see fencing below) or further back; and (c) the design is approved by a licensed civil engineer and the Agency.

Interior side slopes up to the overflow device must be no steeper than 3:1 (H:V) unless stabilization has been approved by a licensed geotechnical engineer. Exterior side slopes shall be no steeper than 2:1 (H:V) unless stabilization has been approved by a licensed geotechnical engineer. For any slope (interior or exterior) greater than 2:1 (H:V), a geotechnical report must be submitted and approved by the Agency.

Sand Specification

The ideal effective diameter of the sand for a sand filter (d10) should be small enough to ensure a high quality effluent from the sand filter while preventing penetration of solids to such a depth that it cannot be removed by surface scraping (~2-3 inches). This effective diameter is between 0.20 and 0.35 mm. Additionally, the coefficient of uniformity, C_u = d60/d10, should be less than 3. The sand media should consist of a medium sand with very little fines meeting ASTM C33 size gradation (by weight) or equivalent as presented in **Table F-7**. Finally, the silica (SiO_2) content of the sand should be greater than 95 percent by weight.

Table F-7. Sand Filter Media Sand Specifications

U.S. Sieve Size	Percent Passing by Weight
3/8 inch	100%
U.S. No. 4	95-100%
U.S. No. 8	80-100%
U.S. No. 16	50-85%
U.S. No. 30	25-60%
U.S. No. 50	5-30%
U.S. No. 100	<10%

Hydraulic Restriction Layer

Either a hydraulic restriction layer, which can be a 60-mil PVC or 30-mil polyethylene pond liner with bentonite clay mats, or a 2-inch transition gradation layer (preferred) must be placed between the sand layer and the drain rock or gravel backfill layer. If a liner is used, one inch of drain rock or gravel backfill should be place above the liner to allow for a transitional zone between sand and gravel and reduce pooling of water at the liner interface. The hydraulic restriction layer should be installed generously with overlapping seams.

Underdrain

Sand filters are require an underdrain to collect and discharge treated stormwater runoff to another stormwater treatment control measure, storm drain system, or receiving water. There are several underdrain system options, which must be reinforced to withstand the weight of the overburden, that can be used:

- A central underdrain collection pipe with lateral collection pipes in a minimum eight-inch gravel backfill or drain rock bed.
- Longitudinal pipes in a minimum eight-inch gravel backfill or drain rock bed, with a collection pipe at the outfall of the sand filter.

- Small sand filters may use a single underdrain pipe in a minimum eight-inch gravel backfill or drain rock bed.

All underdrain pipes must have a minimum mainline diameter of six inches using perforated PVC to allow for pressure water cleaning, if necessary, and ensure free draining of the sand filter bed. Round perforations must be at least 0.5-inch in diameter and the pipe must be laid with perforations downward. The maximum perpendicular distance between any two lateral collection pipes or from the edge of the sand filter and the collection pipes is nine feet. All pipes must be placed with a minimum slope of 0.5 percent.

The underdrain must be placed in a gravel backfill where at least eight inches of gravel backfill must be maintained over all underdrain pipes, and at least six inches must be maintained on both sides and beneath the pipe to prevent damage by heavy equipment during maintenance. Either drain rock or gravel backfill may be used between pipes. The bottom gravel layer must have a diameter at least twice the size of the openings into the storm drain system. The grains should be hard, preferably rounded, with a specific gravity of at least 2.5, and free of clay, debris and organic impurities.

Clean-out risers with diameters equal to the underdrain pipes must be placed at the terminal ends of all pipes and extend to the surface of the filter. A valve box should be provided for access to the clean-outs and the clean-out assembly must be water tight to prevent short circuiting of the sand filter.

To prevent uses that may compact and damage the filter surface, permanent structures are not permitted on sand filters (i.e., playground equipment).

Vegetation

Sand filters must be located away from trees or other plants producing leaf litter.

Overflow Device

While sand filters may only be placed off-line, an overflow device near the inlet to the sand filter must still be provided to divert stormwater runoff in excess of the design capacity of the sand filter or in the event the sand filter becomes clogged. The following, or equivalent, must be provided:

- A vertical PVC pipe (SDR 26) to act as an overflow riser.
- The overflow riser(s) should be eight inches or greater in diameter so it can be cleaned without damage to the pipe.
- The inlet to the riser should be at the freeboard depth and capped with a spider cap to exclude floating debris. Spider caps must be screwed on and include a locking mechanism. The overflow device must convey stormwater runoff in excess of the design capacity of the sand filter to an approved discharge location

(e.g., another stormwater treatment control measure, storm drain system, receiving water).

Exterior Landscaping

Landscaping outside of the sand filter, but within the easement/right-of-way, is required and must adhere to the following specifications such that it will not hinder maintenance operations:

- No trees or shrubs may be planted within ten feet of inlet or outlet pipes or manmade drainage structures such as overflow devices, flow spreaders, or earthen embankments. Species with roots that seek water, such as willow or poplar, must not be used within 50 feet of pipes or manmade structures.
- Non-climate-appropriate plant species are not permitted.

Fencing

Safety is provided by fencing of the stormwater treatment control measure. Fences shall be designed and constructed in accordance with Agency standards and must be located at or above the top of overflow device elevation.

Maintenance Access

Maintenance access must be provided to the structures associated with the sand filter (e.g., pretreatment, inlet, overflow devices) if it is publicly-maintained. Manhole and catch basin lids must be in or at the edge of the access road. An access ramp to the sand filter bottom is required to facilitate the entry of sediment removal (and vegetation maintenance) equipment.

Unless otherwise required by the Agency, access roads must meet the following design specifications:

- All access ramps and roads must be paved with a minimum of six inches concrete over three inches of crushed aggregate base material. This requirement may be modified depending on the soil conditions and intended use of the road at the discretion of Agency.
- The maximum grade is 12 percent unless otherwise approved by the Agency.
- Centerline turning radius must be a minimum of 40 feet.
- Access roads less than 500 feet long must have a 12-foot wide pavement within a minimum 15-foot wide bench. Access roads greater than 500 feet long must have 16-foot wide pavement within a minimum 20-foot wide bench.
- All access roads must terminate with turnaround areas of 40-feet by 40-feet. A hammer type turn around area or a circle drive around the top of the sand filter is also acceptable.

- Adequate double-drive gates and commercial driveways are required at street crossings. Gates should be located a minimum of 25 feet from the street curb except in residential areas where the gates may be located along the property line provided there is adequate sight distance to see oncoming vehicles at the posted speed limit.

Restricted Construction Materials

The use of pressure-treated wood or galvanized metal at or around the sand filter is prohibited. The use of galvanized fencing is permitted if in accordance with the Fencing requirement above.

Construction Considerations

Sand filters are generally suited for sites where there is no base flow, and the sediment load is relatively low. For underground sand filters, the load-carrying capacity of the filter structure must be considered if it is located under parking lots, driveways, roadways, and certain sidewalks.

As part of the site planning process, the areas designated for a sand filter must be identified. The area identified for a sand filter must be protected from construction-related sediment loads. During construction activities if possible, divert all flows around the areas intended for the sand filter. Sediment control measures should also be implemented to prevent sediment from impacting the areas identified for a sand filter. Final grading must produce a level bottom without low spots or depressions. After construction is completed, the entire tributary area to the sand filter must be stabilized before allowing stormwater runoff to enter it.

Maintenance Requirements

Maintenance and regular inspections must be conducted to ensure proper function of sand filters. Sand filters are subject to clogging by fine sediment, oil and grease, and other debris (e.g., trash and organic matter such as leaves).The following activities must be conducted to maintain a sand filter:

- Inspect pretreatment devices and the sand filter every six months during the first year of operation. Inspections should also occur immediately following a storm event to assess the filtration capacity of the sand filter. Once it is determined that the sand filter is performing as designed, the frequency of inspection may be reduced to once per year.
- If a sediment forebay is included, remove sediment buildup exceeding 50 percent of the sediment storage capacity, as indicated by the steel markers. Test removed sediments for toxic substance accumulation in compliance with current disposal requirements if visual or olfactory indications of pollution are noticed. If toxic substances are detected at concentrations exceeding thresholds of Title 22, Section 66261 of the California Code of Regulations, dispose of the sediment in

a hazardous waste landfill and investigate and mitigate the source of the contaminated sediments to the maximum extent possible.

- Inspect the sand filter to ensure that water percolates into filter media completely within the maximum drawdown time. If water is present in the sand filter more than 48 hours after a storm, the sand filter may be clogged. Maintenance activities triggered by a clogged filter include:
  - Check for debris/sediment accumulation, rake surface and remove sediment (if any), and evaluate potential sources of sediment and vegetative or other debris. If suspected upstream sources are outside of the Agency's jurisdiction, additional pretreatment may be necessary.
  - Determine if it is necessary to remove and replace the top layer of the sand filter bed to restore filtration capacity.
- Remove and dispose of trash and debris, as needed, but at least prior to the beginning of the wet season.
- Eliminate standing water to prevent vector breeding.
- Inspect the inlet structures for erosion and re-grade if necessary.
- Inspect the flow spreader and level and/or clean it so that flows are spread evenly over the sand filter bed.
- Inspect, and clean if necessary, the underdrain system. Inspect overflow devices for obstructions or debris, which should be removed immediately. Repair or replace damaged pipes upon discovery.

The Agencies require execution of a Maintenance Access Agreement to be recorded by the property owner for the on-going operation and maintenance of all privately-maintained stormwater treatment control measures. The property owner is responsible for compliance with the Maintenance Access Agreement. An example Maintenance Access Agreement is presented in Appendix G.

T-4: Vegetated Swales

Description

Vegetated swales are open, shallow channels with low-lying vegetation covering the side slopes and bottom that collect and slowly convey stormwater runoff to a downstream stormwater treatment control measure, storm drain system, or receiving water. Vegetated swales can provide limited pollutant removal through settling and filtration in the vegetation (usually grasses) lining the channels, reduce stormwater runoff volume through infiltration and evapotranspiration, and reduce the flow velocity. An effective vegetated swale achieves uniform sheet flow over and through a densely vegetated area for a period of several minutes.

An example schematic of a typical vegetated swale is presented in **Figure F-7**.

Use and Applicability

Vegetated swales do not meet the measures of equivalent effectiveness (Provision E.12.e.(f) of the Phase II Permit) that is required in order to use this stormwater treatment control measure as an alternative to bioretention. However, vegetated swales can be used to convey stormwater runoff to downstream stormwater treatment control measures or as pretreatment.

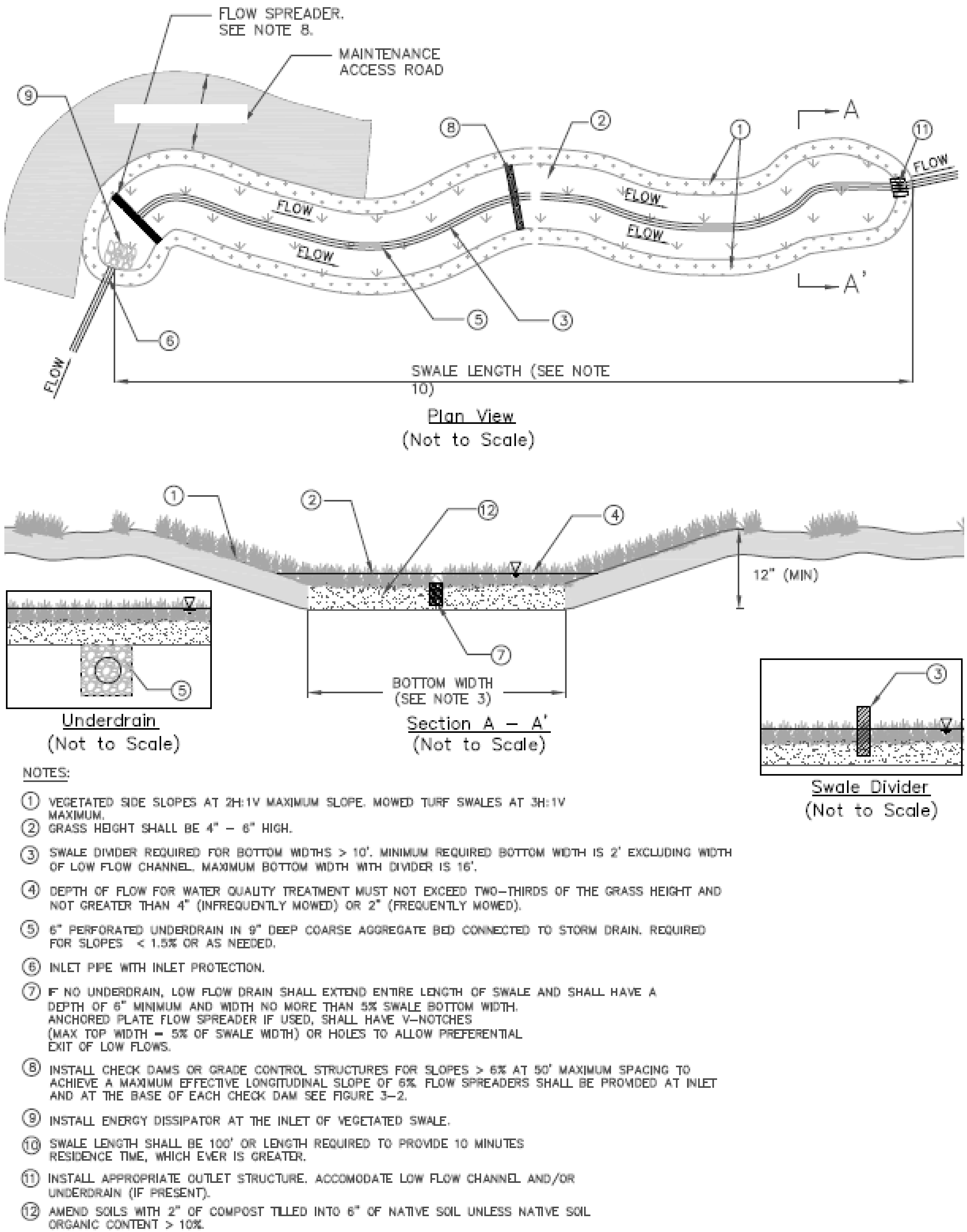


Figure F-7. Example Vegetated Swale Schematic

Design Specifications

The following sections provide design specifications for vegetated swales.

Geotechnical

Due to the potential to contaminate groundwater and/or soil, cause slope instability, and impact surrounding structures, a geotechnical investigation must be conducted during the site assessment to verify the site suitability for vegetated swales. It is important to understand how stormwater runoff will move through the soil (horizontally and vertically) and if there are any geological conditions that could inhibit the movement of water. Soil infiltration rates and the depth to the groundwater table must be evaluated to ensure that conditions are satisfactory for proper operation of vegetated swales. Vegetated swales cannot be located at sites with a slope greater than five percent to prevent channel erosion. For sites that have limited slop, ponding in the vegetated swale may occur. A Site Conditions Report summarizing the relevant findings from the geotechnical investigation must be submitted with the Project Stormwater Plan.

Setbacks

Applicable setbacks must be implemented when siting vegetated swales.

Flow Entrance and Energy Dissipation

The drainage management area(s) (DMA[s]) tributary to the vegetated swale must be graded to minimize erosion as stormwater runoff enters the swale or by providing energy dissipation devices at the inlet. An anchored plate flow spreader must be provided at the inlet to the vegetated swale. Equivalent methods for spreading flows evenly throughout the width the swale are acceptable. The specifications for the flow spreader are listed below:

- The top surface of the flow spreader plate must be level, projecting a minimum of two inches above the ground surface of the vegetated swale, or V-notched with notches six to ten inches on center and one to four inches deep (use shallower notches with closer spacing).
- The flow spreader plate must extend horizontally beyond the bottom width of the vegetated swale to prevent water from eroding the side slope. The horizontal extent should be such that the bank is protected for all flows up to the SDF_{adj} that will enter the swale.
- Flow spreader plates must be securely fixed in place.
- Flow spreader plates may be made of either concrete, stainless steel, or other durable material.
- Anchor posts are constructed of four inches square of concrete, tubular stainless steel, or other material resistant to decay.

The flow spreader will dissipate the entrance velocity and distribute flow uniformly across the whole vegetated swale. If check dams are used to reduce the longitudinal slope, a flow spreader must be installed at the toe of each vertical drop according to the specifications listed in the following Check Dams section below. If flow is to be introduced through curb cuts, the pavement should be placed slightly above the elevation of the vegetated areas. Curb cuts should be at least 12 inches wide to prevent clogging.

Drainage

Vegetated swales provide temporary stormwater runoff storage above ground as it conveys stormwater runoff to a downstream stormwater treatment control measure. Some stormwater runoff may infiltrate into the underlying soil.

Sizing

Step 1: Determine the SDF_{adj}

Vegetated swales are designed to capture and manage the SDF_{adj}, which is the difference between the SDF (Section 5.4) and the volume of stormwater runoff managed through site design measures (Section 5.5), for the tributary DMA(s).

Step 2: Calculate Bottom Width of Vegetated Swale

The width of the bottom of the vegetated swale is calculated using Manning's equation for open channel flow, as follows:

$$SDF_{adj} = \left(\frac{1.49}{n}\right) \times A \times R^{2/3} \times S^{0.5}$$

Where:

SDF_{adj} = stormwater design flow [ft^3/s];
n = Manning's roughness coefficient;
A = flow area [ft^2];
R = hydraulic radius [ft]; and
S = channel slope [ft/ft].

For shallow flow depths in vegetated swales, channel side slopes are ignored in the calculation of bottom width. Use the following equation (a simplified form of Manning's formula) to estimate the vegetated swale bottom width:

$$b = SDF_{adj} \times \left(\frac{1.49}{n_s}\right) \times y^{2/3} \times s^{0.5}$$

Where:

b = bottom width of vegetated swale [ft]
SDF_{adj} = stormwater design flow [ft^3/s];
n_s = Manning's roughness coefficient (use 0.2 for shallow conditions);
y = stormwater design flow depth [ft]; and
s = longitudinal slope (along direction of flow) [ft/ft].

Proceed to Step 3 if the calculated bottom width is between two and ten feet. A minimum two-foot bottom width is required. If the calculated bottom width is less than two feet, increase the width to two feet, and recalculate the design flow depth, y, using the same SDF_{adj} and n_s, but with b equal to two feet. The maximum allowable bottom width is ten feet. If the calculated bottom width exceeds ten feet, then one of the following steps is necessary to reduce the design bottom width:

- Increase the longitudinal slope (*s*) to a maximum of 6 feet in 100 feet (0.06 feet per foot);
- Increase the design flow depth (*y*) to a maximum of four inches; or
- Place a divider lengthwise along the vegetated swale bottom (see **Figure F-7**) at least three-quarters of the vegetated swale length (beginning at the inlet), without compromising the design flow depth and lateral slope requirements. The vegetated swale width can be increased to a maximum of 16 feet if a divider is provided.

<u>Step 3: Determine the Design Flow Velocity</u>

To calculate the design flow velocity through the vegetated swale, use the flow continuity equation:

$$v = \frac{SDF_{adj}}{A}$$

Where:

v = design flow velocity [ft/s];
SDF_{adj} = stormwater design flow [ft^3/s]; and
A = by + Zy^2 = Cross-sectional area of flow at design depth [ft^2] where Z = side slope length per unit height (e.g., Z = 3 if side slope is 3:1 H:V) .

If the design flow velocity exceeds 1 ft/s, go back to Step 2 and modify one or more of the design parameters (i.e., longitudinal slope, bottom width, or flow depth) to reduce the design flow velocity to 1 ft/s or less. If the design flow velocity is calculated to be less than 1 ft/s, proceed to Step 4. It is ideal to have the design velocity as low as possible to improve treatment effectiveness, reduce re-suspension of sediment, and reduce vegetated swale length requirements.

<u>Step 4: Calculate Length of Vegetated Swale</u>

Use the following equation to determine the length of the vegetated swale to achieve a hydraulic residence time of at least 10 minutes (600 seconds):

$$L = 60 \times t_{hr} \times v$$

Where:

L = minimum allowable swale length [ft];
t_{hr} = hydraulic residence time [min]; and
v = design flow velocity [ft/s].

The minimum length for a vegetated swale is 100 feet. If the calculated length for the vegetated swale is less than 100 feet, increase the length to a minimum of 100 feet and leaving the bottom width unchanged. If a larger vegetated swale can be fitted on the project site, consider using a greater length to increase the hydraulic residence time and improve pollutant removal. If the calculated length is too long for the project site or if it would cause layout problems (e.g., encroachment into shaded areas), proceed to Step 5 to further modify the layout. If the length of the vegetated swale can be accommodated on the project site, sizing of the vegetated swale is completed.

Step 5: Adjust Vegetated Swale Layout to Fit On-site

If the length of the vegetated swale calculated in Step 4 is too long for the project site, the length can be reduced (minimum of 100 feet) by increasing the bottom width up to a maximum of 16 feet, as long as the 10-minute retention time is maintained. However, the length cannot be increased in order to reduce the bottom width because Manning's depth-velocity-flow rate relationships will not be preserved. If the bottom width is increased to greater than ten feet, a low flow berm is needed to divide the vegetated swale cross-section in half to prevent channelization.

The length can be adjusted by calculating the top area of the vegetated swale and providing an equivalent top area with the adjusted dimensions.

Calculate the top area of the vegetated swale based on its length in Step 4:

$$A_{top} = \left(b_i + b_{slope}\right) \times L_i$$

Where:

A_{top} = top area at the design depth [ft^2];
b_i = bottom width calculated in Step 2 [ft];
b_{slope} = additional top width above the side slope for the design depth (for 3:1 H:V side slope and a 4-inch water depth, b_{slope} = 2 ft) [ft]; and
L_i = initial length calculated in Step 4 [ft].

Use the vegetated swale top area and a reduced swale length, L_f, to increase the bottom width using the following equation:

$$L_f = \frac{A_{top}}{(b_f + b_{slope})}$$

Where:

L_f = reduced vegetated swale length [ft];
A_{top} = top area at the design depth [ft^2];
b_f = increased bottom width [ft]; and
b_{slope} = additional top width above the side slope for the design depth (for 3:1 H:V side slope and a 4-inch water depth, b_{slope} = 2 ft) [ft].

Recalculate the design flow velocity according to Step 3 using the revised cross-sectional area based on the increased bottom width. Revise the design as necessary if the design flow velocity exceeds 1 ft/s. If necessary, recalculate to ensure that the 10-minute hydraulic residence time is maintained.

Step 6: Design Other Vegetated Swale Features

Other sizing specifications for vegetated swales include the following:

- The water depth in the vegetated swale must not exceed four inches (or two-thirds of the expected vegetation height) except for frequently mowed turf swales. For mowed turf swales, the water depth must not exceed two inches. Once design specifications have been determined, the resulting flow depth for the design flow is checked. If the depth restriction is exceeded, swale parameters (e.g., longitudinal slope, width) must be adjusted to reduce the flow depth. Overall depth from the top of the side walls to the swale bottom shall be at least 12 inches.
- In general, trapezoidal channel shape is assumed for sizing calculations, but a more naturalistic channel cross-section is preferred.
- Vegetated swale length can be increased by meandering the swale. Gradual meandering bends in the swale are desirable for aesthetic purposes and to promote slower flow.
- The minimum width of the vegetated swale bottom is two feet to allow for ease of mowing. The maximum width of the vegetated swale bottom is ten feet unless a dividing berm is provided. If a dividing berm is provided, the maximum width of the vegetated swale bottom can be 16 feet.
- The longitudinal slope (along the direction of flow) must be between 1 and 6 percent. If the longitudinal slope is less than 1.5 percent and the soils are poorly drained (e.g., silts and clays), then an underdrain must be installed. If the longitudinal slope is greater than 6 percent, check dams with vertical drops of 12 inches or less must be provided to achieve a bottom slope of 6 percent or less between the drop structures.

- The lateral slope (horizontal to the direction of flow) is zero (flat) to discourage channelization.
- A side slope of 2:1 (H:V) is acceptable, but milder slopes are necessary if turf is used (maximum 3:1 H:V).
- A low flow drain must be provided for dry weather flows extending the entire length of the swale. The drain must have a minimum depth of six inches and a width no more than five percent of the calculated bottom swale width. The width of the drain is in addition to the required bottom width. If an anchored plate is used for flow spreading at the swale inlet, the plate wall must have V-notches (maximum top width = five percent of swale width) or holes to allow low flow into the drain. If an underdrain is installed, the vegetated swale does not require a low flow drain.

Check Dams

The effectiveness of vegetated swales may be enhanced by adding check dams at approximately 50 foot increments along the length. Check dams maximize retention time within the vegetated swale, decrease flow velocity, and promote particulate settling. However, check dams may not be appropriate if prolonged ponding occurs.

If check dams are required, they can be designed using riprap, earthen berms, or removal stop logs. Check dams must be placed to achieve the desired slope (less than 6 percent) and desired velocity (less than 1 ft/s for the SDF_{adj}) at a maximum of 50 feet apart. If riprap is used, the material should consist of well-graded stone consisting of a mixture of rock sizes. The following is an example of an acceptable gradation:

Particle Size	% Passing by Weight
24 in	100%
15 in	75%
9 in	50%
4 in	10%

Swale Divider

- If a swale divider is used, the divider must be constructed of a firm material (e.g., concrete, compacted soil seeded with grass) that will resist weathering and not erode. Use of treated wood is prohibited. Selection of divider material must take into account maintenance activities, such as mowing.
- The divider must have a minimum height of one inch greater than the design depth.
- Earthen berms must be no steeper than 2:1(H:V).
- Material other than earth must be embedded to a depth sufficient to be stable.

Underlying Base

The underlying soil for a vegetated swale must be amended with two inches of well-rotted compost, unless the organic content is already greater than 10 percent. The compost must be mixed into the underlying soils to a depth of six inches to prevent soil layering and washout of compost. The compost must contain no sawdust, green or under-composted material, unsterilized manure, or any other toxic or harmful substance.

Underdrain

If necessary, an underdrain may be included in the design of a vegetated swale to convey stormwater runoff that has been filtered through the soil media, but not infiltrated, to another stormwater treatment control measure, storm drain system, or receiving water. The underdrain must have a mainline diameter of six inches using slotted PVC SDR 26 or C900. Slotted PVC allows for pressure water cleaning and root cutting, if necessary. The slotted pipe should have two to four rows of slots cut perpendicular to the axis of the pipe or at right angles to the pitch of corrugations. Slots should be 0.04 to 0.1 inches wide with a length of 1 to 1.25 inches. Slots should be longitudinally-spaced such that the pipe has a minimum of one square inch opening per lineal foot and should face down. Underdrains should be sloped at a minimum of 0.5 percent in order to drain freely to an approved location.

The underdrain must be placed in a gravel envelope (Class 2 Permeable Material per Caltrans Spec. 68-1.025) that measures three feet wide and six inches deep. The underdrain is elevated from the bottom of the vegetated swale by six inches within the gravel envelope. The top and sides of the underdrain pipe should be covered with gravel to a minimum depth of 12 inches. The underdrain and gravel envelope must be covered with a hydraulic restriction layer to prevent clogging. The following aggregate can be used for the gravel envelope:

Particle Size (ASTM D422)	% Passing by Weight
¾ inch	100%
¼ inch	30-60%
#8	20-50%
#50	3-12%
#200	0-1%

Clean-out risers with diameters equal to the underdrain pipe must be placed at the terminal ends of the underdrain and can be incorporated into the flow spreader and outlet structure to minimize maintenance obstacles in the vegetated swale. Intermediate clean-out risers may also be placed in the check dams or grade control structures. The clean-out risers shall be capped with a lockable screw cap.

Vegetation

The vegetated swale must be vegetated with a mix of erosion-resistant, climate-appropriate plants that effectively bind the soil and require less maintenance, including chemical treatments. Vegetated swales can provide some stormwater runoff treatment through maximization of water contact with vegetation and the soil surface. Vegetation must meet the following specifications:

- Above the design elevation, a typical climate-appropriate lawn mix or landscape plants can be used provided they do not shade the vegetated swale.
- Vegetated swales must be located away from large trees that may drop leaves or needles. Excessive tree debris may smother the grass or impede stormwater runoff flow through the swale.
- Climate-appropriate grasses must be specified to minimize irrigation requirements. Irrigation may be required if seeds are planted in spring or summer.
- Vegetative cover should be at least four inches in height, although six inches is preferred.

A sample list of suitable vegetation species is included in Appendix H. Prior to installation, a landscape architect must certify that all proposed vegetation is appropriate for the project site. Stormwater runoff must be diverted around the vegetated swale during the period of vegetation establishment.

Irrigation System

Provide an irrigation system to maintain the viability of vegetation, if necessary. If possible, the general landscape irrigation system should be incorporate the vegetated swales. The irrigation system must be designed to local code or ordinance specifications and must comply with the requirements in Section 4. Supplemental irrigation may be required for the establishment period even if it is not needed later.

Restricted Construction Materials

Use of pressure-treated wood or galvanized metal at or around the vegetated swale is prohibited.

Construction Considerations

Areas to be used for vegetated swales should be clearly marked before site work begins to avoid soil disturbance and compaction during construction. No vehicular traffic, except that specifically used to construct the vegetated swale, should be allowed within 10 feet of the swale areas. Vegetated swales can be integrated into roadside buffers or parking lot landscaping. For parking lots, if tire curbs are provided and parking stalls are shortened, cars may overhang the vegetated swale.

As part of the site planning process, the areas designated for vegetated swales must be identified. The area identified for vegetated swales must be protected from construction-related sediment loads. During construction activities if possible, divert all flows around the areas intended for the vegetated swales. Sediment control measures should also be implemented to prevent sediment from impacting the areas identified for vegetated swales. After construction is completed, the entire tributary area to the vegetated swales must be stabilized before allowing stormwater runoff to enter it.

Maintenance Requirements

Maintenance and regular inspections must be conducted to ensure proper function of vegetated swales. The following activities must be conducted to maintain vegetated swales:

- Inspect vegetated swales for erosion or damage to vegetation after every storm greater than 0.50 inches. Vegetated swales should be checked for debris and litter and areas of sediment accumulation.
- Remove sediment and debris from the flow spreader if it is blocking flows. Repair splash pads, as needed, to prevent erosion. Check and re-level the flow spreader if necessary.
- Remove sediment if vegetation growth is inhibited in more than 10 percent of the swale or if sediment is blocking even distribution and entry of stormwater runoff. Re-plant and/or re-seed vegetation, as needed, following sediment removal activities to re-establish vegetation.
- Stabilize slopes with appropriate erosion control measures if the underlying soils are exposed or erosion channels are forming.
- Remove trash and debris, as needed, but at least annually prior to the beginning of the wet season.
- Inspect vegetation for health and density to ensure that it is providing sufficient treatment and protecting the underlying soils from erosion. As needed, conduct the following maintenance activities for the vegetation:
  - Replenish mulch to ensure survival of vegetation.
  - Prune and/or remove vegetation, large shrubs, or trees that interfere with the operation of the vegetated swale.
  - Mow grass to four to six inches and remove grass clippings.
  - Remove fallen leaves and debris from deciduous plant foliage.
  - Remove invasive, poisonous, nuisance, and noxious vegetation and replace with climate-appropriate vegetation
  - Remove dead vegetation if greater than 10 percent of area coverage or when swale function is impaired. Replace and establish vegetation before the wet season to maintain cover density and control erosion where soils

are exposed. It may be necessary to re-grade eroded areas prior to replacing vegetation.

- Eliminate standing water to prevent vector breeding. If standing water is observed more than 72 hours after a storm event, it may be necessary to till the underlying soils and re-vegetate.
- Inspect, and repair if necessary, check dams that are causing altered water flow and/or channelization. Remove obstructions as needed.
- Inspect, and clean if necessary, the underdrain pipe. Repair or replace damaged pipes upon discovery.

The Agencies require execution of a Maintenance Access agreement to be recorded by the property owner for the on-going operation and maintenance of all privately-maintained stormwater treatment control measures. The property owner is responsible for compliance with the Maintenance Access Agreement. An example Maintenance Access Agreement is presented in Appendix G.

T-5: Proprietary Stormwater Treatment Control Measures

Introduction

The 2015 Post-Construction Stormwater Standards Manual provides information for selecting and designing the more common stormwater treatment control measures for projects. Stormwater treatment control measures included in this appendix are non-proprietary (public domain) designs that have been reviewed and evaluated by the Agencies and determined to be generally acceptable.

Proprietary devices are commercial products that typically aim at providing stormwater treatment in space-limited applications, often using patented innovative technologies. The most commonly encountered classes of proprietary stormwater treatment control measures include hydrodynamic separation, catch basin insert technologies, cartridge filter-type controls, and proprietary biotreatment devices.

Hydrodynamic separation devices (alternatively, swirl concentrators) are devices that remove trash, debris, and coarse sediment from incoming flows using screening, gravity settling, and centrifugal forces generated by forcing the influent into a circular motion. By having the water move in a circular fashion, rather than a straight line, it is possible to obtain significant removal of suspended sediments and attached pollutants with less space as compared to wet vaults and other settling devices. Hydrodynamic separation has been adapted for stormwater treatment by several manufacturers and is currently used to remove trash, debris, and other coarse solids down to sand-sized particles. Several types of hydrodynamic separation devices are also designed to remove floating oils and grease using sorbent media.

Catch basin inserts are manufactured filters or fabric placed in a drop inlet to remove sediment and debris and may include sorbent media to remove floating oils and grease. Most types of catch basin inserts fall into one of three configurations: socks, boxes, and trays. Sock-type filters, which are intended for vertical (drop) inlets, are typically constructed of a fabric (e.g., polypropylene) that may be attached to a frame or the grate of the inlet. Boxes, which are typically constructed of plastic or wire mesh, include a polypropylene “bag”, shaped as a box, that is placed in the wire mesh to allow for settling and filtration of stormwater runoff. Trays are designed to hold different types of media (e.g., polypropylene, porous polymer, treated cellulose, activated carbon) to treat stormwater runoff. Catch basin inserts are an easy, inexpensive retrofitting option because drain inlets are already a component of most storm drain systems. Inserts are usually only suitable for mitigating relatively small tributary areas (less than one acre) because they are limited by treatment capacity and influent flow rate.

Cartridge filter-type devices typically consist of a series of vertical filters contained in a vault or catch basin that provide treatment through filtration and sedimentation. The vault may be divided into multiple chambers where the first chamber acts as a pre-settling basin for removal of coarse sediment while another chamber acts as the filter bay and houses the filter cartridges. The performance and capacity of a cartridge filter installation depends on the properties of the media contained in the cartridges.

Cartridge filter manufacturers often provide an array of media types each with varying properties, targeting various pollutants and a range of particle sizes. Commonly used media include media that target solids, such as perlite, and media that target both dissolved and non-dissolved constituents, such as compost leaf media, zeolite, and iron-infused polymers. Manufacturers try to distinguish their products through innovative designs that aim at providing self-cleaning and draining, uniformly loaded, and clog resistant cartridges that functional properly over a wide range of hydraulic loadings and pollutant concentrations.

Proprietary biotreatment devices are devices that are manufactured to mimic natural systems such as wetlands by incorporating plants, soil, and microbes engineered to provide treatment at higher flow rates or higher volumes and with smaller footprints than their natural counterparts. Influent flows are typically filtered through natural media (e.g., mulch, compost, soil, plants, microbes) and either infiltrated or collected by an underdrain and delivered to the storm drain system. Tributary areas for biotreatment devices tend to be limited to 0.5 to 1.0 acres.

The vendors of the various proprietary stormwater treatment control measures provide detailed documentation for device selection, sizing, and maintenance requirements. Tributary area sizes are limited to the capacities of the largest available model. The latest manufacturer supplied documentation must be used for sizing and selection of all proprietary devices.

Proprietary stormwater treatment control measure vendors are constantly updating and expanding their product lines, so refer to the latest design guidance from the vendors. General guidelines on the performance, sizing, and operation and maintenance of proprietary devices are provided in the following sections.

Use and Applicability

In order to provide a rationale and basis for approval of proprietary treatment control measures, the Agencies have elected to recognize, as approved for general and pilot use, those proprietary treatment control measures that are approved for general, conditional, or pilot use by other selected major stormwater programs that have established and are actively conducting a comprehensive testing protocol and approval process. Currently, the Agencies recognize the lists of proprietary treatment control measures approved for general, condition, and pilot use from the following stormwater programs:

- Sacramento Stormwater Quality Partnership (http://www.beriverfriendly.net/newdevelopment/propstormwatertreatdevice)
- State of Washington Department of Ecology Stormwater Program (http://www.ecy.wa.gov/programs/wq/stormwater/newtech/technologies.html)

The Agencies may recognize lists from other stormwater programs in the future and will update this list accordingly.

The Phase II Permit (Provision E.12.e.(f)) identifies bioretention as the preferred stormwater treatment control measure unless (1) it is determined to be infeasible and an alternative treatment control measure that is equivalent to bioretention is proposed and demonstrated (Provision E.12.e.(g)), or (2) a specific exemption applies (Provision E.12.e.(i)). Proprietary devices may be proposed as an alternative to bioretention if it meets all of the following measures of equivalent effectiveness:

- Equal or greater amount of stormwater runoff infiltrated or evapotranspired;
- Equal or lower pollutant concentrations in stormwater runoff that is discharged after biotreatment;
- Equal or greater protection against shock loadings and spills; and
- Equal or greater accessibility and ease of inspection and maintenance.

In general, proprietary treatment control measures may not be able to meet all measures of equivalent effectiveness listed above in order to be accepted as an alternative to bioretention. However, proprietary treatment control measures may be used in combination with other stormwater treatment control measures (e.g., pretreatment) to reduce sediment and pollutant loads.

Expected Performance

For hydrodynamic devices, it has been stated with respect to combined sewer overflows that the practical lower limit of hydrodynamic separation is a particle with a settling velocity of 12 to 16.5 ft/hr (0.10 to 0.14 cm/s). As such, the focus for hydrodynamic separation in combined sewer overflows has been with settleable solids generally 200 μm and larger, given the presence of the lighter organic solids. For inorganic sediment, the above settling velocity range represents a particle diameter of 50 to 100 μm. Thus, hydrodynamic separation devices are effective for removal of course sediment, trash, and debris and useful for pretreatment in combination with other types of stormwater treatment control measures that target smaller particle sizes.

Because there is a wide range of catch basin insert configurations, it is not possible to generalize the expected performance. Inserts are primarily used for catching coarse sediments and floatable trash and are effective for pretreatment in combination with other types of stormwater treatment control measures. Trash and large objects can greatly reduce the effectiveness of catch basin inserts with respect to sediment and hydrocarbon capture. Frequent maintenance and the use of screens and grates to keep trash out may decrease the likelihood of clogging and prevent obstruction and bypass of incoming flows.

Cartridge filters are proven to provide efficient removals for both dissolved and non-dissolved pollutants. However, cartridge filters are less adept at handling high flow rates when compared to catch basin inserts and hydrodynamic devices due to the enhanced treatment provided through the filtration mechanism.

Because proprietary biotreatment devices are relatively new compared to the other types of proprietary treatment devices discussed in this fact sheet, there are fewer third party studies on proprietary biotreatment devices. The available performance information is mostly vendor-supplied. According to the vendors, like their natural counterparts, proprietary biotreatment devices are highly efficient at mitigating dissolved metals, nutrients, and suspended solids.

Sizing

Hydrodynamic devices, catch basin inserts, and cartridge filters are flow-based stormwater treatment control measures, but can be sized to capture and treat a design stormwater runoff volume with additional facilities to manage stormwater runoff flow. Proprietary biotreatment devices on the other hand include both volume-based and flow-based stormwater treatment control measures. Volume-based proprietary devices should be sized to capture and treat the design stormwater runoff volume if used as a standalone stormwater treatment control measure.

Auxiliary components of proprietary devices such as sorbent media, screens, baffles, and sumps are selected based on site-specific conditions such as the expected loading and the desired frequency of maintenance. Sizing of proprietary devices is reduced to a simple process whereby a model can simply be selected from a table or a chart based on a few known quantities (e.g., tributary area, location, design flow rate, design volume). Some manufacturers can size devices for potential clients or offer calculators on their websites that simplify the design process even further and lessens the possibility of using obsolete design information. For the latest sizing guidelines, refer to the manufacturer’s website.

Operation and Maintenance

The Agencies require execution of a Maintenance Access agreement to be recorded by the property owner for the on-going operation and maintenance of all privately-maintained stormwater treatment control measures, including proprietary treatment control measures. The property owner is responsible for compliance with the Maintenance Access Agreement. An example Maintenance Access Agreement is presented in Appendix G.

Hydrodynamic Separation Devices

Hydrodynamic separators do not have moving parts and are not maintenance intensive. However, maintenance is important to ensure that the device operates as efficiently as possible. Proper maintenance involves frequent inspections throughout the first year of installation, especially after major storm events. These systems are considered full when the sediment level is within one foot from the top of the unit, at which point it must be cleaned out. Removal of sediment can be performed with a sump vacuum or vactor truck. Some hydrodynamic separator devices may contribute to mosquito breeding if they do not fully drain stormwater runoff between storm events. Refer to manufacturer's guidelines for inspection and maintenance activities.

Catch Basin Inserts

Catch basin inserts can be maintenance-intensive because of their susceptibility for accumulating trash and debris. Regular maintenance activities include the clean-up and removal of accumulated trash and sediment while major maintenance activities include replacing filter media (if expended) and/or repairing/replacing fabrics. Refer to manufacturer's guidelines for inspection and maintenance activities.

Cartridge Filters

For cartridge filters, maintenance activities include periodically removing trash, debris, and sediment from the vault floor, typically twice per year depending on the accumulation rate, using a sump vacuum or vactor truck. The cartridges may need to be replaced when they become saturated, which will occur approximately every other year depending on the pollutant accumulation rate. The manufacturers of these devices typically provide contract operation and maintenance services.

All stormwater vaults that contain standing water can become a breeding area for vectors. Manufacturers have developed systems, such as a perforated pipe installed in the bottom of the vault that is encased in a filter sock to prevent clogging, to completely drain the vault.

Biotreatment Devices

Maintenance of biotreatment devices can be provided by the manufacturer and typically consists of routine inspection and hand removal of accumulated trash and debris. Vactor trucks or mechanical maintenance activities are not needed for biotreatment devices.

HM-1: Extended Detention Basin

Description

Extended detention basins are permanent basins formed by excavation and/or construction of embankments to temporarily detain stormwater runoff to allow for settling of sediment particles before the stormwater runoff is discharged. An extended detention basin reduces peak stormwater runoff flow rates and provides stormwater runoff treatment and hydromodification control. Extended detention basins are designed to drain completely between storm events over a specified period of time.

Stormwater runoff enters a sediment forebay where coarse solids are removed prior to flowing into the main cell of the basin where finer sediment and associated pollutants settle as stormwater is detained and slowly released through a controlled outlet structure. The slopes, bottom, and forebay of extended detention basins are typically vegetated. During storm events that exceed the design capacity, stormwater runoff will pass through the extended detention basin and discharge over a primary overflow outlet untreated, or during extreme events, over a spillway.

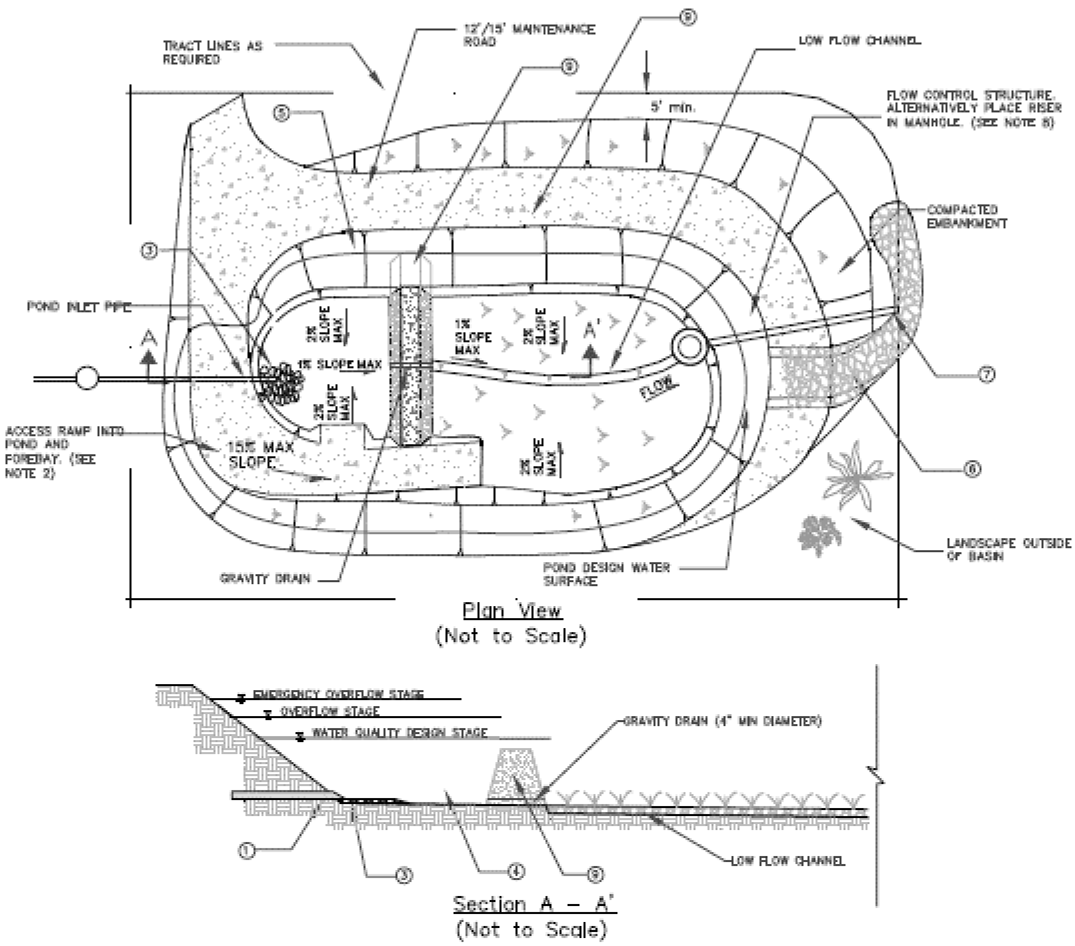
An example schematic of a typical extended detention basin is presented in **Figure F-8**.

Use and Applicability

The Phase II Permit (Provision E.12.e.(f)) identifies bioretention as the standard stormwater treatment control measure unless (1) it is determined to be infeasible and an alternative treatment control measure that is equivalent to bioretention is proposed and demonstrated (Provision E.12.e.(g)), or (2) a specific exemption applies (Provision E.12.e.(i)). An alternative to bioretention can be proposed if it meets <u>all</u> of the following measures of equivalent effectiveness:

- Equal or greater amount of stormwater runoff infiltrated or evapotranspired;
- Equal or lower pollutant concentrations in stormwater runoff that is discharged after biotreatment;
- Equal or greater protection against shock loadings and spills; and
- Equal or greater accessibility and ease of inspection and maintenance.

An extended detention basin is typically used to meet hydromodification and flood control requirements.



NOTES:

① INLET PIPE SHALL BE DESIGNED AND LOCATED SO THAT NON–EROSIVE VELOCITIES OCCUR IN THE FOREBAY

② MAINTENANCE RAMP SHOULD BE PAVED. SLOPE SHOULD NOT EXCEED 12%. MAINTENANCE RAMP SHOULD PROVIDE ACCESS TO BOTH THE FOREBAY AND MAIN BASIN.

③ RIP RAP APRON OR OTHER INLET ENERGY DISSIPATION SHALL BE PROVIDED SUCH THAT VELOCITIES IN THE FOREBAY ARE < 4 FT/S.

④ SEDIMENT FOREBAY SHOULD BE SIZED TO PROVIDE 25% OF THE TOTAL BASIN VOLUME.

⑤ SIDE SLOPES SHOULD NOT EXCEED 3:1 UNLESS APPROVED BY AN ENGINEER. SIDE SLOPES SHALL NOT EXCEED 2:1 WITHOUT A SUPPORTING GEOTECHNICAL REPORT.

⑥ EMERGENCY SPILLWAY MUST BE SIZED TO PASS CAPITAL DEVELOPMENT PEAK FLOW FOR ON–LINE BASINS, AND WATER QUALITY DESIGN FLOW FOR OFF–LINE BASINS.

⑦ OUTLET PIPE. ENERGY DISSIPATION SHALL BE PROVIDED UNLESS DISCHARGE IS TO PIPE OR HARDENED CHANNEL.

⑧ OUTLET STRUCTURE SHOULD BE SIZED TO DRAIN WATER QUALITY VOLUME IN 36 – 48 HOURS. ALTERNATIVELY PLACE RISER STRUCTURE IN A MANHOLE

⑨ INSTALL EARTHEN BERM OR EQUIVALENT. TOP OF BERM SHALL BE 2" MINIMUM BELOW DESIGN WATER QUALITY STAGE. BERM SHALL BE KEYED INTO EMBANKMENT A MINIMUM OF 1' ON BOTH SIDES.

Figure F-8. Example Extended Detention Basin Schematic

Design Specifications

The following sections provide design specifications for extended detention basins.

Geotechnical

A geotechnical investigation must be conducted during the site assessment process to verify site conditions for an extended detention basin. It is critical to understand how stormwater runoff will move through the soil (horizontally and vertically) and if there are any geologic conditions that may impact the movement of water. Soil infiltration rates and the depth to the groundwater table must be evaluated to ensure that conditions are satisfactory for proper operation of an extended detention basin. Extended detention basins can be used with almost all soils and geology with design adjustments for rapidly draining soils. If rapidly draining soils are present, extended detention basins must be designed by a licensed geotechnical engineer to include lower permeability soils in the subgrade to prevent rapid, untreated infiltration. Extended detention basins are typically located on sites with a slope no greater than 15 percent. A Site Conditions Report summarizing the relevant findings from the geotechnical investigation must be submitted with the Project Stormwater Plan.

Setbacks

Applicable setbacks must be implemented when siting an extended detention basin.

Pretreatment

Pretreatment, which refers to design features that provide settling of large particles before stormwater runoff enters a stormwater treatment control measure, is important to ensure proper operation of an extended detention basin and reduce the long-term maintenance burden. Pretreatment (e.g., vegetated swales, proprietary devices) may be provided to reduce the sediment load entering an extended detention basin in order to prevent sediment buildup that will reduce the capacity of the detention basin.

If a sediment forebay is used for pretreatment to remove coarse solids, it may be constructed with an internal berm made out of earthen embankment material, grouted riprap, or other structurally-sound material. The sediment forebay must be designed as follows:

- All inlets to the extended detention basin must enter the sediment forebay first.
- The sediment forebay must have a minimum volume equal to 25 percent of the total extended detention basin volume.
- Permanent steel post depth markers must be placed in the sediment forebay to identify the settled sediment removal limits at 50 and 100 percent of the sediment storage depth.

- The longitudinal slope (direction of flow) in the sediment forebay will be one percent.
- A gravity drain outlet from the sediment forebay (minimum four-inch diameter) must extend the entire width of the internal berm.
- The sediment forebay outlet must be off-set from the inflow flow line to prevent short-circuiting.

Flow Entrance and Energy Dissipation

The drainage management area(s) (DMA[s]) tributary to the extended detention basin must be graded to minimize erosion as stormwater runoff enters the basin or by providing energy dissipation devices at the inlet. Piped entrances must include rock, splash blocks, or other erosion controls at the entrance to dissipate energy and disperse flows. If a sediment forebay is included in the design, the energy dissipation devices must be installed at the inlet to the sediment forebay. Flow velocities into the sediment forebay must be 4 ft/s or less.

Drainage

Extended detention basins provide stormwater runoff storage above ground. Because extended detention basins are used primarily to meet hydromodification and flood control requirements, the basin must completely drain within 72 hours in order to allow the basin to receive stormwater runoff from subsequent storm events and prevent vector breeding.

Sizing

Step 1: Determine the Stormwater Runoff Volume

If the extended detention basin is demonstrated and approved as an alternative to bioretention, it must be designed to capture and manage the SDV_{adj}, which is the difference between the SDV (Section 5.2) and the volume of stormwater runoff managed through site design measures (Section 5.5), for the tributary DMA(s).

If the extended detention basin is used for hydromodification management, it must be designed to capture, detain, and discharge the stormwater runoff volume determined from hydrologic routing modeling (Section 7.2) to mitigate the peak stormwater runoff flow rate.

Step 2: Design Extended Detention Basin Dimensions

The dimensions of the extended detention basin must meet the following specifications:

- The total extended detention basin volume must be the volume of stormwater runoff (Step 1) that must be managed plus an additional five percent to allow for total suspended solids (TSS) accumulation. The extended detention basin must also have a minimum freeboard of one foot above the maximum water surface elevation over the spillway.

- To improve TSS removal, the length-to-width ratio at half basin depth must be a minimum of 1.5:1.
- The cross-sectional geometry across the width of the extended detention basin should be approximately trapezoidal with a maximum interior side slope of 3:1 (H:V) unless otherwise permitted by the Agency.
- Pond walls may be vertical retaining walls provided: (a) they are constructed of reinforced concrete; (b) a fence is provided along the top of the wall (see Fencing below) or further back; and (c) the design is stamped by a licensed civil engineer and approved by the Agency.
- A low flow channel, which is a narrow, shallow trench filled with pea gravel (or equivalent) that runs the length of the extended detention basin, must be provided to drain the basin of dry weather flows. Lining the low flow channel with concrete is recommended to prevent erosion. The low flow channel must have a depth of six inches and a width of one foot and tie into the outlet structure.
- The longitudinal slope (direction of flow) in the main basin may range from zero to one percent. The bottom of the extended detention basin must have a two percent slope toward the low flow channel.

Outlet Structure

An extended detention basin must drain within 72 hours after a storm event. The outlet structure is designed to release the bottom 50 percent of the detention volume (half-full to empty) over 24 to 36 hours and the top 50 percent (full to half-full) in 48 to 72 hours. Detention of low flows, which account for the majority of incoming flows, for longer periods enhances stormwater runoff treatment.

A trash rack or gravel pack around perforated risers may be provided to protect outlet orifices from clogging. Trash racks are better suited for use with perforated vertical plates for outlet control and allow easier access to outlet orifices for purposes of inspection and cleaning. Trash racks must be sized to prevent clogging of the primary outlet without restricting the hydraulic capacity of the outlet control orifices.

The two options that can be used for the outlet structure are:

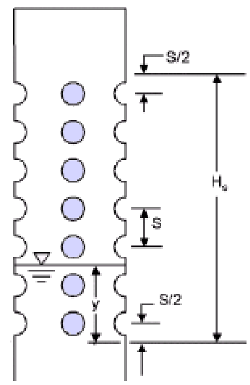
- Uniformly perforated riser structures; and
- Multiple orifice structures (orifice plate).

The primary overflow (typically a riser pipe connected to the outlet works) must be sized to pass the stormwater runoff volumes exceeding the design stormwater runoff volume. The primary overflow is intended to protect against overtopping or breaching of the extended detention basin embankment. Seepage collars may need to be installed on outlet pipes to prevent seepage through embankments. The outlet structure can be placed in the extended detention basin with a debris screen (see **Figure F-9**) or housed in a standard manhole (see **Figure F-10**).

Uniformly Perforated Riser Outlet Sizing Methodology (**Figure F-9**)

The following characteristics influence the perforated riser outlet sizing:

- Shape of the extended detention basin (i.e., trapezoidal);
- Depth and volume of the extended detention basin;
- Elevation and depth of first row of holes;
- Elevation and depth of last row of holes;
- Size of holes;
- Number of rows and number of holes per row; and
- Desired drawdown time.



The rate of discharge from a perforated riser structure with uniform holes at equal spacing can be calculated using the following:

$$Q = C_p \times \frac{2 \times A_p}{3 \times H_s} \times \sqrt{2 \times g} \times H^{3/2}$$

Where:

Q = riser discharge rate [ft^3/s];
C_p = discharge coefficient for perforations (use 0.61);
A_p = cross-sectional area of all the holes [ft^2];
H_s = distance from s/2 below the lowest row of holes to s/2 above the top row of holes (McEnroe 1988) [ft];
s = Center to center vertical spacing between perforations [ft];
g = Acceleration due to gravity (use 32.2 ft/s); and
H = Effective head on the orifice (measured from the center of orifice to water surface) [ft].

For the iterative computations needed to size the holes in the riser and determine the riser height, a simplified version of the equation above may be used, as shown below:

$$Q = k \times H^{3/2}$$

Where:

$$k = C_p \times \frac{2 \times A_p}{3 \times H_s} \times \sqrt{2 \times g}$$

Uniformly perforated riser designs are defined by the depth or elevation of the first row of perforations, the length of the perforated section of pipe, and the size or diameter of each perforation.

Multiple Orifice (Non-Uniform Outlet) Sizing Methodology (**Figure F-10**)

The following characteristics influence the multiple orifice outlet sizing:

- Shape of the extended detention basin (i.e., trapezoidal);
- Depth and volume of the extended detention basin;
- Elevation of each orifice; and
- Desired drawdown time.

The rate of discharge from a single orifice can be calculated using the following equation:

$$Q = C \times A \times (2 \times g \times H)^{0.5}$$

Where:

Q = orifice discharge rate [ft^3/s];
C = discharge coefficient;
A = cross-sectional area of orifice or pipe [ft^2];
g = acceleration due to gravity (use 32.2 ft/s);
H = effective head on the orifice (measured from the center of orifice to water surface) [ft].

Multiple orifice designs are defined by the depth (or elevation) and the size (or diameter) of each orifice.

Overflow Structure and Spillway

An overflow spillway or overflow riser must be provided. If an overflow spillway potentially discharges to a steep slope, an overflow riser and a spillway must be provided. The overflow device must be designed to pass the maximum storm size diverted to the extended detention basin, with a minimum one-foot freeboard, directly to an approved discharge location (e.g., another stormwater treatment control measure, storm drain system, receiving water).

The emergency overflow spillway must be constructed of grouted riprap and designed to withstand the energy of the spillway flows (**Figure F-11**). Spillways must meet the California Department of Water Resources, Division of Safety of Dams *Guidelines for the Design and Construction of Small Embankment Dams* (www.water.ca.gov/damsafety/docs/GuidelinesSmallDams.pdf).

Embankments

Embankments are earthen slopes or berms used to detain or redirect the flow of water. For extended detention basins, the embankments must be designed with the following specifications:

- All earthworks must be conducted in accordance with the Agency's Standard Specifications.
- The interior side slopes up to the overflow water surface must be no greater than 3:1 (H:V) unless stabilization has been approved by a licensed geotechnical engineer.
- The exterior side slopes must be no greater than 2:1 (H:V) unless stabilization has been approved by a licensed geotechnical engineer.
- The minimum top width of all berm embankments must be 20 feet, unless otherwise approved by the Agency.
- Berm embankments must be constructed on consolidated underlying soils or adequately compacted and stable fill soils approved by a licensed geotechnical engineer. Soils must be free of loose surface soil materials, roots, and other organic debris.
- Berm embankments must be constructed of compacted soil (95 percent minimum dry density, Modified Proctor method per ASTM D1557) and placed in six inch lifts.
- Berm embankments greater than 4 feet in height must be constructed by excavating a key equal to 50 percent of the berm embankment cross-sectional height and width. This requirement may be waived if specifically recommended by a licensed geotechnical engineer.
- Low growing, climate-appropriate grasses must be planted on the exterior embankment slopes.

Vegetation and Landscaping

- A thick mat of climate-appropriate grass must be established on the extended detention basin floor and embankment side slopes following construction. Grasses help prevent erosion and increase evapotranspiration. Additional active growing vegetation helps break up surface crusts that accumulate from sedimentation of fine particulates. Note that grass may need to be irrigated during the establishment period.
- Landscaping outside of the extended detention basin, but within the easement/right-of-way, may be included as long as it does not hinder maintenance access and operations.
- Trees or shrubs must not be planted within 10 feet of inlet or outlet pipes or manmade drainage structures such as spillways or earthen embankments.

Species with roots that seek water (e.g., willow, poplar) must not be planted within 50 feet of pipes or manmade drainage structures. Weeping willow (*Salix babylonica*) may not be planted in or near extended detention basins.

- Plant species that are not climate-appropriate are not permitted. A sample list of suitable vegetation species is included in Appendix H. Prior to installation, a landscape architect must certify that all proposed vegetation is appropriate for the project site.

Fencing

Safety is provided by fencing of the stormwater treatment control measure. Fences shall be designed and constructed in accordance with Agency standards and must be located at or above the top of overflow structure elevation.

Maintenance Access

Maintenance access must be provided to the structures associated with the extended detention basin (e.g., pretreatment, inlet, outlet, overflow structure) if it is publicly-maintained. Manhole and catch basin lids must be in or at the edge of the access road. An access ramp to the extended detention basin bottom is required to facilitate the entry of sediment removal and vegetation maintenance equipment.

Access roads must meet the following design specifications:

- All access ramps and roads must be paved with a minimum of six inches concrete over three inches of crushed aggregate base material. This requirement may be modified depending on the soil conditions and intended use of the road at the discretion of the Agency.
- The maximum grade is 12 percent unless otherwise approved by the Agency.
- Centerline turning radius must be a minimum of 40 feet.
- Access roads less than 500 feet long must have 12-foot wide pavement within a minimum 15-foot wide bench. Access roads greater than 500 feet long must have 16-foot wide pavement within a minimum 20-foot wide bench.
- All access roads must terminate with turnaround areas of 40-feet by 40-feet. A hammer type turn around area or a circle drive around the top of the extended detention basin is also acceptable.
- Adequate double-drive gates and commercial driveways are required at street crossings. Gates should be located a minimum of 25 feet from the street curb except in residential areas where the gates may be located along the property line provided there is adequate sight distance to see oncoming vehicles at the posted speed limit.

Restricted Construction Materials

The use of pressure-treated wood or galvanized metal at or around an extended detention basin is prohibited. The use of galvanized fencing is permitted if in accordance with the Fencing requirement above.

Construction Considerations

In general, approximately 0.5 to 2 percent of the tributary development area is required for an extended detention basin. If constructed early in the development project, an extended detention basin can serve as a sediment trap for the tributary area. Depending on the underlying soil, extended detention basins may provide incidental infiltration of stormwater runoff; however, extended detention basins are not designed for this purpose. In areas with rapidly percolating soils, the underlying soils may need to be amended under the guidance of a licensed geotechnical engineer or an impermeable liner may be need to be installed to prevent significant infiltration of stormwater runoff into the soils. The areas planned for extended detention basins should be clearly marked before site work begins to avoid soil disturbance and minimize compaction during construction. After construction is completed, the entire tributary area to the extended detention basin must be stabilized.

Maintenance Requirements

Maintenance and regular inspections must be conducted to ensure proper function of an extended detention basin. The following activities must be conducted to maintain an extended detention basin:

- At a minimum, inspect the extended detention basin annually. Inspections after major storm events are encouraged.
- Remove sediment accumulation exceeding 50 percent of the sediment storage capacity in the sediment forebay, as indicated on the permanent steel post depth markers. Remove sediment from the remainder of the basin when six inches of sediment accumulates. Test removed sediments for toxic substance accumulation in compliance with current disposal requirements if visual or olfactory indications of pollution are noticed. If toxic substances are detected at concentrations exceeding thresholds of Title 22, Section 66261 of the California Code of Regulations, dispose of the sediment in a hazardous waste landfill and investigate and mitigate the source of the contaminated sediments to the maximum extent possible.
- Remove trash and debris, as needed, but at least annually prior to the beginning of the wet season.
- Maintain vegetation as needed to sustain the aesthetic appearance of the site and to prevent clogging of outlets as follows:

  - Prune and/or remove vegetation, large shrubs, or trees that limit access or interfere with operation of the extended detention basin.
  - Mow grass to four to nine inches high and remove grass clippings.
  - Rake and remove fallen leaves and debris from deciduous plant foliage.
  - Remove invasive, poisonous, nuisance, or noxious vegetation and replace with climate-appropriate vegetation.
  - Remove dead vegetation if it exceeds 10 percent of area coverage. Replace vegetation immediately to maintain cover density and control erosion where soils are exposed. It may be necessary to re-grade eroded areas prior to replacing vegetation.
  - Do not use herbicides or other chemicals to control vegetation.
- Inspect inlet structure for erosion and re-grade if necessary.
- Inspect overflow structure for obstructions or debris, which should be removed immediately. Repair or replace damaged structures if necessary.

The Agencies require execution of a Maintenance Access Agreement to be recorded by the property owner for the on-going operation and maintenance of all privately-maintained stormwater treatment control measures. The property owner is responsible for compliance with the Maintenance Access Agreement. An example Maintenance Access Agreement is presented in Appendix G.

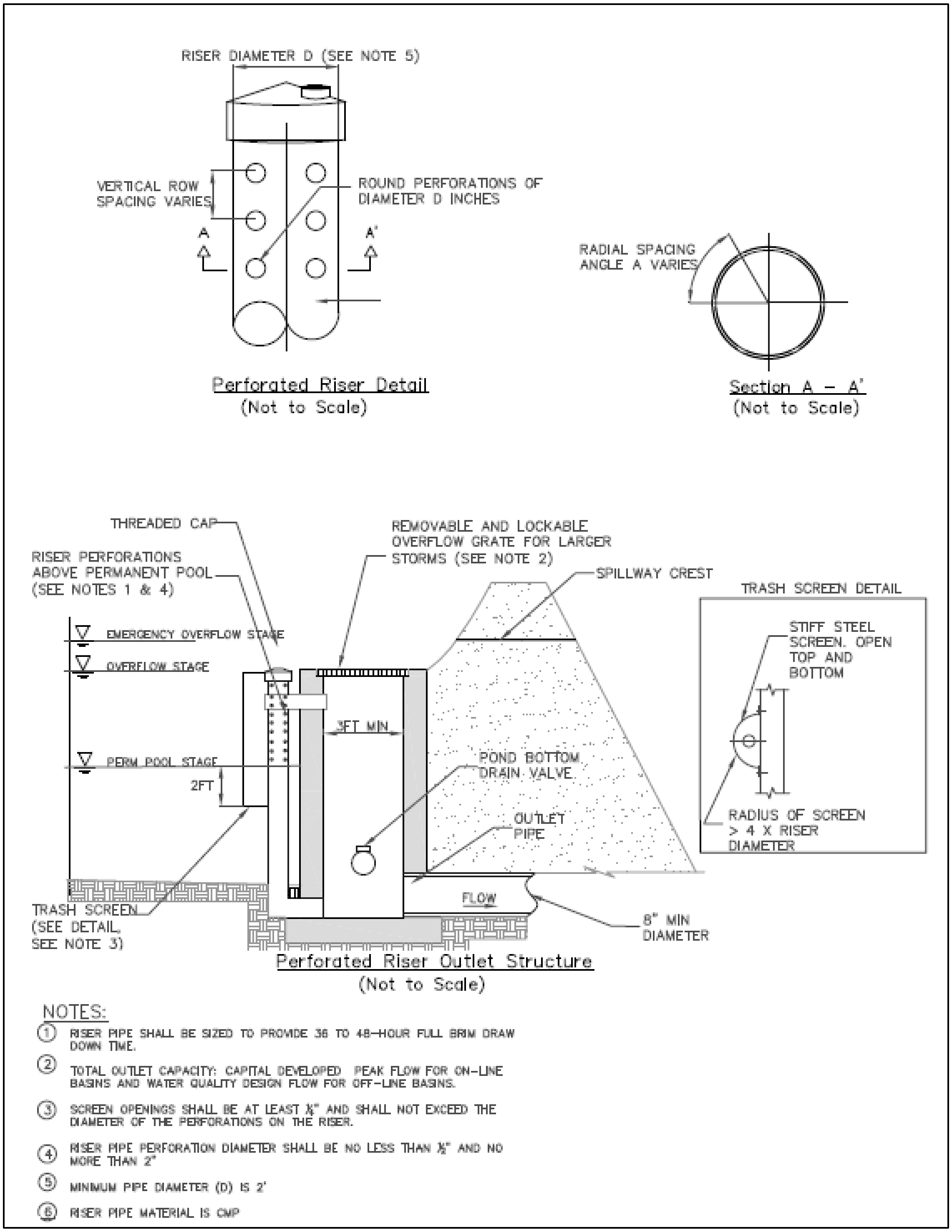


Figure F-9. Perforated Riser Structure

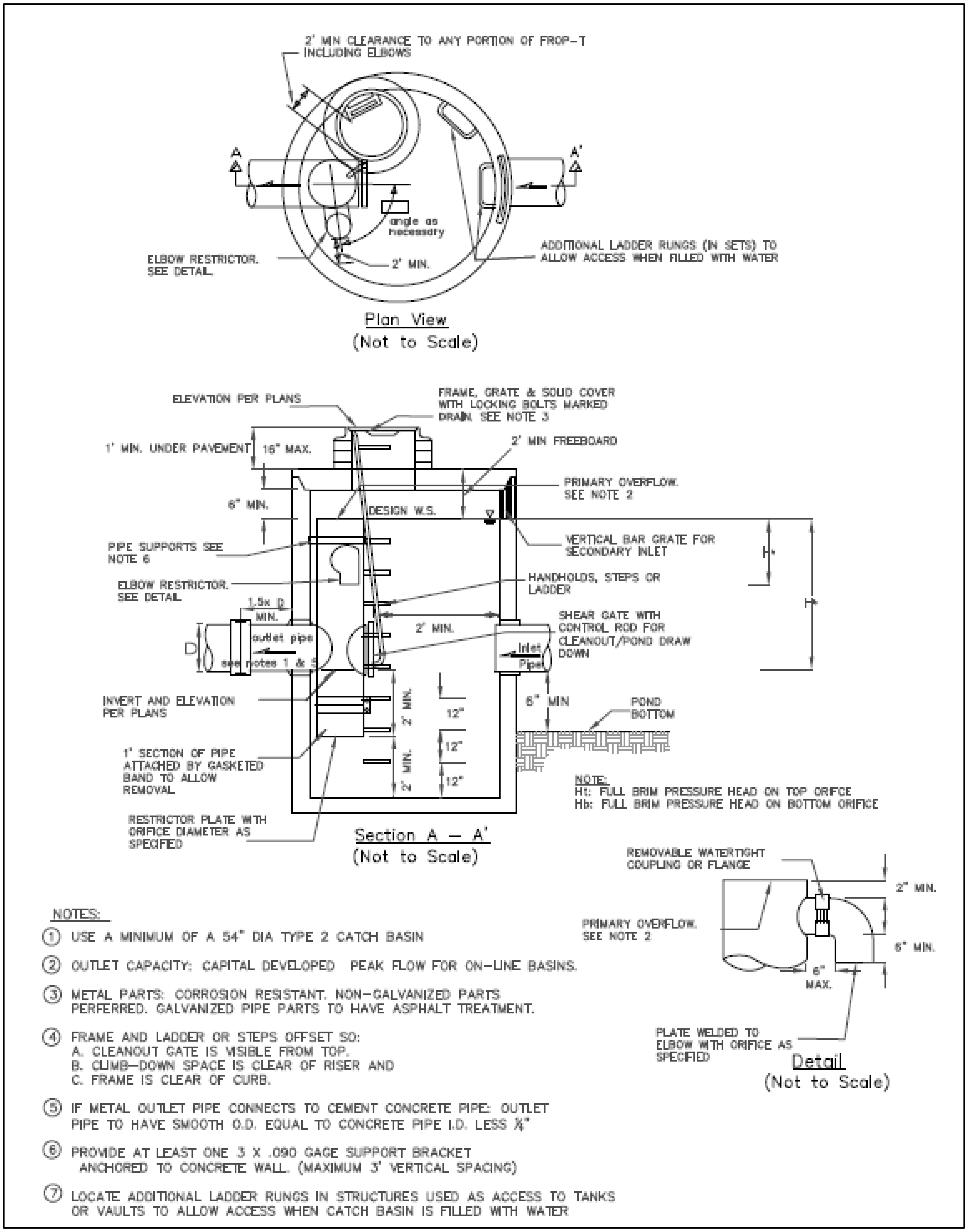


Figure F-10. Multiple Orifice Outlet

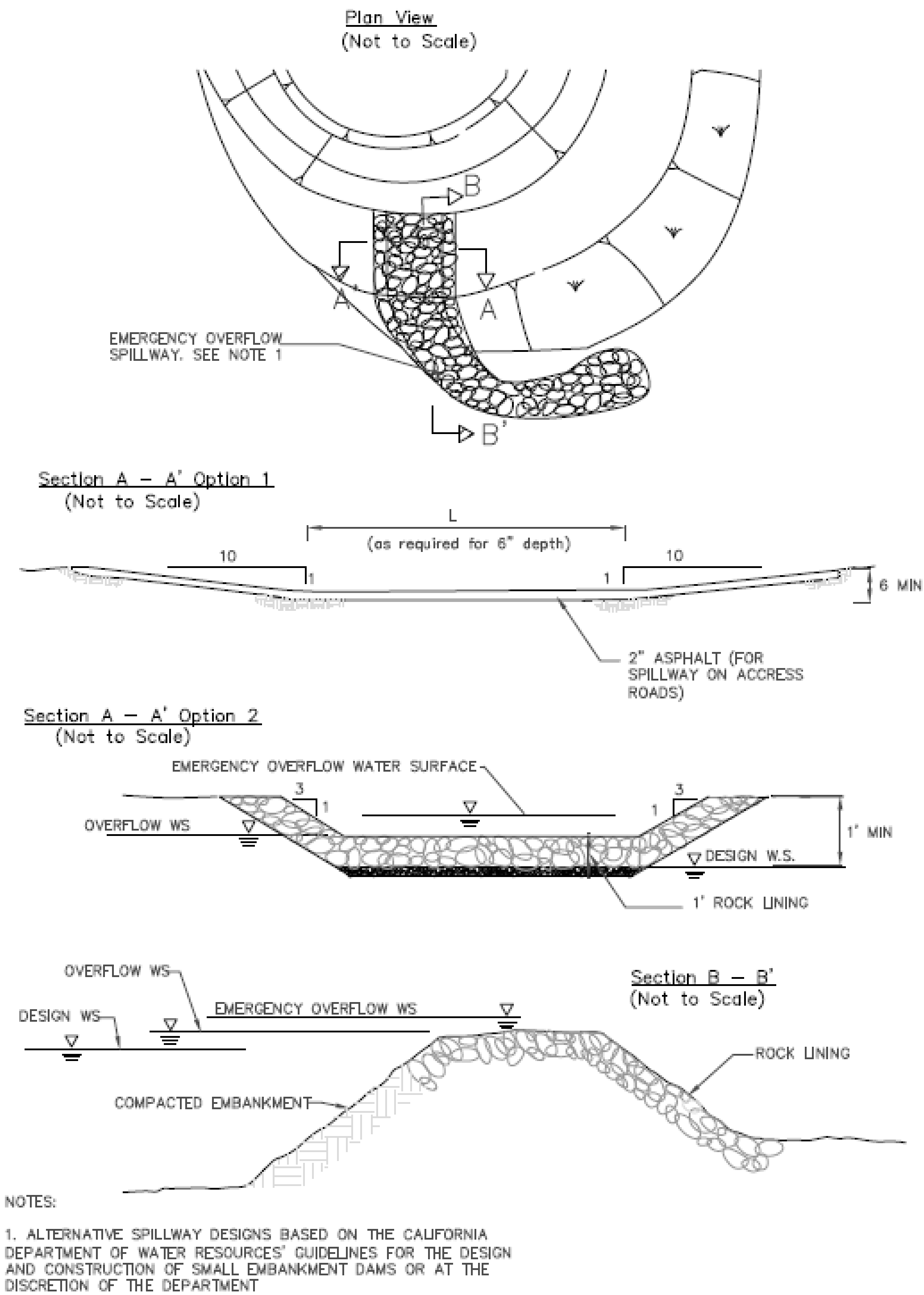


Figure F-11. Spillway Design Schematic

HM-2: Wet Pond

Description

Wet ponds are open earthen basins that feature a permanent pool of water that is displaced by stormwater runoff, in part or in total, during storm events. Like extended detention basins, wet ponds are designed to temporarily retain stormwater runoff, which reduces peak stormwater runoff flow rates and provides some stormwater runoff treatment and hydromodification control. Wet ponds differ from extended detention basins in that influent stormwater runoff mixes with and displaces the permanent pool as it enters the pond. A dry weather base flow is required to maintain a permanent pool in the wet pond. The primary treatment mechanism is sedimentation as stormwater runoff resides in this pool, but pollutant removal, particularly nutrients, also occurs through biological activity in the wet pond.

Wet ponds may also be designed with extended detention above the permanent pool. The extended detention portion of the wet pond above the permanent pool, if provided, functions like an extended detention basin to provide additional hydromodification control. If there is no extended detention provided, wet ponds must be sized to provide a minimum permanent pool volume.

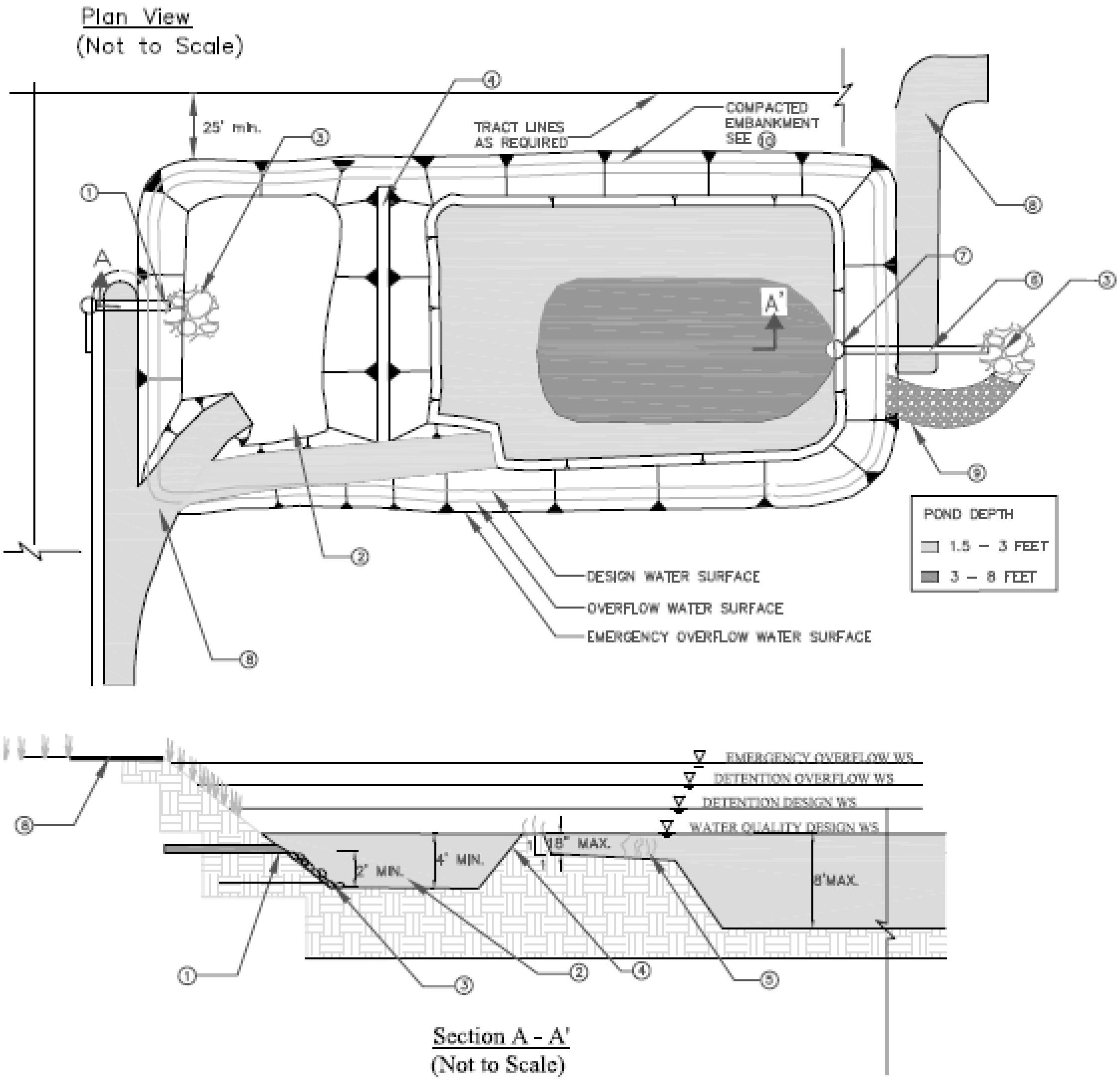
An example schematic of a wet pond with extended detention is presented in **Figure F-12**.

Use and Applicability

The Phase II Permit (Provision E.12.e.(f)) identifies bioretention as the standard stormwater treatment control measure unless (1) it is determined to be infeasible and an alternative treatment control measure that is equivalent to bioretention is proposed and demonstrated (Provision E.12.e.(g)), or (2) a specific exemption applies (Provision E.12.e.(i)). An alternative to bioretention can be proposed if it meets <u>all</u> of the following measures of equivalent effectiveness:

- Equal or greater amount of stormwater runoff infiltrated or evapotranspired;
- Equal or lower pollutant concentrations in stormwater runoff that is discharged after biotreatment;
- Equal or greater protection against shock loadings and spills; and
- Equal or greater accessibility and ease of inspection and maintenance.

A wet pond is typically used to meet hydromodification and flood control requirements.



NOTES:

① INLET PIPE SHOULD BE SUBMERGED WITH A MINIMUM OF 2' DISTANCE FROM THE BOTTOM

② FIRST CELL VOLUME SHALL EQUAL 25% TO 35% OF TOTAL WETPOND VOLUME. DEPTH SHALL BE 4' MIN TO 8' MAX PLUS AN ADDITIONAL 1' MIN SEDIMENT STORAGE DEPTH.

③ RIP RAP APRON OR OTHER ENERGY DISSIPATION.

④ BERM SHALL EXTEND ACROSS ENTIRE WIDTH OF THE WETPOND.

⑤ EMERGENT VEGETATION SHALL BE PLANTED IN REGIONS OF THE POND THAT ARE 3' DEEP OR LESS.

⑥ SIZE OUTLET PIPE TO PASS 100-YEAR PEAK FLOW FOR ON-LINE PONDS AND WATER QUALITY PEAK FLOW FOR OFF-LINE PONDS.

⑦ WATER QUALITY OUTLET STRUCTURE.

⑧ MAINTENANCE ACCESS ROAD SHOULD PROVIDE ACCESS TO BOTH THE FIRST CELL AND MAIN BASIN.

⑨ INSTALL EMERGENCY OVERFLOW SPILLWAY AS NEEDED.

Figure F-12. Example Wet Pond Schematic

Design Specifications

The following sections provide design specifications for wet ponds.

Geotechnical

A geotechnical investigation must be conducted during the site assessment process to verify site conditions for a wet pond. It is critical to understand how stormwater runoff will move through the soil (horizontally and vertically) and if there are any geologic conditions that may impact the movement of water. Soil infiltration rates and the depth to the groundwater table must be evaluated to ensure that conditions are satisfactory for proper operation of a wet pond.

Implementation of a wet pond in an area with rapidly draining soils requires impermeable liners to maintain permanent pools and/or micro-pools in the pond. Liners can be either synthetic materials (geomembrane liner) or imported lower permeability soils (e.g., clays). A water balance must be conducted to determine whether a liner is required. The following conditions can be used as a guideline:

- The sediment forebay must retain at least three feet of water year-round in order for pre-settling to be effective.
- The permanent pool must retain water for at least ten months of the year. Because plants can adapt to periods of summer drought, a limited drought period is allowed in the permanent pond. This may allow for a soil liner rather than a synthetic liner.

If low permeability soils are used for the impermeable liner, a minimum of 18 inches of the underlying soil amended with topsoil or compost (one part compost mixed with three parts of the underlying soil) must be placed over the liner. If a synthetic liner is used, a soil depth of two feet is recommended to prevent damage to the liner during planting.

Wet ponds are typically located on sites with a slope no greater than 15 percent. A Site Conditions Report summarizing the relevant findings from the geotechnical investigation and water balance must be submitted with the Project Stormwater Plan.

Setbacks

Applicable setbacks must be implemented when siting a wet pond.

Pretreatment

Pretreatment, which refers to design features that provide settling of large particles before stormwater runoff enters a stormwater treatment control measure, is important to ensure proper operation of a wet pond and reduce the long-term maintenance burden. Pretreatment may be provided to reduce the sediment load entering a wet pond in order to prevent sediment buildup that will reduce the capacity of the wet pond.

For wet ponds, typically a sediment forebay is used for pretreatment to remove coarse solids. The sediment forebay may be constructed with an internal berm made out of earthen embankment material, grouted riprap, or other structurally-sound material. The sediment forebay must be designed as follows:

- All inlets to the wet pond must enter the sediment forebay first.
- The sediment forebay must have a minimum volume equal to 5 to 10 percent of the total wet pond volume.
- Permanent steel post depth markers must be placed in the sediment forebay to identify the settled sediment removal limits at 50 and 100 percent of the sediment storage depth.
- The depth of the sediment forebay must be between four and eight feet, excluding sediment storage. One foot of sediment storage must be provided in the sediment forebay.
- A gravity drain outlet from the sediment forebay (minimum four-inch diameter) must extend the entire width of the internal berm.
- The sediment forebay outlet must be off-set from the inflow flow line to prevent short-circuiting.
- The sediment forebay outlet must be off-set from the inflow flow line to prevent short-circuiting.

Flow Entrance and Energy Dissipation

The drainage management area(s) (DMA[s]) tributary to the wet pond must be graded to minimize erosion that may enter the wet pond. The inlet to the wet pond must be submerged with the inlet pipe invert a minimum of two feet from the bottom (not including sediment storage). The top of the inlet pipe should be submerged at least one foot, if possible. A submerged inlet will dissipate energy from incoming flow. The distance from the bottom is required to minimize resuspension of settled sediments. Alternative inlet designs that meet these objectives are acceptable.

Drainage

Wet ponds provide stormwater runoff storage above ground. Wet ponds must have a base flow to maintain the permanent pool at least ten months of the year.

Sizing

Step 1: Calculate the Stormwater Runoff Volume

If the wet pond is demonstrated and approved as an alternative to bioretention, it must be designed to capture and manage the SDV_{adj}, which is the difference between the SDV (Section 5.2) and the volume of stormwater runoff managed through site design m measures (Section 5.5), for the tributary DMA(s).

If the wet pond is used for hydromodification management, it must be designed to capture, detain, and discharge the stormwater runoff volume determined from hydrologic routing modeling (Section 7.2) to mitigate the peak stormwater runoff flow rate.

Step 2: Determine Active Design Volume for Wet Pond without Extended Detention

The active volume of the wet pond (V_a) is equal to the stormwater runoff volume (Step 1) plus an additional five percent for sediment accumulation.

$$V_a = 1.05 \times V_{SW}$$

Where:

V_a = active volume of wet pond [ft^3]; and
V_{SW} = stormwater runoff volume [ft^3].

Step 3: Determine Preliminary Geometry

Based on site constraints, determine the pond geometry and the storage available by developing an elevation-storage relationship for the wet pond. Note that a more natural geometry may be used and is in many cases recommended; the preliminary wet pond geometry calculations are used for sizing purposes only.

Calculate the width of the wet pond footprint (W_{tot}) as follows:

$$W_{tot} = \frac{A_{tot}}{L_{tot}}$$

Where:

W_{tot} = total width of wet pond [ft];
A_{tot} = total surface area of wet pond footprint [ft^2]; and
L_{tot} = total length of wet pond [ft].

Calculate the length of the active volume surface area ($L_{av\text{-}tot}$), including the internal berm, but excluding the freeboard as follows:

$$L_{av-tot} = L_{tot} - 2 \times Z \times d_{fb}$$

Where:

$L_{av\text{-}tot}$ = length of the active volume surface of wet pond [ft];
L_{tot} = total length of wet pond [ft];
Z = interior side slope as length per unit height [ft/ft]; and
d_{fb} = freeboard depth (minimum 1 ft) [ft].

Calculate the width of the active volume surface area ($W_{av\text{-}tot}$), including the internal berm, but excluding the freeboard as follows:

$$W_{av-tot} = W_{tot} - 2 \times Z \times d_{fb}$$

Where:

$W_{av\text{-}tot}$ = width of the active volume surface of wet pond [ft];
W_{tot} = total width of wet pond footprint [ft];
Z = interior side slope as length per unit height [ft/ft]; and
d_{fb} = freeboard depth (minimum 1 ft) [ft].

Calculate the total active volume surface area ($A_{av\text{-}tot}$), including the internal berm, but excluding the freeboard as follows:

$$A_{av-tot} = L_{av-tot} \times W_{av-to}$$

Where:

$A_{av\text{-}tot}$ = total active volume surface area [ft^2];
$L_{av\text{-}tot}$ = length of total active volume surface of wet pond [ft]; and
$W_{av\text{-}tot}$ = width of total active volume surface of wet pond [ft].

Calculate the area of the berm (A_{berm}) as follows:

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

Where:

A_{berm} = area of berm [ft^2];
L_{berm} = length of berm [ft]; and
W_{berm} = width of berm [ft].

Calculate the active volume surface area ($A_{av\text{-}tot}$), excluding the internal berm and freeboard as follows:

$$A = A_{av-tot} - A_{berm}$$

Where:

A = active volume surface area, including the internal berm, but excluding the freeboard [ft^2];
$A_{av\text{-}tot}$ = total active volume surface area, including the internal berm, but excluding the freeboard [ft^2]; and
A_{berm} = Area of berm [ft^2].

Step 4: Determine Dimensions of Sediment Forebay (if included)

If a sediment forebay is included in the design, the wet pond must be divided into two cells separated by a berm. If a sediment forebay is not included in the design, skip this step and all subsequent design calculations will be zero or omitted for the purposing of sizing the sediment forebay. The sediment forebay must have a minimum volume equal to 5 to 10 percent of the total wet pond volume. The berm volume does not count as part of the total volume.

Calculate the active volume of the sediment forebay (V_f) as follows:

$$V_f = \frac{V_a \times \%V_f}{100}$$

Where:

V_f = active volume of sediment forebay [ft^3];
V_a = active volume of wet pond [ft^3]; and
$\%V_f$ = percent of stormwater runoff volume in sediment forebay (minimum 5 percent) [%].

Calculate the surface area for the active volume of sediment forebay (A_f) as follows:

$$A_f = \frac{V_f}{d_f}$$

Where:

A_f = surface area of active volume of sediment forebay [ft^2];
V_f = active volume of sediment forebay [ft^3]; and
d_f = average depth of the active volume of sediment forebay (2-4 ft) [ft].

Calculate the length of the sediment forebay (L_f). Note that the inlet(s) and outlet(s) of the sediment forebay should be configured to maximize the hydraulic residence time.

$$L_f = \frac{A_f}{W_f}$$

$$W_f = W_{av-tot} = L_{berm}$$

Where:

L_f = length of sediment forebay [ft];
A_f = surface area of active volume of sediment forebay [ft^2];
W_f = width of sediment forebay [ft];
$W_{av\text{-}tot}$ = width of total active volume surface area [ft]; and
L_{berm} = length of berm [ft].

Step 5: Determine Dimensions of Permanent Pool

The permanent pool consists of the remainder of the active volume of the wet pond. Calculate the active volume of the permanent pool (V_p) as follows:

$$V_p = V_a - V_f$$

Where:

V_p = active volume of permanent pool of wet pond [ft^3];
V_a = active volume of wet pond [ft^3]; and
V_f = active volume of the sediment forebay [ft^3].

The minimum permanent pool surface area includes 0.3 acres of permanent pool per acre-foot of permanent pool volume. Calculate $A_{p,min}$:

$$A_{p,min} = 0.3 \frac{acres}{acre - ft} \times V_p$$

Where:

$A_{p,min}$ = minimum permanent pool surface area [ft^2]; and
V_p = Active volume of the permanent pool [ft^3].

Calculate the actual permanent pool surface area (A_p) as follows:

$$A_p = A - A_f$$

Where:

A_p = actual surface area of permanent pool [ft^2];
A = active volume surface area, including the internal berm, but excluding the freeboard [ft^2]; and
A_f = active volume of sediment forebay [ft^2].

Verify that A_p is greater than $A_{p,min}$. If A_p is less than $A_{p,min}$, modify the input parameters to increase A_p until it is greater than $A_{p,min}$. If site constraints limit this criterion, then another site for the wet pond may need to be selected.

Calculate the top length of the permanent pool (L_p) as follows:

$$L_p = \frac{A_p}{W_p}$$

$$W_p = W_f = W_{av-tot} = L_{berm}$$

Where:

A_p = surface area of permanent pool [ft^2];
W_p = width of permanent pool [ft];
W_f = width of sediment forebay [ft];
$W_{av\text{-}tot}$ = width of total active volume surface area [ft]; and
L_{berm} = length of berm [ft].

Verify that the length-to-width ratio of the permanent pool is at least 1.5:1 with greater than 2:1 preferred. If the length-to-width ratio is less than 1.5:1, modify the input parameters until a ratio of at least 1.5:1 is achieved. If the input parameters cannot be modified as a result of site constraints, another site for the wet pond may need to be selected.

Step 6: Design Other Wet Pond Features

Other sizing specifications for the wet pond include the following:

- A minimum freeboard of one foot above the maximum water surface elevation must be maintained.
- A 25-foot (minimum) buffer must be provided around the top perimeter of the wet pond.
- The flow path length-to-width ratio must be a minimum of 1.5:1, but preferably 3:1 or greater. A higher flow path length to width ratio increases the removal efficiency of total suspended solids (TSS).
- The edge of the wet pond should slope from the surface of the permanent pool to a depth of 12 to 18 inches at a slope of 1:1 (H:V) or greater. If soil conditions cannot support a 1:1 (H:V) slope, then the steepest slope that can be supported should be used or a shallow retaining wall constructed (18 inches maximum). Beyond the edge of the wet pond, a bench sloped at 4:1 (H:V) maximum should extend into the wet pond to a depth of at least three feet. A steeper slope may be used beyond the three foot depth to a maximum of eight feet. The steep slope at the water's edge will minimize very shallow areas that can support vector breeding.
- Wet ponds must be designed with a hydraulic residence time for dry weather flows of less than seven days to minimize vector breeding and stagnation issues.
- At least 25 percent of the permanent pool must be deeper than three feet to prevent growth of emergent vegetation across the entire pond. If greater than 50 percent of the permanent pool is deeper than six feet deep, a recirculation system (e.g., fountain, aerator) must be provided to prevent stratification, stagnation, and low dissolved oxygen conditions.

Step 7: Design Berm

The berm separating the sediment forebay, if one is provided, and the permanent pool must meet the following specifications:

- The top of the berm must be either at the stormwater runoff volume (Step 1) water surface or submerged one foot below the stormwater runoff volume water surface.
- The side slopes of the berm must meet the following specifications:
  - If the top of the berm is at the stormwater runoff volume water surface, the berm side slopes must be no steeper than 3:1 (H:V); or
  - If the top of berm is submerged one foot below the stormwater runoff volume water surface, the upstream side slope has a maximum slope of 2:1 (H:V).

Step 8: Design Extended Detention (if necessary)

If extended detention is included, then the extended detention volume must provide detention of 10 percent of the stormwater runoff volume (Step 1) while the surcharge volume makes up the remaining 90 percent of the sizing.

Outlet Structure

An outlet pipe and structure must be sized, at a minimum, to pass stormwater runoff volumes exceeding the design stormwater runoff volume (Step 1). The outlet pipe may be a perforated riser strapped to a manhole (**Figure F-13**) or placed in an embankment suitable for extended detention or may be back-sloped to a catch basin with a grated opening (jail house window) or manhole with a cone grate (birdcage) (**Figure F-14**). The grate or birdcage openings provide an overflow route should the wet pond outlet pipe become clogged. Seepage collars may be required on outlet pipes to prevent seepage through embankments. Energy dissipation controls must also be used at the outlet from the wet pond unless it discharges to the storm drain system or a hardened channel.

Overflow Structure and Spillway

An overflow spillway or overflow riser must be provided. If an overflow spillway potentially discharges to a steep slope, an overflow riser and a spillway must be provided. The overflow device must be designed to pass the maximum storm size diverted to the wet pond, with a minimum one-foot freeboard, directly to an approved discharge location (e.g., another stormwater treatment control measure, storm drain system, receiving water).

The emergency overflow spillway must be constructed of grouted riprap and designed to withstand the energy of the spillway flows (**Figure F-11**). Spillways must meet the California Department of Water Resources, Division of Safety of Dams *Guidelines for the Design and Construction of Small Embankment Dams* (www.water.ca.gov/damsafety/docs/GuidelinesSmallDams.pdf).

Embankments

Embankments are earthen slopes or berms used to detain or redirect the flow of water. For wet ponds, the embankments must be designed with the following specifications:

- All earthworks must be conducted in accordance with the Agency's Standard Specifications.
- The interior side slopes up to the overflow water surface must be no greater than 3:1 (H:V) unless stabilization has been approved by a licensed geotechnical engineer.
- The exterior side slopes must be no greater than 2:1 (H:V) unless stabilization has been approved by a licensed geotechnical engineer.
- The minimum top width of all berm embankments must be 20 feet, unless otherwise approved by the Agency.
- Berm embankments must be constructed on consolidated underlying soil or adequately compacted and stable fill soils approved by a licensed geotechnical engineer. Soils must be free of loose surface soil materials, roots, and other organic debris.
- Berm embankments must be constructed of compacted soil (95 percent minimum dry density, Modified Proctor method per ASTM D1557) and placed in six inch lifts.
- Berm embankments greater than 4 feet in height must be constructed by excavating a key equal to 50 percent of the berm embankment cross-sectional height and width. This requirement may be waived if specifically recommended by a licensed geotechnical engineer.
- Low growing, climate-appropriate grasses must be planted on the exterior of the embankment slopes.

Water Supply

A water balance must be conducted to demonstrate that adequate water supply will be present to maintain a permanent pool of water during a drought year when precipitation is 50 percent of average for the site. The water balance must consider evapotranspiration, infiltration, precipitation, spillway discharge, and nuisance flow (where appropriate). If a water balance indicates that losses will exceed inputs, a source of water must be provided to maintain the water surface elevation for at least ten months of the year. The water supply must be of sufficient quantity and quality to not have an adverse impact on the water quality of the wet pond.

Vegetation and Landscaping

- A thick mat of climate-appropriate grass must be established on the wet pond embankment exterior side slopes following construction. Grasses help prevent erosion. Note that grass may need to be irrigated during the establishment period.

- If the permanent pool is three feet or shallower, the bottom area must be planted with emergent wetland vegetation for 25 to 75 percent coverage. A mix of erosion-resistant plant species that effectively bind the soil must be used on the interior slopes and a diverse selection of climate-appropriate plants must be specified for the pool bottom. The pool bottom must not be planted with trees, shrubs, or other large woody plants that may interfere with maintenance activities.
- Landscaping outside of the wet pond, but within the easement/right-of-way, may be included as long as it does not hinder maintenance operations.
- Trees or shrubs must not be planted within 10 feet of inlet or outlet pipes or manmade drainage structures such as spillways or earthen embankments. Species with roots that seek water (e.g., willow, poplar) must not be planted used within 50 feet of pipes or manmade drainage structures. Weeping willow (*Salix babylonica*) may not be planted in or near wet ponds.
- Plant species that are not climate-appropriate are not permitted. A sample list of suitable vegetation species is included in Appendix H. Prior to installation, a landscape architect must certify that all proposed vegetation is appropriate for the project site.

Fencing

Safety is provided by fencing of the stormwater quality control measure. Fences shall be designed and constructed in accordance with Agency standards and must be located at or above the top of the overflow structure elevation.

Maintenance Access

Maintenance access must be provided to the structures associated with the wet pond (e.g., sediment forebay, inlet, outlet, overflow structure) if it is publicly-maintained. Manhole and catch basin lids must be in or at the edge of the access road. An access ramp to the wet pond bottom is required to facilitate the entry of sediment removal and vegetation maintenance equipment.

Access roads must meet the following design specifications:

- All access ramps and roads must be paved with a minimum of six inches concrete over three inches of crushed aggregate base material. This requirement may be modified depending on the soil conditions and intended use of the road at the discretion of the Agency.
- The maximum grade is 12 percent unless otherwise approved by the Agency.
- Centerline turning radius must be a minimum of 40 feet.

- Access roads less than 500 feet long must have 12-foot wide pavement within a minimum 15-foot wide bench. Access roads greater than 500 feet long must have 16-foot wide pavement within a minimum 20-foot wide bench.
- All access roads must terminate with turnaround areas of 40-feet by 40-feet. A hammer type turn around area or a circle drive around the top of the wet pond is also acceptable.
- Adequate double-drive gates and commercial driveways are required at street crossings. Gates should be located a minimum of 25 feet from the street curb except in residential areas where the gates may be located along the property line provided there is adequate sight distance to see oncoming vehicles at the posted speed limit.

Restricted Construction Materials

The use of pressure-treated wood or galvanized metal at or around a wet pond is prohibited. The use of galvanized fencing is permitted if in accordance with the Fencing requirement above.

Construction Considerations

In general, approximately two to three percent of the tributary development area is required for a wet pond. Wet ponds are most appropriate for sites with low-permeability soil, which help to maintain the permanent pool. Depending on the underlying soil, a wet pond may provide incidental infiltration of stormwater runoff; however, wet ponds are not designed for this purpose. An impermeable liner may be required to maintain the permanent pool in areas with rapidly draining soils. The areas planned for wet ponds should be clearly marked before site work begins to avoid soil disturbance. After construction is completed, the entire tributary area to the wet pond must be stabilized.

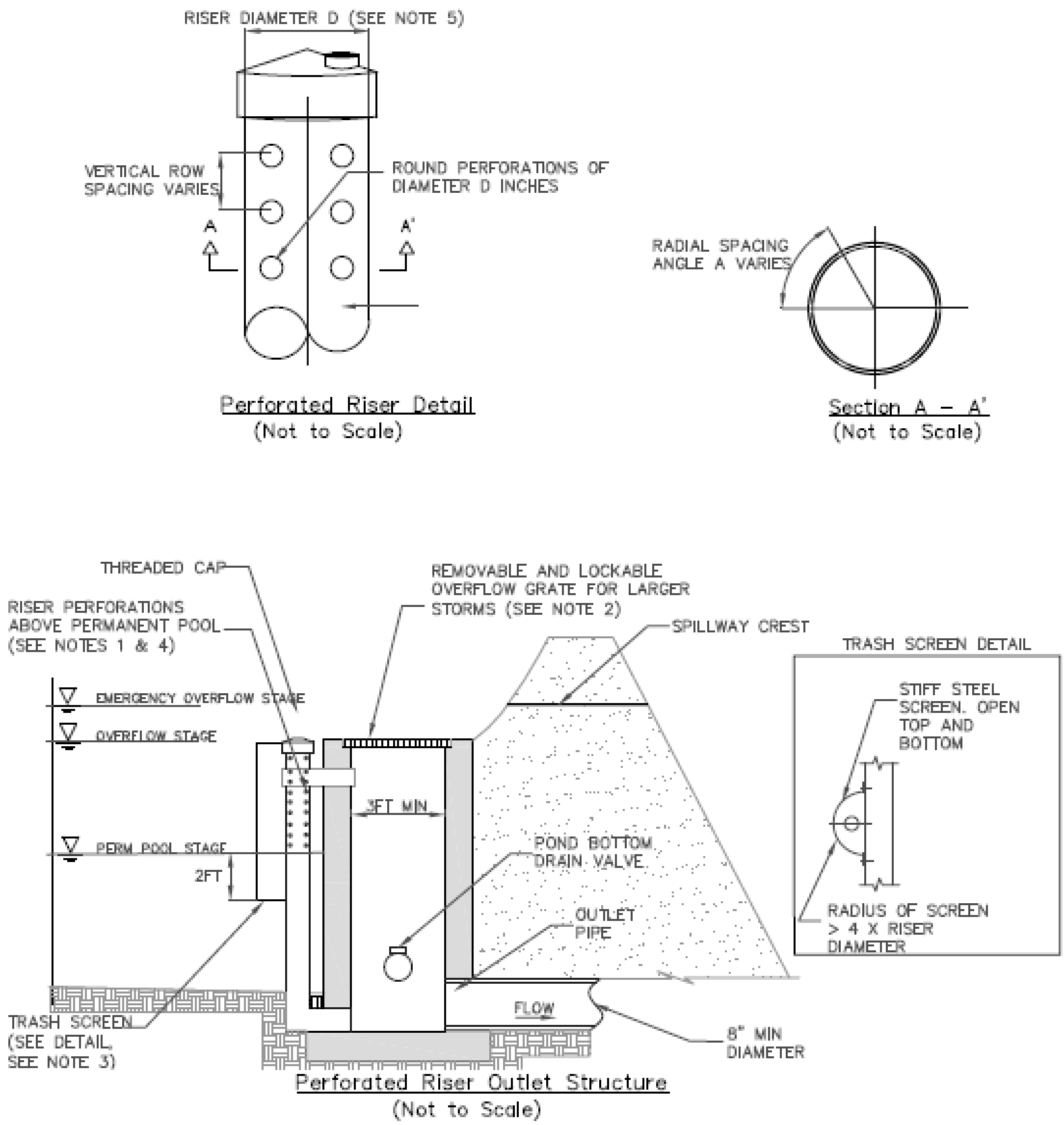
Maintenance Requirements

Maintenance and regular inspections must be conducted to ensure proper function of a wet pond. The following activities must be conducted to maintain a wet pond:

- At a minimum, inspect the wet pond annually. Inspections after major storm events are encouraged.
- Remove sediment accumulation exceeding 50 percent of the sediment storage capacity of the sediment forebay, as indicated on the permanent steel post depth markers. Test removed sediments for toxic substance accumulation in compliance with current disposal requirements if visual or olfactory indications of pollution are noticed. If toxic substances are detected at concentrations exceeding thresholds of Title 22, Section 66261 of the California Code of Regulations, dispose of the sediment in a hazardous waste landfill and investigate and mitigate the source of the contaminated sediments to the maximum extent possible.

- Remove trash and debris, as needed, but at least annually prior to the beginning of the wet season.
- Maintain site vegetation as frequently as necessary to maintain the aesthetic appearance of the site and to prevent clogging of outlets, creation of dead spaces, and barriers to mosquito fish to access pooled areas, and as follows:
  - Prune and/or remove vegetation, large shrubs, or trees that limit access or interfere with operation of the wet pond.
  - Remove invasive, poisonous, nuisance, or noxious vegetation and replace with climate-appropriate vegetation.
  - Remove dead vegetation if it exceeds 10 percent of area coverage. Replace vegetation immediately to maintain cover density and control erosion where soils are exposed. It may be necessary to re-grade eroded areas prior to replacing vegetation.
  - Do not use herbicides or other chemicals to control vegetation.
  - Remove algae mats that cover more than 20 percent of the surface of the wet pond.
- Inspect inlet structure for erosion and re-grade if necessary.
- Inspect overflow structure for obstructions or debris, which should be removed immediately. Repair or replace damaged structures if necessary.

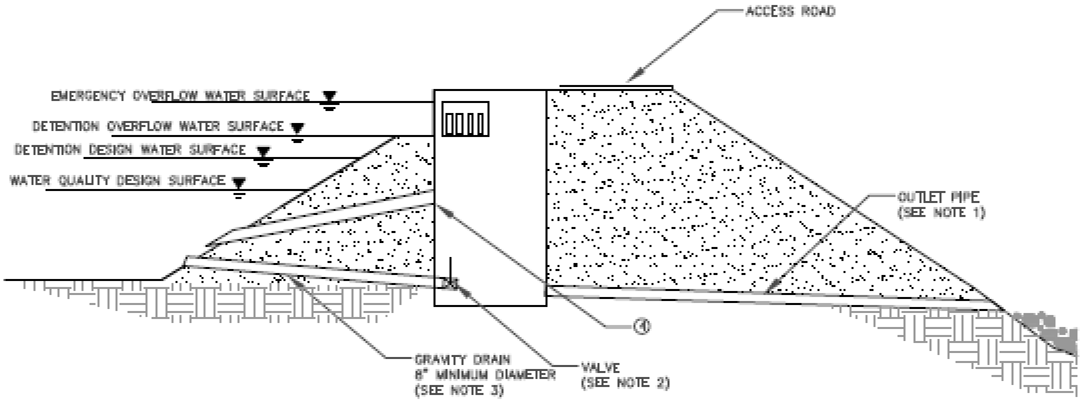
The Agencies require execution of a Maintenance Access Agreement to be recorded by the property owner for the on-going operation and maintenance of any privately-maintained stormwater treatment control measures. The property owner is responsible for compliance with the Maintenance Access Agreement. An example Maintenance Access Agreement is presented in Appendix G.



NOTES:

1. RISER PIPE SHALL BE SIZED TO PROVIDE 36 TO 48-HOUR FULL BRIM DRAW DOWN TIME.
2. TOTAL OUTLET CAPACITY: CAPITAL DEVELOPED PEAK FLOW FOR ON-LINE BASINS AND WATER QUALITY DESIGN FLOW FOR OFF-LINE BASINS.
3. SCREEN OPENINGS SHALL BE AT LEAST ¼" AND SHALL NOT EXCEED THE DIAMETER OF THE PERFORATIONS ON THE RISER.
4. RISER PIPE PERFORATION DIAMETER SHALL BE NO LESS THAN ½" AND NO MORE THAN 2"
5. MINIMUM PIPE DIAMETER (D) IS 2'
6. RISER PIPE MATERIAL IS CMP

Figure F-13. Riser Outlet Schematic



Inverted Pipe Outlet Structure
(Not to Scale)

NOTES:

1. SIZE OUTLET PIPE SYSTEM TO PASS CAPITAL PEAK FLOW FOR ON–LINE PONDS AND WATER QUALITY PEAK FLOW FOR OFF–LINE PONDS.
2. VALVE MAY BE LOCATED INSIDE MANHOLE OR OUTSIDE WITH APPROVED OPERATIONAL ACCESS
3. INVERT OF DRAIN SHALL BE 6" MINIMUM BELOW TOP OF INTERNAL BERM. LOWER PLACEMENT IS DESIRABLE. INVERT SHALL BE 6" MINIMUM ABOVE BOTTOM OF POND.
4. OUTLET PIPE INVERT SHALL BE AT WETPOOL WATER SURFACE ELEVATION

Figure F-14. Inverted Pipe Outlet Schematic

APPENDIX G

Example Maintenance Access Agreement

Example Maintenance Access Agreement

(Long Form)

Recorded at the request of:

City/County of____

After recording, return to:

City/County of____

City/County Clerk

____

____

STORMWATER TREATMENT CONTROL MEASURE MAINTENANCE ACCESS AGREEMENT

OWNER: ____

PROPERTY ADDRESS:____

APN:____

THIS AGREEMENT is made and entered into in______________________, California, this___day of_________________, by and between__________________________, hereinafter referred to as “Owner” and the CITY/COUNTY OF________________ ______, a municipal corporation, located in the County of _______________, State of California hereinafter referred to as “CITY/COUNTY”;

WHEREAS, the Owner owns real property (“Property”) in the City/County of __________ ______, County of _______, State of California, more specifically described in Exhibit “A” and depicted in Exhibit “B”, each of which exhibits is attached hereto and incorporated herein by this reference;

WHEREAS, at the time of initial approval of development project known as___________ __________________________________within the Property described herein, the City/County required the project to employ on-site control measures to minimize pollutants in urban runoff;

WHEREAS, the Owner has chosen to install (a/n) _________________________________ ____, hereinafter referred to as “Stormwater Treatment Control Measure(s)”, as the on-site control measure to minimize pollutants in urban runoff;

WHEREAS, said Stormwater Treatment Control Measure(s) has/have been installed in accordance with plans and specifications accepted by the City/County;

WHEREAS, said Stormwater Treatment Control Measure(s), with installation on private property and draining only private property, is a private facility with all maintenance or replacement, therefore, the sole responsibility of the Owner in accordance with the terms of this Agreement;

WHEREAS, the Owner is aware that periodic and continuous maintenance, including, but not necessarily limited to, vegetation management, filter material replacement, and sediment removal, is required to assure peak performance of the Stormwater Treatment Control Measure(s) and that, furthermore, such maintenance activity will require compliance with all Local, State, or Federal laws and regulations, including those pertaining to confined space and waste disposal methods, in effect at the time such maintenance occurs;

WHEREAS, the Owner is required to implement the Operations and Maintenance Plan, more specifically described in Exhibit “C”, which is attached hereto and incorporated herein by this reference;

NOW THEREFORE, it is mutually stipulated and agreed as follows:

1) Owner hereby provides the City/County or City’s/County’s designee complete access, of any duration, to the Stormwater Treatment Control Measure(s) and its immediate vicinity at any time, upon reasonable notice, or in the event of emergency, as determined by City’s/County’s Director of Public Works no advance notice, for the purpose of inspection, sampling, testing of the Stormwater Treatment Control Measure(s), and in case of emergency, to undertake all necessary repairs or other preventative measures at Owner’s expense as provided in paragraph 3 below. City/County shall make every effort at all times to minimize or avoid interference with Owner’s use of the Property.

2) Owner shall use its best efforts diligently to operate and maintain the Stormwater Treatment Control Measure(s) in a manner assuring peak performance at all times in accordance with the Operation and Maintenance Plan, which is incorporated into this Agreement as Exhibit C. All reasonable precautions shall be exercised by Owner and Owner’s representative or contractor in the removal and extraction of material(s) from the Stormwater Treatment Control Measure(s) and the ultimate disposal of the material(s) in a manner consistent with all relevant laws and regulations in effect at the time. As may be requested from time to time by the City/County, the Owner shall provide the City/County with documentation identifying the material(s) removed, the quantity, and disposal destination.

3) In the event Owner, or its successors or assigns, fails to accomplish the necessary maintenance contemplated by this Agreement, within five (5) days of being given written notice by the City/County, the City/County is hereby authorized to cause any maintenance necessary to be done and charge the entire cost and expense to the Owner or Owner’s successors or assigns, including administrative costs, attorneys’ fees and interest thereon at the maximum rate authorized by the Civil Code from the date of the notice of expense until paid in full.

4) The City/County may require the Owner to post security in form and for a time period satisfactory to the City/County of guarantee of the performance of the obligations stated herein. Should the Owner fail to perform the obligations under the Agreement, the City/County may, in the case of a cash bond, act for the Owner using the proceeds from it, or in the case of a surety bond, require the sureties to perform the obligations of the Agreement. As an additional remedy, the Director may withdraw any previous stormwater related approval with respect to the Property on which a Stormwater Treatment Control Measure has been installed until such time as Owner repays to City/County its reasonable costs incurred in accordance with paragraph 3 above.

5) This Agreement shall be recorded in the Office of the Recorder of ________ ____________County, California, at the expense of the Owner and shall constitute notice to all successors and assigns of the title to said Property of the obligation herein set forth, and also a lien in such amount as will fully reimburse the City/County, including interest as herein above set forth, subject to foreclosure in event of default in payment.

6) In event of legal action occasioned by any default or action of the Owner, or its successors or assigns, then the Owner and its successors or assigns agree(s) to pay all costs incurred by the City/County in enforcing the terms of this Agreement, including reasonable attorney's fees and costs, and that the same shall become a part of the lien against said Property.

7) It is the intent of the parties hereto that burdens and benefits herein undertaken shall constitute covenants that run with said Property and constitute a lien there against.

8) The obligations herein undertaken shall be binding upon the heirs, successors, executors, administrators and assigns of the parties hereto. The term "Owner" shall include not only the present Owner, but also its heirs, successors, executors, administrators, and assigns. Owner shall notify any successor to title of all or part of the Property about the existence of this Agreement. Owner shall provide such notice prior to such successor obtaining an interest in all or part of the Property. Owner shall provide a copy of such notice to the City/County at the same time such notice is provided to the successor.

9) Time is of the essence in the performance of this Agreement.

10) Any notice to a party required or called for in this Agreement shall be served in person, or by deposit in the U.S. Mail, first class postage prepaid, to the address set forth below. Notice(s) shall be deemed effective upon receipt, or seventy-two (72) hours after deposit in the U.S. Mail, whichever is earlier. A party may change a notice address only by providing written notice thereof to the other party.

IF TO CITY/COUNTY:

____

____

____

IF TO OWNER:

____

____

____

IN WITNESS THEREOF, the parties hereto have affixed their signatures as of the date first written above.

APPROVED AS TO FORM:

____

City/County Attorney

OWNER:

____

Owner

Name: __________________________

Title: ____________________________

CITY/COUNTY OF________________:

____

Name:___________________________

Title:_____________________________

OWNER:

____

Name:______________________________

Title:________________________________

ATTEST:

____

City/County Clerk Date

Notaries on Following Page

EXHIBIT A

(Legal Description)

EXHIBIT B

(Map/illustration)

EXHIBIT C

(Operations and Maintenance Plan)

(Short Form)

Recorded at the request of and mail to:

____

____

____

Covenant and Agreement Regarding

Stormwater Treatment Control Measure Maintenance and Access

The undersigned hereby certify that we are the owners of hereinafter legally described real property located in the City/County of ____________________, County of _____________, State of California.

Legal Description: ____

____

as recorded in Book _____________________, Page___________, Records of ______ County, which property is located and known as **(Address):** ________________.

And in consideration of the City/County of _______ allowing_____________________

____

on said property, we do hereby covenant and agree to and with said City/County to maintain according to the Operations and Maintenance Plan (Attachment 1), all structural stormwater treatment control measures including the following:

____

____.

This Covenant and Agreement shall run all of the above described land and shall be binding upon ourselves, and future owners, encumbrances, their successors, heirs, or assignees and shall continue in effect until released by the authority of the City/County upon submittal of request, applicable fees, and evidence that this Covenant and Agreement is no longer required by law.

NOTARIES ON FOLLOWING PAGE

OWNER'S CERTIFICATION
OPERATION AND MAINTENANCE PLAN
for
(PROJECT NAME)

This Operations and Maintenance Plan (Plan) was prepared for ______(Project Owner / Developer)____________ by ___(Name of Preparing Firm/Individual)____ ______. This Plan is intended to comply with all requirements specified in the City/County of ___________Stormwater Management and Discharge Control Ordinance ___________.

The undersigned understands that stormwater treatment control measures are enforceable requirements under the Municipal Code. The undersigned, while owning the property on which such stormwater treatment control measures are to be implemented, is responsible for the implementation of the provisions of this Plan and for the operation and maintenance of all structural stormwater treatment control measures and agrees to ensure that the conditions on the project site conform to the requirements specified in the Municipal Code.

Once the undersigned transfers its interest in the project property, its successors-in-interest shall bear the aforementioned responsibility to maintain

Name of Owner: ____

Address of Owner: ____

Phone number of Owner: ____

Signature: ____

Print Name: ____

Title ____

Date ____

APPENDIX H

Suitable Vegetation Species

For stormwater treatment control measures designed for biotreatment (e.g., bioretention, stormwater planters, tree-well filters), the primary purposes of vegetation are to reduce pollutants in stormwater runoff and provide increased transpiration to reduce stormwater runoff volume. Vegetation also maintains soil porosity and prevents erosion. In selecting appropriate vegetation for stormwater treatment control measures, the following factors must be considered:

- Can the vegetation tolerate summer drought, ponding fluctuations, and saturated soil conditions following a storm event?
- Is the vegetation climate-appropriate?
- Is the vegetation dense and strong enough to stay upright even in flowing water?
- Does the vegetation require fertilizers or other nutrient supplements?
- Is the vegetation prone to pests or disease?
- What are the irrigation requirements for the vegetation?
- Is it consistent with local water conservation ordinance requirements?

A sample list of suitable vegetation species is provided in **Table H-1**. Information in **Table H-1** includes the plant type (i.e., perennial and ground cover, grasses, shrubs, trees), irrigation requirements, and saturation tolerance (i.e., Zones 1 or 2). The plant list, was adapted from Water Use Classification of Landscape Species (WUCOLS IV) database[1] and Appendix F of the Bay Area Stormwater Management Agencies Association Post-Construction Manual (July 2014)[2]. The Western Sunset Zone Guide[3] is another source that provides useful information on climate-appropriate plants.

In biotreatment systems Zone 1 is the lower area where the soil experience extended periods of saturation. Vegetation suitable for Zone 1 are common riparian, and wetland plants capable of surviving in saturated soils for long durations throughout the year. However, most of these types of plants are not drought-tolerant and require some irrigation throughout the growing season. Zone 2 is at the higher grade in the biotreatment system and the soil is saturated for shorter periods. Vegetation suitable for Zone 2 includes plants common in riparian/upland transition areas, moist woodlands, and seasonal wetlands. These plants are capable of surviving in saturated soils for

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[1] Water Use Classification of Landscape Species (http://ucanr.edu/sites/WUCOLS/, Last Accessed May 15, 2015).

[2] Bay Area Stormwater Management Agencies Association. *Design Guidance for Stormwater Treatment and Control for Projects in Marin, Sonoma, Napa, and Solano Counties*. July 14, 2014.

[3] Western Sunset Zone Guide (http://www.sunset.com/garden/climate-zones/climate-zones-intro-us-map, Last Accessed May 18, 2015).

shorter durations especially in the winter or spring and are drought-tolerant, but could benefit from some year-round irrigation.

The project applicant is not limited to the vegetation listed in **Table H-1** and may proposed other climate-appropriate vegetation suitable for biotreatment systems. Vegetation for biotreatment systems must be designed by a landscape architect experienced with biotreatment systems.

Table H-1. Suitable Vegetation Species

Species Name	Common Name	Vegetation Type				California Native	Irrigation Requirement			Saturation Tolerance	
		Perennial and Ground Cover	Grass	Shrub	Tree		Very Low	Low	Moderate	Zone 1	Zone 2
Scaevola 'Mauve Clusters'	fan flower	X						X			X
Artemisia douglasiana	California mugwort	X				X		X		X	X
Carex pansa	sand dune sedge	X				X			X	X	X
Carex praegracilis	California field sedge	X				X			X	X	X
Chondropetalum tectorum	cape reed	X						X		X	X
Epipactis gigantea	stream orchid	X				X			X	X	X
Erigeron glaucus	beach aster	X				X			X		X
Heuchera micrantha	crevice alum root	X				X			X		X
Iris douglasiana	Douglas iris	X				X		X			X
Juncus pallidus	pale rush	X							X	X	X
Mirabilis multiflora	four o' clock	X				X		X			X
Sisyrinchium californicum	golden-eyed grass	X				X			X	X	X
Verbena lasiostachys	robust verbena	X				X		X		X	X
Danthonia californica	California oatgrass		X			X			X	X	X
Festuca rubra	creeping red fescue		X			X			X		X
Muhlenbergia rigens	deer grass		X			X		X			X
Carpenteria californica	bush anemone			X		X		X		X	X
Heteromeles arbutifolia	toyon			X		X	X				X
Lonicera involucrata	twinberry			X		X			X		X

Species Name	Common Name	Vegetation Type				California Native	Irrigation Requirement			Saturation Tolerance	
		Perennial and Ground Cover	Grass	Shrub	Tree		Very Low	Low	Moderate	Zone 1	Zone 2
Physocarpus capitatus	ninebark			X		X			X	X	X
Rhamnus crocea	redberry			X		X		X			X
Ribes speciosum	fuchsia flowering gooseberry			X		X		X			X
Rosa californica	California wild rose			X		X		X		X	X
Rubus parviflorus	thimbleberry			X		X		X		X	X
Rubus spectabilis	salmonberry			X		X		X		X	X
Rubus ursinus	California blackberry			X		X		X		X	X
Acer negundo	box elder				X	X			X	X	X
Calocedrus decurrens	incense cedar				X	X			X		
Chilopsis linearis	desert willow				X	X	X			X	X
Fraxinus latifolia	Oregon ash				X	X			X	X	X
Fraxinus velutina	Arizona ash				X	X			X		X
Pittosporum eugenioides	tarata				X				X		X
Platanus racemosa	California sycamore				X	X			X		X
Populus fremontii	western cottonwood				X	X			X		X
Quercus agrifolia	coast live oak				X	X	X				X
Quercus chrysolepis	canyon live oak				X	X		X			X
Quercus douglasii	blue oak				X	X	X				X
Quercus lobata	valley oak				X	X		X			X
Quercus wislizeni	interior live oak				X	X	X				X
Umbellularia californica	California bay				X	X			X		X

APPENDIX I

Sample Calculations

Stormwater Design Volume

The following are examples of how to calculate the stormwater design volume (SDV) for two drainage management areas, one which is pervious and one which is impervious. For the purpose of these examples, it is assumed that a 30,000 ft^2 (20,000 ft^2 impervious, 10,000 ft^2 pervious) site will be developed in Stockton. The project will be designed with a 48-hour drawdown period.

Example 1: Pervious Drainage Management Area

Calculate the stormwater runoff coefficient using the following equation:

$$C = 0.858 \times i^3 - 0.78 \times i^2 + 0.774 \times i + 0.04$$
$$= 0.858 \times 0^3 - 0.78 \times 0^2 + 0.774 \times 0 + 0.04 = 0.04$$

Where:

C = stormwater runoff coefficient [unitless]; and
i = DMA imperviousness ratio [expressed as a decimal]. For pervious areas, this ratio is 0.

Calculate the unit stormwater volume using the following equation:

$$P_0 = (a \times C) \times P_6 = (1.963 \times 0.04) \times 0.36\ in = 0.028\ in$$

Where:

P_0 = unit stormwater volume [in];
a = regression constant (1.963 for 48-hr drawdown); and
P_6 = mean annual runoff-producing rainfall depth [in] (see Table 5-1 of the *2015 Post-Construction Stormwater Standards Manual*).

Calculate the SDV using the following equation:

$$SDV = A \times \frac{P_0}{12} = 10{,}000\ ft^2 \times \frac{0.028\ in}{12\ in/ft} = 24\ ft^3$$

Where:

SDV = stormwater design volume [ft^3];
A = total area of drainage management area [ft^2]; and
P_0 = unit stormwater volume [in].

In this example, the pervious drainage management area will generate 24 ft^3 of stormwater runoff that may need to be managed if the pervious area does not drain into self-treating or self-retaining areas.

Example 2: Impervious Drainage Management Area

Calculate the stormwater runoff coefficient using the following equation:

$$C = 0.858 \times i^3 - 0.78 \times i^2 + 0.774 \times i + 0.04$$
$$= 0.858 \times 1^3 - 0.78 \times 1^2 + 0.774 \times 1 + 0.04 = 0.89$$

Where:

C = stormwater runoff coefficient [unitless]; and
i = DMA imperviousness ratio [expressed as a decimal]. For impervious areas, this ratio is 1.

Calculate the unit stormwater volume using the following equation:

$$P_0 = (a \times C) \times P_6 = (1.963 \times 0.89) \times 0.36\ in = 0.63\ in$$

Where:

P_0 = unit stormwater volume [in];
a = regression constant (1.963 for 48-hr drawdown); and
P_6 = mean annual runoff-producing rainfall depth [in] (see Table 5-1 of the *2015 Post-Construction Stormwater Standards Manual*).

Calculate the SDV using the following equation:

$$SDV = A \times \frac{P_0}{12} = 20{,}000\ ft^2 \times \frac{0.63\ in}{12\ in/ft} = 1{,}050\ ft^3$$

Where:

SDV = stormwater design volume [ft^3];
A = total area of drainage management area [ft^2]; and
P_0 = unit stormwater volume [in].

In this example, the impervious drainage management area will generate 1,050 ft^3 of stormwater runoff that must be managed using stormwater control measures.

Stormwater Design Flow

The following are examples of how to calculate the stormwater design flow (SDF) for two drainage management areas, one which is pervious and one which is impervious. For the purpose of these examples, it is assumed that the project site is 30,000 ft^2 with 20,000 ft^2 of pavement and 10,000 ft^2 of managed turf overlaying Type A soils.

Example 3: Pervious Drainage Management Area

Calculate the SDF using the following equation:

$$SDF = 1.008 \times i \times A \times C_r = 1.008 \times 0.2\ in/hr \times 0.23\ ac \times 0.18 = 0.008\ cfs$$

Where:

SDF = stormwater design flow [ft^3/s or cfs];
1.008 = unit conversion factor;
i = design rainfall intensity [0.2 in/hr];
A = total area of drainage management area [acre]; and
C_r = stormwater runoff coefficient for drainage management area (see Table 5-2 of the *2015 Post-Construction Stormwater Standards Manual*).

In this example, the pervious drainage management area will generate a stormwater flow rate of 0.008 cfs that may need to be managed if the pervious area does not drain into self-treating or self-retaining areas.

Example 4: Impervious Drainage Management Area

Calculate the SDF using the following equation:

$$SDF = 1.008 \times i \times A \times C_r = 1.008 \times 0.2\ in/hr \times 0.46\ ac \times 0.95 = 0.088\ cfs$$

Where:

SDF = stormwater design flow [ft^3/s or cfs];
1.008 = unit conversion factor;
i = design rainfall intensity [0.2 in/hr];
A = total area of drainage management area [acre]; and
C_r = stormwater runoff coefficient for drainage management area (see Table 5-2 of the *2015 Post-Construction Stormwater Standards Manual*).

In this example, the impervious drainage management area will generate a stormwater flow rate of 0.088 cfs that must be managed using stormwater control measures.

Bioretention Facility Design

This example design of a bioretention facility is based on the SDV calculated in Example 2 above.

Step 1: Determine the Adjusted SDV (SDV_{adj})

For the purposes of this example, it is assumed that porous pavement will be implemented as a site design measure for this drainage management area. Using the State Water Resources Control Board's Post-Construction Calculator, the volume credit (SDM_{credit}) is 460 ft^3. The SDV_{adj} is calculated using the following equation:

$$SDV_{adj} = SDV - SDM_{credit} = 1{,}050\ ft^3 - 460\ ft^3 = 590\ ft^3$$

Where:

SDV_{adj} = adjusted stormwater design volume [ft^3];
SDV = stormwater design volume [ft^3]; and
SDM_{credit} = site design measure volume credit [ft^3].

Step 2: Determine the Design Infiltration Rate

For this example, the in-situ infiltration rate of the underlying soil is 2.80 in/hr. After applying a safety factor of 4, the design infiltration rate is 0.70 in/hr.

Step 3: Determine Size of Bioretention Facility Design Layers

The typical design depths of the layers of the bioretention facility are presented in Table 6-1 of the *2015 Post-Construction Stormwater Standards Manual*. For this example, the following design depths of the layers of the bioretention facility are used:

Bioretention Facility Layer	Design depth
Ponding zone	1.5 ft
Planting media (excluding the mulch layer, if provided)	2 ft
Planting media/gravel layer separation zone (1)	4 in
Gravel	1 ft

Step 4: Calculate the Bottom Surface Area of the Bioretention Facility

Calculate the bottom surface area of the bioretention facility (surface area at the base of side slopes, not at the top of side slopes) assuming porosities of the planting media and gravel layers of 0.25 and 0.40, respectively, using the following equation:

$$A = \frac{SDV_{adj}}{d_{pz} + (\eta_{pm} \times d_{pm}) + (\eta_{gl} \times d_{gl})} = \frac{590\ ft^3}{1.5\ ft + (0.25 \times 2\ ft) + (0.40 \times 1\ ft)} = 250\ ft^2$$

Where:

A = bottom surface area of bioretention facility [ft^2];
SDV_{adj} = adjusted stormwater design volume [ft^3];
d_{pz} = depth of ponding zone [ft];
η_{pm} = porosity of planting media [unitless];
d_{pm} = depth of planting media [ft];
η_{gl} = porosity of gravel layer [unitless]; and
d_{gl} = depth of gravel layer [ft].

To verify that the bioretention facility is designed to infiltrate stormwater runoff within the maximum drawdown time, verify that the following equation is satisfied:

$$d_{pz} + (\eta_{pm} \times d_{pm}) + (\eta_{gl} \times d_{gl}) \leq \frac{f_{design}}{12} \times t_{max}$$

Where:

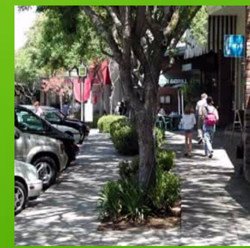
d_{pz} = depth of ponding zone [ft];
η_{pm} = porosity of planting media [unitless];
d_{pm} = depth of planting media [ft];
η_{gl} = porosity of gravel layer [unitless];
d_{gl} = depth of gravel layer [ft]
f_{design} = design infiltration rate [in/hr]; and
t_{max} = drawdown time (max 48 hrs) [hr].

$$1.5\ ft + (0.25 \times 2\ ft) + (0.40 \times 1\ ft) = 2.4\ ft \leq \frac{0.70\ in/hr}{12\ in/ft} \times 48\ hr = 2.8\ ft$$

The design of this bioretention facility will meet the maximum drawdown time.

APPENDIX J

Managing Wet Weather with Green Infrastructure Municipal Handbook Green Streets (EPA 833-F-08-009, December 2009)



Managing Wet Weather with Green Infrastructure

Municipal Handbook

Green Streets

Managing Wet Weather with Green Infrastructure

Municipal Handbook

Green Streets

prepared by

Robb Lukes
Christopher Kloss
Low Impact Development Center

The Municipal Handbook is a series of documents
to help local officials implement green infrastructure in their communities.

December 2008

EPA-833-F-08-009

Front Cover Photos
Top: rain garden; permeable pavers; rain barrel;
planter; tree boxes.
Large photo: green alley in Chicago

Green Streets

Introduction

By design and function, urban areas are covered with impervious surfaces: roofs, roads, sidewalks, and parking lots. Although all contribute to stormwater runoff, the effects and necessary mitigation of the various types of surfaces can vary significantly. Of these, roads and travel surfaces present perhaps the largest urban pollution sources and also one of the greatest opportunities for green infrastructure use.

The Federal Highway Administration (FHA) estimates that more than 20% of U.S. roads are in urban areas.[1] Urban roads, along with sidewalks and parking lots, are estimated to constitute almost two-thirds of the total impervious cover and contribute a similar ratio of runoff.[2] While a significant source of runoff, roads are also a part of the infrastructure system, conveying stormwater along gutters to inlets and the buried pipe network. Effective road drainage, translated as moving stormwater into the conveyance system quickly, has been a design priority while opportunities for enhanced environmental management have been overlooked especially in the urban environment.

Table 1. Examples of Stormwater Pollutants Typical of Roads.[3, 4]

Pollutant	Source	Effects
Trash	---	Physical damage to aquatic animals and fish, release of poisonous substances
Sediment/solids	Construction, unpaved areas	Increased turbidity, increased transport of soil bound pollutants, negative effects on aquatic organisms reproduction and function
Metals • Copper • Zinc • Lead • Arsenic	 • Vehicle brake pads • Vehicle tires, motor oil • Vehicle emissions and engines • Vehicle emissions, brake linings, automotive fluids	Toxic to aquatic organisms and can accumulate in sediments and fish tissues
Organics associated with petroleum (e.g., PAHs)	Vehicle emissions, automotive fluids, gas stations	Toxic to aquatic organisms
Nutrients	Vehicle emissions, atmospheric deposition	Promotes eutrophication and depleted dissolved oxygen concentrations

The altered flow regime from traditional roadways, increased runoff volume, more frequent runoff events, and high runoff peak flows, are damaging to the environment and a risk to property downstream. These erosive flows in receiving streams will cause down cutting and channel shifting in some places and excessive sedimentation in others. The unnatural flow regime destroys stream habitat and disrupts aquatic systems.

Compounding the deliberate rapid conveyance of stormwater, roads also are prime collection sites for pollutants. Because roads are a component of the stormwater conveyance system, are impacted by atmospheric deposition, and exposed to vehicles, they collect a wide suite of pollutants and deliver them into the conveyance system and ultimately receiving streams (See Table 1). The metals, combustion by-products, and automotive fluids from vehicles can present a toxic mix that combines with the ubiquitous nutrients, trash, and suspended solids.

Green Streets achieve multiple benefits, such as improved water quality and more livable communities, through the integration of stormwater treatment techniques which use natural processes and landscaping.

While other impervious surfaces can be replaced, for example using green roofs to decrease the amount of impervious roof surface, for the most part, impervious roads will, for some time to come, constitute a significant percentage of urban imperviousness because of their current widespread existence. Reducing road widths and other strategies to limit the amount of impervious surface are critical, but truly addressing road runoff requires mitigating its effects.

Roads present many opportunities for green infrastructure application. One principle of green infrastructure involves reducing and treating stormwater close to its source. Urban transportation right-of-ways integrated with green techniques are often called "green streets". Green streets provide a source control for a main contributor of stormwater runoff and pollutant load. In addition, green infrastructure approaches complement street facility upgrades, street aesthetic improvements, and urban tree canopy efforts that also make use of the right-of-way and allow it to achieve multiple goals and benefits. Using the right-of-way for treatment also links green with gray infrastructure by making use of the engineered conveyance of roads and providing connections to conveyance systems when needed.

Green streets are beneficial for new road construction and retrofits. They can provide substantial economic benefits when used in transportation applications. Billions of dollars are spent annually on road construction and rehabilitation, with a large percentage focused on rehabilitation especially in urban areas. Coordinating green infrastructure installation with broader transportation improvements can significantly reduce the marginal cost of stormwater management by including it within larger infrastructure improvements. Also, and not unimportantly, right-of-way installations allow for easy public maintenance. A large municipal concern regarding green infrastructure use is maintenance; using roads and right-of-ways as locations for green infrastructure not only addresses a significant pollutant source, but also alleviates access and maintenance concerns by using public space.

In urban areas, roads present many opportunities for coordinated green infrastructure use. Some municipalities are capitalizing on the benefits gained by introducing green infrastructure in transportation applications. This paper will evaluate programs and policies that have been used to successfully integrate green infrastructure into roads and right-of-ways.

Green Street Designs

Green streets can incorporate a wide variety of design elements including street trees, permeable pavements, bioretention, and swales. Although the design and appearance of green streets will vary, the functional goals are the same: provide source control of stormwater, limit its transport and pollutant conveyance to the collection system, restore predevelopment hydrology to the extent possible, and provide environmentally enhanced roads. Successful application of green techniques will encourage soil and vegetation contact and infiltration and retention of stormwater.

Alternative Street Designs (Street Widths)

A green street design begins before any BMPs are considered. When building a new street or streets, the layout and street network must be planned to respect the existing hydrologic functions of the land (preserve wetlands, buffers, high-permeability soils, etc.) and to minimize the impervious area. If retrofitting or redeveloping a street, opportunities to eliminate unnecessary impervious area should be explored.

Implementation Hurdles

Many urban and suburban streets, sized to meet code requirements for emergency service vehicles and provide a free flow of traffic, are oversized for their typical everyday functions. The Uniform Fire Code requires that streets have a *minimum 20 feet of unobstructed width;* a street with parking on both sides would require a width of at least 34 feet. In addition to stormwater concerns, wide streets have many detrimental implications on neighborhood livability, traffic conditions, and pedestrian safety.[5]

> **Oregon State Code Granting Authority for Street Standards to Local Government**
>
> ORS 92.044 - Local governments shall *supersede and prevail over any specifications and standards for roads and streets set forth in a uniform fire code adopted by the State Fire Marshal, a municipal fire department or a county firefighting agency*.... Local governments shall consider the needs of the fire department or fire-fighting agency when adopting the final specifications and standards.

The Transportation Growth and Management Program of Oregon, through a Stakeholder Design Team, developed a guide for reducing street widths titled the *Neighborhood Street Design Guidelines.*[6] The document provides a helpful framework for cities to conduct an inclusive review of street design profiles with the goal of reducing widths. Solutions for accommodating emergency vehicles while minimizing street widths are described in the document. They include alternative street parking configurations, vehicle pullout space, connected street networks, prohibiting parking near intersections, and smaller block lengths.

Figure 1. The street-side swale and adjacent porous concrete sidewalk are located in the High Point neighborhood of Seattle, WA
(Source: Abby Hall, US EPA).

In 1997, Oregon, which has adopted the *Uniform Fire Code,* specifically granted local government the authority to establish alternative street design standards but requires them to consult with fire departments before standards are adopted. Table 2 provides examples of alternative street widths allowed in U.S. jurisdictions.[7]

Swales

Swales are vegetated open channels designed to accept sheet flow runoff and convey it in broad shallow flow. The intent of swales is to reduce stormwater volume through infiltration, improve water quality through vegetative and soil filtration, and reduce flow velocity by increasing channel roughness. In the simple roadside grassed form, they have been a common historical component of road design. Additional benefit can be attained through more complex forms of swales, such as those with amended soils, bioretention soils, gravel storage areas, underdrains, weirs, and thick diverse vegetation.

Implementation Hurdles

There is a common misconception of open channel drainage being at the bottom of a street development hierarchy in which curb and gutter are at the top. Seattle's Street Edge Alternative Project and other natural drainage swale pilot projects have demonstrated that urban swales not only mitigate stormwater impacts, but they can also enhance the urban environment.[8]

Table 2. Examples of Alternative Street Widths

Jurisdiction	Street Width	Parking Condition
Phoenix, AZ	28'	parking both sides
Santa Rosa, CA	30' 26'-28' 20' 20'	parking both sides, <1000ADT parking one side no parking neck downs @ intersection
Orlando, FL	28' 22'	parking both sides, res. Lots<55' wide parking both sides, res. Lots>55' wide
Birmingham, MI	26' 20'	parking both sides parking one side
Howard County, MD	24'	parking unregulated
Kirkland, WA	12' 20' 24' 28'	alley parking one side parking both sides – low density only parking both sides
Madison, WI	27' 28'	parking both sides, <3DU/AC parking both sides, 3-10 DU/AC

ADT: Average Daily Traffic DU/AC: dwelling units per acre

Bioretention Curb Extensions and Sidewalk Planters

Bioretention is a versatile green street strategy. Bioretention features can be tree boxes taking runoff from the street, indistinguishable from conventional tree boxes. Bioretention features can also be attractive attention grabbing planter boxes or curb extensions. Many natural processes occur within bioretention cells: infiltration and storage reduces runoff volumes and attenuates peak flows; biological and chemical reactions occur in the mulch, soil matrix, and root zone; and stormwater is filtered through vegetation and soil.

Figure 2. This bioretention area takes runoff from the street through a trench drain in the sidewalk as well as runoff from the sidewalk through curb cuts *(Source: Abby Hall, US EPA).*

Implementation Hurdles

A few municipal DOT programs have instituted green street requirements in roadway projects, but as of yet, specifications for street bioretention have not yet been incorporated into municipal DOT specifications. Many cities do have street bioretention pilot projects; two of the well documented programs are noted in the table. Several concerns and considerations have prevented standard implementation of bioretention by DOTs.

Table 3. Municipalities with Swale Specifications and Standard Details

Municipality	Document	Section Title	Section #
City of Austin[9]	Standard Specifications and Standard Details	Grass-Lined Swale and Grass-Lined Swale with Stone Center	627S
City of Seattle[10]	2008 Standard Specifications for Municipal Construction	Natural Drainage Systems	7-21

Table 4. Municipalities with Bioretention Pilot Projects in the Right-of-Way

Municipality	Bioretention Type	Document
Maplewood, MN	Rain gardens	*Implementing Rainwater in Urban Stormwater Management* [11]
Portland, OR	• Curb extensions • Planters • Rain gardens	*2006 Stormwater Management Facility Monitoring Report* [12]

The diversity of shapes, sizes, and layouts bioretention can take is a significant obstacle to their incorporation with DOT specifications and standards. Street configurations, topography, soil conditions, and space availability are some of the factors that will influence the design of the bioretention facility. These variables make documentation of each new bioretention project all the more important. By building a menu of templates from local bioretention projects, future projects with similar conditions will be easier to implement and cost less to design. The documentation should include copies of the details and specifications for the materials used. A section on construction and operation issues, costs, lessons learned, and recommendations for similar designs should also be included in project documentation. Portland's Bureau of Environmental Services has proven adept at documenting each of its Green Streets projects and making them accessible online.[13]

Utilities are a chief constraint to implementing bioretention as a retrofit in urban areas. The Prince George's County, MD Bioretention Design Specifications and Criteria manual recommends applying the same clearance criteria recommended for storm drainage pipes.[14] Municipal design standards should specify the appropriate clearance from bioretention or allowable traversing.

Prince George's County, MD - 2.12.1.16 Utility Clearance

Utility clearances that apply to storm drainage pipe and structure placement also apply to bioretention. Standard utility clearances for storm drainage pipes have been established at 1' vertical and 5' horizontal. However, bioretention systems are shallow, non-structural IMP's consisting of mostly plant and soil components, (often) with a flexible underdrain discharge pipe. For this reason, other utilities may traverse a bioretention facility without adverse impact. Conduits and other utility lines may cross through the facility but construction and maintenance operations must include safeguard provisions. In some instances, bioretention could be utilized where utility conflicts would make structural BMP applications impractical.

Plants are another common concern of municipal staff, whether it is maintenance, salt tolerance, or plant height with regard to safety and security. Cities actively implementing LID practices in public spaces maintain lists of plants which fit the vegetated stormwater management practice niche. These are plants that flourish in the regional climate conditions, are adapted to periodic flooding, are low maintenance, and, if in cold climates, salt tolerant. Most often these plants are natives, but sometimes an approved non-native will best fit necessary criteria. A municipal plant list should be periodically updated based on maintenance experience, and vegetation health surveys.

Permeable Pavement

Permeable pavement comes in four forms: permeable concrete, permeable asphalt, permeable interlocking concrete pavers, and grid pavers. Permeable concrete and asphalt are similar to their impervious counterparts but are open graded or have reduced fines and typically have a special binder added. Methods for pouring, setting, and curing these permeable pavements also differ from the impervious versions. The concrete and grid pavers are modular systems. Concrete pavers are installed with gaps between them that allow water to pass through to the base. Grid pavers are typically a durable plastic matrix that can be filled with gravel or vegetation. All of the permeable pavement systems have an aggregate base in common which provides structural support, runoff storage, and pollutant removal through filtering and adsorption. Aside from a rougher unfinished surface, permeable concrete and asphalt look very similar to their impervious versions. Permeable concrete and asphalt and certain permeable concrete pavers are ADA compliant.

Implementation Hurdles

Figure 3. Pervious pavers used in the roadway of a neighborhood development in Wilsonville, OR
(Source: Abby Hall, US EPA).

Of all the green streets practices, municipal DOTs have been arguably most cautious about implementing permeable pavements, though it should be noted that some DOTs have, for decades, specified open-graded asphalt for low use roadways because of lower cost; to minimize vehicle hydroplaning; and to reduce road noise. The reticence to implement on a large-scale, however, is understandable given the lack of predictability and experience behind impervious pavements. However, improved technology, new and ongoing research, and a growing number of pilot projects are dispelling common myths about permeable pavements.

The greatest concern among DOT staff seems to be a perceived lack of long-term performance and maintenance data. Universities and DOTs began experimenting with permeable pavements in parking lots, maintenance yards, and pedestrian areas as early as twenty years ago in the U.S., even earlier in Europe. There is now a wealth of data on permeable pavements successfully used for these purposes in nearly every climate region of the country. In recent years, the cities of Portland, OR, Seattle, WA, and Waterford, CT and several private developments have constructed permeable pavement pilots within the roadway with positive results.

> Permeable pavement concerns in the roadway often raise concerns of safety, maintenance, and durability. Municipalities can replace impervious surfaces in other non-critical areas such as sidewalks, alleys, and municipal parking lots. These types of applications help municipalities build experience and a market for the technology.

The two typical maintenance activities are periodic sweeping and vacuuming. The City of Olympia, WA has experimented with several methods of clearing debris from permeable concrete sidewalks. Each of the methods was evaluated on the ease of use, debris removal, and the performance pace. The cost analysis by Olympia, WA found that the maintenance cost for pervious pavement was still lower than the traditional pavement when the cost of stormwater management was considered.

Table 5. Municipalities with Permeable Pavement Specifications and Standard Details

Municipality	Document	Section Title	Section #
Portland	2007 Standard Construction Specifications	Unit Pavers (includes permeable pavers)	00760
Olympia	WSDOT Specification	Pervious Concrete Sidewalks	8-30

Freeze/thaw and snow plows are the major concerns for permeable pavements in cold climate communities. However, these concerns have proven to be generally unwarranted when appropriate design and maintenance practices are employed. A well designed permeable pavement structure will always drain and never freeze solid. The air voids in the pavement allow plenty of space for moisture to freeze and ice crystals to expand. Also, rapid drainage through the pavement eliminates the occurrence of freezing puddles and black ice. Cold climate municipalities will need to make adjustments to snow plowing and deicing programs for permeable pavement areas. Snow plow blades must be raised enough to prevent scraping the surface of permeable pavements, particularly paver systems. Also, sand should not be applied.

Table 6. A Study in Olympia, WA Comparison of the cost of permeable concrete sidewalks to the cost of traditional impervious sidewalks[15]

Traditional Concrete Sidewalk		Permeable Concrete Sidewalk	
Construction Cost	Maintenance Cost	Construction Cost	Maintenance Cost
$5,003,000*	$156,000	$2,615,000*	$147,000
Total = $5,159,000 $101.16 per square yard		Total = $2,762,000 $54.16 per square yard	

*The cost of stormwater management (stormwater pond) for the added impervious surface is factored into the significantly higher cost of constructing the traditional concrete sidewalk. Maintenance of the stormwater pond is also factored into the traditional concrete sidewalk maintenance cost.

Sidewalk trees and tree boxes

Figure 4. Trees planted at the same time but with different soil volumes, Washington DC
(Source: Casey Trees)

From reducing the urban heat island effect and reducing stormwater runoff to improving the urban aesthetic and improving air quality, much is expected of street trees. Street trees are even good for the economy. Customers spend 12% more in shops on streets lined with trees than on those without trees.[16] However, most often street trees are given very little space to grow in often inhospitable environments. The soil around street trees often becomes compacted during the construction of paved surfaces and minimized as underground utilities encroach on root space. If tree roots are surrounded by compacted soils or are deprived of air and water by impervious streets and sidewalks, their growth will be stunted, their health will decline, and their expected life span will be cut short. By providing adequate soil volume and a good soil mixture, the benefits obtained from a street tree multiply. To obtain a healthy soil volume, trees can simply be provided larger tree boxes, or structural soils, root paths, or "silva cells" can be used under sidewalks or other paved areas to expand root zones. These allow tree roots the space they need to grow to full size. This increases the health of the tree and provides the benefits of a mature sized tree, such as shade and air quality benefits, sooner than a tree with confined root space.

Table 7. Healthy Tree Volume and Permeable Pavement Specifications and Standard Details

Jurisdictions	Minimum Soil Volume		Section Title	Section #
Prince William County, VA	Large tree Medium tree Small tree	970 cf 750 cf 500 cf	Design Construction Manual (Sec 800)	Table 8-8
Alexandria, VA		300 cf	Landscape Guidelines	II.B. (2)

Implementation Hurdles

Providing an adequate root volume for trees comes down to a trade off between space in the right-of-way and added construction costs. The least expensive way to obtain the volume needed for roots to grow to full size is providing adequate space unhindered by utilities or other encroachments. However, it is often hard to reserve space dedicated just to street trees in an urban right-of-way with so many other uses competing for the room they need. As a result, some creative solutions, though they cost more to install, have become useful alternatives in crowded subsurface space. Structural soils, root paths, and “silva cells” leave void space for roots and still allow sidewalks to be constructed near trees.

Root Paths can be used to increase tree root volume by connecting a small tree root volume with a larger subsurface volume nearby. A tunnel-like system extends from the tree underneath a sidewalk and connects to an open space on the other side.

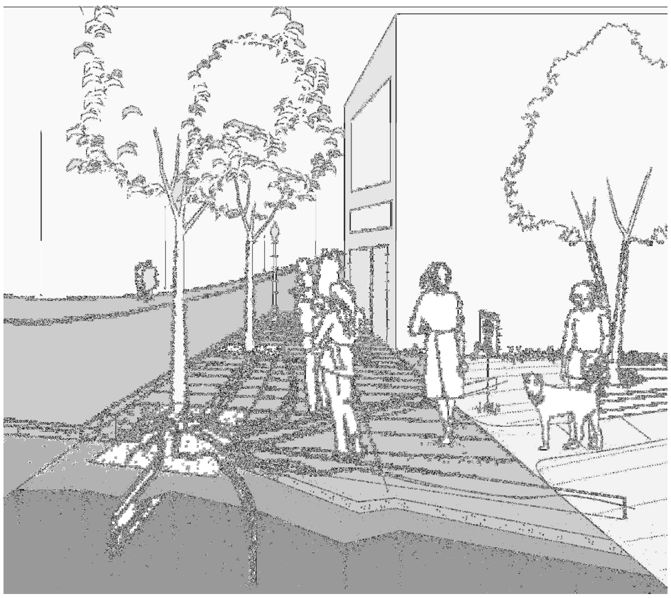


Figure 5. Root Paths direct tree roots under paving and into better soil areas for tree root growth
(Source: Arlington County, VA).

Silva Cells[17] are another option for supporting sidewalks near trees while still providing enough space for roots to grow. These plastic milk crate-like frames fit together and act as a supporting structure for a sidewalk while leaving room for uncompacted soil and roots inside the frame.

Permeable pavement sidewalks are another enhancement to the root space. They provide moisture and air to roots under sidewalks. Soils under permeable pavements can still become compacted. Structural soils[18] are a good companion tree planting practice to permeable pavement. When planting a tree in structural soils an adequate tree root volume is excavated and filled with a mix of stone and soil that still provides void space for healthy roots and allows for sidewalks, plazas or other paved surfaces to be constructed over them.

Case Studies

Portland, OR: Green Street Pilot Projects

Portland, Oregon is a national leader in developing green infrastructure. Portland’s innovation in stormwater management was necessitated by the need to satisfy a Combined Sewer Overflow consent decree, Safe Drinking Water Act requirements, impending Total Maximum Daily Load limitations, Superfund cleanup measures and basement flooding. Through the 1990s, over 3 billion gallons of combined sewer overflow discharged to the Willamette River every year.[19] All of these factors plus leadership and local desires to create green solutions and industries compelled the city to implement green infrastructure as a complement to adding capacity to the sewer system with large pipe overflow interceptors. Despite gaps in long-term performance data, Portland took a proactive approach in implementing green infrastructure pilot projects.

Portland’s green infrastructure pilot projects have their roots in the city’s 2001 Sustainable Infrastructure Committee. The committee, consisting of representatives from Portland’s three infrastructure management Bureaus, documented the city’s ongoing efforts toward sustainable infrastructure, gathered research on green infrastructure projects from around the country, and identified opportunities for local pilots.[20, 21, 22]

Figure 6. Silva cell structures support the sidewalk while providing root space for street trees
(Source: Deep Root Partners, LP).

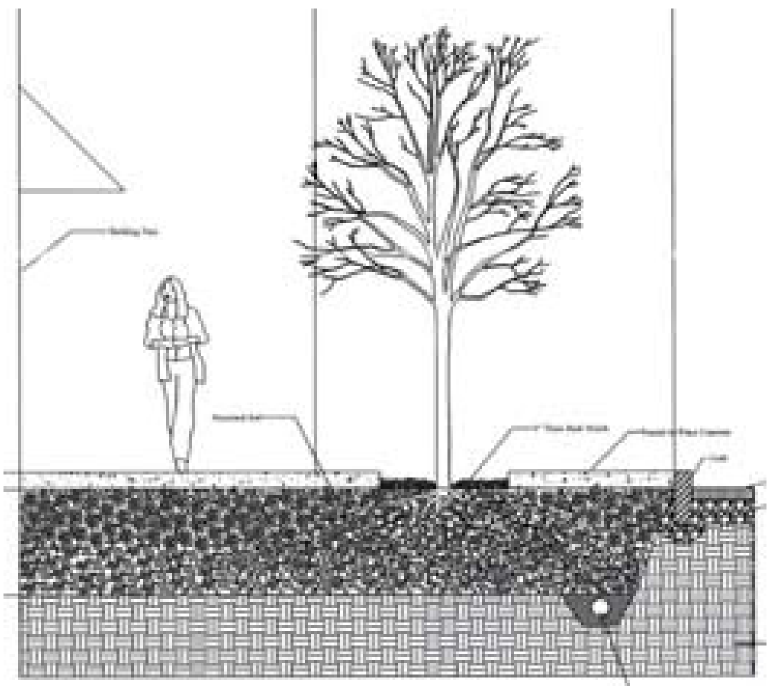


Figure 7. Structural soils provide void space for root growth and load-bearing for sidewalk
(Source: Urban Horticulture Institute, Cornell University).

One of the Bureau of Environmental Services' (BES) earliest green infrastructure retrofit projects within the right-of-way was a set of two stormwater curb extensions on NE Siskiyou Street. Portland had been retrofitting many streets with curb extensions for the purpose of pedestrian safety, but this was the first done for the purpose of treating street runoff. In a simulated 25-year storm event flow test, the curb extensions captured 85% of the runoff volume that would be discharged to the combined sewer system and reduced peak flow by 88%.[23]

Between 2003 and 2007, Portland designed and implemented a variety of Green Street pilots. Funding sources for these projects have come from BES, Portland Department of Transportation, U.S. EPA, and an Innovative Wet Weather Fund. BES combined funds with an EPA grant to create the Innovative Wet Weather Fund. In 2004, nearly $3 million from the Innovative Wet Weather Fund was budgeted for a long list of projects from city green roofs, public-private projects, and a number of pilot projects within the right-of-way.[24] Several pilots have been cost competitive with or less costly than conventional upgrades. The Bureau recognizes that costs will decrease once these projects become more routine. Many of the pilot project costs included one time costs such as the development of outreach materials and standard drawings.

Figure 8: NE Siskiyou Vegetated Curb Extensions
Source: City of Portland – Bureau of Environmental Services

Table 8. Portland, OR - Green Street Pilot Projects

Location	Design	Year Completed	Cost
NE Siskiyou b/w NE 35th Pl. and NE 36th Ave	Stormwater curb extension	2003	$20,000
3 blocks of the Westmoreland Neighborhood	Permeable Pavers in parking lanes and curb to curb	2004	$412,000
SE Ankeny b/w SE 56th and SE 57th Ave.	Stormwater curb extensions	2004	$11,946
NE Fremont b/w NE 131st and 132nd Av	Stormwater curb extension	2005	$20,400
SW 12th Ave b/w SW Montgomery and Mill	Stormwater planters	2005	$34,850
East Holladay Park	Pervious paver parking lot	2005	$165,000
4 blocks of North Gay Avenue b/w N Wygant and N Sumner	Porous concrete in curb lanes and curb to curb; porous asphalt in curb lanes and curb to curb	2005	--
SW Texas	Stormwater wetlands and swales	2007	$2.3 million
Division St. – New Seasons Market	Stormwater planters and swales	--	--
SE Tibbetts and SE 21st Ave.	Stormwater curb extension and planters	--	--

Source: Portland Bureau of Environmental Services, 2008
http://www.portlandonline.com/bes/index.cfm?c=44463&

Each of the pilot projects have been well documented by BES. A consistent format has been used to describe pilot background, features, engineering design, landscaping, project costs, maintenance, monitoring, and, most importantly, lessons learned. These case studies as well as other Green Street documentation can be found on BES's Sustainable Stormwater webpage, http://www.portlandonline.com/BES/index.cfm?c=34598. Due to physical factors (drainage, slope, soil, existing utilities, multiple uses) and development factors (retrofit, redevelopment, and new construction), there will be many variations on Green Streets. As part of the program, a continually updated Green Street Profile Notebook will catalog the successful green street projects. Users can use the Notebook for permitting guidance, to identify green streets facilities appropriate for various factors, but the document is not a technical document with standard details.

The Green Streets Team

The City of Portland, OR is widely acknowledged for long term, forward thinking, and comprehensive transportation and environmental planning. Portland recognized the fact that 66% of the City's total runoff is collected from streets and the right-of-way.[25] The city also saw the potential for transportation corridors to meet multiple objectives, including:

- Comprehensively address numerous City goals for neighborhood livability, sustainable development, increased green spaces, stormwater management, and groundwater protection;
- Integrate infrastructure functions by creating "linear parks" along streets that provide both pedestrian/bike areas and stormwater management;
- Avoid the key impacts of unmanaged stormwater whereby surface waterbodies are degraded, and water quality suffers;
- Manage stormwater with investments citizens can support, participate in, and see;
- Manage stormwater as a resource, rather than a waste;
- Protect pipe infrastructure investments (extend the life of pipe infrastructure, limit the additional demand on the combined sewer system as development occurs);
- Protect wellhead areas by managing stormwater on the surface; and
- Provide increased neighborhood amenities and value.

In a two phased process from 2005 to 2007, the Green Streets Team, a cross agency and interdisciplinary team, developed a comprehensive green streets policy and a way forward for the green streets agenda. Phase 1 identified challenges and issues and began a process for addressing them. Barriers to the public initiation of green street projects included a code and standards that would disallow or discourage green street strategies, long term performance unknowns, and maintenance responsibilities. To address these barriers, the Green Streets Team organized into subgroups focusing on outreach, technical guidance, infrastructure, maintenance, and resources.

Phase 2 of the Green Streets project synthesized the opportunities and solutions identified in Phase 1 into a citywide Green Streets Program. The first priority for this phase was the drafting of a binding citywide policy. The resolution was adopted by the Portland City Council in March 2007.

Prior to the start of the Portland effort, 90% of implemented green street projects were issued by private permits rather than city initiated projects.

Six Approaches to Implementing Green Streets	
Pathway	**Implementation**
City-initiated street improvement projects	City designs, manages, maintains
City-initiated stormwater retrofits	City designs, manages, maintains
Neighborhood-initiated LIDs	
Developer-initiated subdivisions with public streets	Developer designs and builds via City permit and review process, then turns over new right of way to the City after warranty period
Developer-initiated subdivisions with private streets	Developer designs and builds via City permit and review process, and turns over to home-owner association
Developer-related initiated frontage improvements on existing public streets	Developer designs and builds new sidewalks and curbs via City permit and review process, usually because the City required it via a building permit or via a land division

Source: Portland Green Streets, Phase 1

Portland City Council Approved Green Streets Policy

Goal: City of Portland will promote and incorporate the use of green street facilities in public and private development.

City elected officials and staff will:

1. Infrastructure Projects in the Right of Way:

   a. Incorporate green street facilities into all City of Portland funded development, redevelopment or enhancement projects as required by the City's September 2004 (or updated) Stormwater Management Manual. Maintain these facilities according to the May 2006 (or updated) Green Streets Maintenance Policy.

   If a green street facility (infiltrating or flow through) is not incorporated into the Infrastructure Project, or only partial management is achieved, then an off site project or off site management fee will be required.

   b. Any City of Portland funded development, redevelopment or enhancement project, that does not trigger the Stormwater Manual but requires a street opening permit or occurs in the right of way, shall pay into a "% for Green" Street fund. The amount shall be 1% of the construction costs for the project.
   Exceptions: Emergency maintenance and repair projects, repair and replacement of sidewalks and driveways, pedestrian and trail replacement, tree planting, utility pole installation, street light poles, traffic, signal poles, traffic control signs, fire hydrants, where this use of funds would violate contracted or legal restrictions.

2. Project Planning and Design:

   a. Foster communication and coordination among City Bureaus to encourage consideration of watershed health and improved water quality through use of green street facilities as part of planning and design of Bureau projects.
   b. Coordinate Bureau work programs and projects to implement Green Streets as an integrated aspect of City infrastructure.
   c. Plan for large-scale use of Green Streets as a means of better connecting neighborhoods, better use of the right of way, and enhancing neighborhood livability.
   d. Strive to develop new and innovative means to cost-effectively construct new green street facilities.
   e. Develop standards and incentives (such as financial and technical resources, or facilitated permit review) for Green Streets projects that can be permitted and implemented by the private sector. These standards and incentives should be designed to encourage incorporation of green street facilities into private development, redevelopment and enhancement projects.

3. Project and Program Funding:

   a. Seek opportunities to leverage the work and associated funding of projects in the same geographic areas across Bureaus to create Green Street opportunities.
   b. Develop a predictable and sustainable means of funding implementation and maintenance of Green Street projects.

4. Outreach:

   a. Educate citizens, businesses, and the development community/industry about Green Streets and how they can serve as urban greenways to enhance, improve, and connect neighborhoods to encourage their support, demand and funding for these projects.
   b. Establish standard maintenance techniques and monitoring protocols for green street facilities across bureaus, and across groups within bureaus.

5. Project Evaluation:

   a. Conduct ongoing monitoring of green street facilities to evaluate facility effectiveness as well as performance in meeting multiple City objectives for:
   - Gallons managed;
   - Projects distributed geographically by watershed and by neighborhood; and

The second priority for Phase 2 was developing communication and planning procedures for incorporating multi-bureaus plans into the scheduled Portland DOT Capital Improvement Program (CIP). Three timeframes for green street project planning were recommended. In the short term, the CIP Planning Group, backed by the citywide policy directive, will shift to a focus on "identifying and evaluating opportunities to partner." For example, coordinating Water Bureau and BES pipe replacement projects with DOT maintenance, repair, and improvement projects. The mid-term approach is more proactive and involves forecasting potential green street projects using existing bureau data and GIS tools. As for the long term, green street objectives will be incorporated into the citywide systems plan which guides city bureaus for the next 20 years.

The Green Street Team methodology propelled Portland's early green street pilot projects into a comprehensive, citywide multi-bureau program. The program built on previous efforts by the Sustainable Infrastructure Committee as well as other efforts such as the 2005 Portland Watershed Management Plan, established a City Council mandated policy, and institutionalized green street development. The outcome of this approach is multi-agency buy-in and responsibility for the effort. For instance, because of their knowledge of plant maintenance, Portland Parks and Recreation is responsible for the maintenance of some DOT installations.

Chicago, IL: Green Alleys Program

The City of Chicago, Illinois has an alley system that is perhaps the largest in the world. These 13,000 publicly owned alleys result in 1,900 miles, or 3,500 acres, of impermeable surfaces in addition to the street network. Because the alley system was not originally paved, there are no sewer connections as part of the original design. Over time the alleys were paved and flooding in garages and basements began to occur as a result of unmanaged stormwater runoff. Since the city already spends $50 million each year to clean and upgrade 4,400 miles of sewer lines and 340,000 related structures, the preferred solution to the flooded alleys is one that doesn't put more stress on an already overburdened and expensive sewer system.[26]

In 2003, the Chicago Department of Transportation (CDOT) used permeable pavers and French drain pilot applications to remedy localized flooding problems in alleys in the 48th Ward.[27] These applications proved to be successful and by 2006, CDOT launched its Green Alley Program with the release of the Chicago Green Alley Handbook (Handbook).[28]

The Chicago Green Alley Program is unique because it marries green infrastructure practices in the public right-of-way with green infrastructure efforts on private property. The user-friendly Handbook, which describes both facets of the program including the design techniques and their benefits, is an award winning document. The American Society of Landscape Architects awarded the creators of the Handbook the 2007 Communications Honor Award for the clear graphics and simple, yet effective, message.[29] The Handbook explains to the residents why green infrastructure is important, how to be good stewards of the Green Alley in their neighborhood, and what sorts of "green" practices they can implement on their property to reduce waste, save water, and help manage stormwater wisely.

While the initial impetus behind the Green Alley Program was stormwater management, Chicago decided to use this opportunity to address other environmental concerns as well as reducing the urban heat island effect, recycling, energy conservation, and light pollution.

Green Infrastructure in the Right-of-Way

Chicago's Green Alley Program uses the following five techniques in the public right-of-way to "green" the alley:

1. Changing the grade of the alley to drain to the street rather than pond water in the alley or drain toward garages or private property.

2. Using permeable pavement that allows water to percolate into the ground rather than pond on the surface.

3. Using light colored paving material that reflects sunlight rather than adsorbing it, reducing urban heat island effect.

4. Incorporating recycled materials into the pavement mix to reduce the need for virgin materials and reduce the amount of waste going into the landfill.

5. Using energy efficient light fixtures that focus light downward, reducing light pollution.

Figure 9: Permeable Asphalt Installation Using Ground Tire Rubber.
Source: Chicago Department of Transportation, Sustainable Development Initiatives; Streetscape and Urban Design Program, CDOT Division of Project Development.

Four design approaches were created using these techniques. Based on the local conditions, the most appropriate approach is selected. In areas where soils are well-draining, permeable pavement is used. In areas where buildings come right up to the edge of pavement and infiltrated water could threaten foundations, impermeable pavement strips are used on the outside with a permeable pavement strip down the middle. In areas where soils do not provide much infiltration capacity, the alley is regraded to drain properly and impermeable pavement made with recycled materials is used. Another approach utilizes an infiltration trench down the middle of the alley. Light colored (high albedo) pavement, recycled materials, and energy efficient, glare reducing lights are a part of each design approach.

Green Infrastructure on Private Property

The Handbook also describes actions that property owners can take to "green" their own piece of Chicago. The Handbook describes the costs, benefits, and utility of the following practices:

- Recycling;
- Composting;
- Planting a tree;
- Using native landscape vegetation;
- Constructing a rain garden;
- Installing a rain barrel;
- Using permeable pavement for patios;
- Installing energy efficient lighting; and
- Utilizing natural detention.

By bringing this wide range of "green" practices to the attention of homeowners, the positive impacts of the Green Alley Program spread beyond the boundaries of the right-of-way, increasing awareness and providing practical resources to help community members be a part of the solution.

Chicago Green Alley Cost Considerations

When the program began in 2006, repaving the alleys with impermeable pavement ranged in cost from $120,000 to $150,000, whereas a total Green Alley reconstruction was more along the lines of $200,000 to $250,000.[30] While less expensive conventional rehabilitation options may seem more attractive, they don't provide a solution to the localized flooding issues or the combined sewer system overflow problems. Sewer system connections could be established to solve the localized flooding problem, but it would add to the already overburdened sewer system and increase the cost of the reconstruction to that of the impermeable alley option. Consequently, the higher priced Green Alley option proved to be the best investment as it has multiple benefits in addition to solving localized flooding and reducing flow into the combined sewer system. The additional benefits of the Green Alley Program include not only urban heat island effect reduction, material recycling, energy conservation, and light pollution reduction, but also the creation of a new market.

In 2006, when the Green Alley Program began, the city paid about $145 per cubic yard of permeable concrete. Just one year later, the cost of permeable concrete had dropped to only $45 per cubic yard. Compared with the cost of ordinary concrete, $50 per cubic yard, permeable concrete may have seemed like an infeasible option in the past to customers wanting to purchase concrete.[31] After the city's initial investment in the local permeable concrete market, the product cost has come down making permeable concrete a more affordable option for other consumers besides the city. This has resulted in an increased application of permeable concrete throughout the region.

Figure 10: Permeable Pavers and Permeable Concrete Chicago Alleys
(Source: Abby Hall, US EPA)

The success of the Chicago Green Alley Program is evident. Not only are the alleys been "greened" as a result of the program, the surrounding properties and even the surrounding neighborhoods are experiencing the positive impacts of the program's implementation.

Conclusions and Recommendations

Incorporating green streets as a feature of urban stormwater management requires matching road function with environmental performance. Enhancing roads with green elements can improve their primary function as a transportation corridor while simultaneously mitigating their negative environmental impacts. In theory and practice many municipalities are not far removed from dedicated green streets programs. Street tree and other greenscaping programs are often identified and promoted along urban transportation corridors. Adapting them to become fully functional green streets requires minor design modifications and an evaluation of how to maximize the benefits of environmental systems.

Portland's green streets program demonstrates how common road and right-of-way elements (e.g., traffic calming curb extensions, tree boxes) can be modified and optimized to provide stormwater management in addition to other benefits. The curb cuts and design variations to allow runoff to enter the vegetated areas are subtle changes with a significant impact and demonstrate how stormwater can be managed successfully at the source. One of the biggest successes of the program was reassessing common design features and realizing that environmental performance can be improved by integrating stormwater management.

Where Portland used vegetation, Chicago's Green Alley Program similarly demonstrates that hardscape elements can be an integral part of a greening program. By incorporating permeable pavements that simulate natural infiltration, Chicago enhances the necessary transportation function of alleys while enhancing infrastructure and environmental management. Portland also contrasts the "soft" and "hard" elements of green streets by using both permeable pavements and vegetated elements. The green options available demonstrate the flexibility of green infrastructure to satisfy road function and environmental objectives and highlight why transportation corridors are well suited for green infrastructure.

Elements necessary for a successful green streets program:

- **Pilot projects are critical.** The most successful municipal green street programs to date all began with well documented and monitored pilot projects. These projects have often been at least partially grant funded and receive the participation of locally active watershed groups working with the city infrastructure programs. The pilot projects are necessary to demonstrate that green streets can work in the local environment, can be relied upon, and fit with existing infrastructure. Pilot projects will help to dispel myths and resolve concerns.
- **Leadership in sustainability from the top.** The cities with the strongest green streets programs are those with mayors and city councils that have fully bought into sustainable infrastructure. Council passed green policies and mayoral sustainability mandates or mission statements are needed to institutionalize green street approaches and bring it beyond the token green project.
- **Buy-in from all municipal infrastructure departments.** By their nature, green streets cross many municipal programs. Green street practices impact stormwater management, street design, underground utilities, public lighting, green space planning, public work maintenance, and budgeting. When developing green streets, all of the relevant agencies must be represented. Also, coordination between the agencies on project planning is important for keeping green infrastructure construction costs low. Superior green street design at less cost occurs when sewer and water line replacement projects can be done in tandem with street redevelopment. These types of coordination efforts must happen at the long-term planning stage.
- **Documentation.** Green street projects need to be documented on two levels, the design and construction level and on a citywide tracking level. Due to the different street types and siting conditions, green street designs will take on many variations. By documenting the costs, construction, and design, the costs of similar future projects can be minimized and construction or design problems can be avoided or addressed. Tracking green street practices across the city is crucial for managing maintenance and quantifying aggregate benefits.
- **Public outreach.** Traditional pollution prevention outreach goes hand in hand with green street programs. Properly disposing of litter, yard waste, and hazardous chemicals and appropriately applying yard chemicals will help prolong the life of green street practices. An information campaign should also give the public an understanding of how green infrastructure works and the benefits and trade offs. In many cases, remedial maintenance of green street practices will be performed by neighboring property owners; they need to know how to maintain the practices to keep them performing optimally.

As public spaces, roads are prime candidates for green infrastructure improvements. In addition to enabling legislation, and technical guidance, developing a green streets program requires an institutional re-evaluation of how right-of-ways are most effectively managed. This process typically includes:

- Assessing the necessary function of the road and selecting the minimum required street width to reduce impervious cover;
- Enhancing streetscaping elements to manage stormwater and exploring opportunities to integrate stormwater management into roadway design; and
- Integrating transportation and environmental planning to capitalize on economic benefits.

The use of green streets offers the capability of transforming a significant stormwater and pollutant source into an innovative treatment system. Green streets optimize the performance of public space easing maintenance concerns and allowing municipalities to coordinate the progression and implementation of stormwater control efforts. In addition, green streets optimize the performance of both the transportation and water infrastructure. Effectively incorporating green techniques into the transportation network provides significant opportunity to decrease infrastructure demands and pollutant transport.

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APPENDIX K

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