Biofiltration Swale

Design Guidance

December 2020

California Department of Transportation
HQ Division of Design

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List of Abbreviations

AASHTO	American Association of State Highway and Transportation Officials
BEES	Basic Engineering Estimating System
BMP	Best Management Practice
CDA	contributing drainage area
CF	cubic feet
cfs	cubic feet per second
CRZ	Clear Recovery Zone, (AASHTO Clear Zone)
CY	cubic yards
DPP	Design Pollution Prevention
DPPIA	Design Pollution Prevention Infiltration Area
ECTC	Erosion Control Technology Council
EPP	Erosion Prediction Procedure
FHWA	Federal Highway Administration
ft	foot/feet
ft/s	foot/feet per second
g/cm^3	grams/cubic centimeter
GSRDs	Gross Solid Removal Devices
H:V	Horizontal:Vertical
HDM	Highway Design Manual
HEC	Hydraulic Engineering Circular
HQ	Headquarters
hr	hour
HRT	Hydraulic Residence Time
in	inch/inches
LID	Low Impact Development
max	maximum
min	minimum
MSE	Mechanically Stabilized Embankments
MWELO	Model Water Efficient Landscape Ordinance
NPDES	National Pollutant Discharge Elimination System
NRCS	Natural Resources Conservation Service
nSSP	non-Standard Special Provision
OHSD	Office of Hydraulics and Stormwater Design
PA/ED	Project Approval/Environmental Document
PDT	Project Development Team
PE	Project Engineer
PECE	Preliminary Engineer's Cost Estimate
PEP	plant establishment period
PID	Project Initiation Document
PPCE	Project Planning Cost Estimate
PPDG	Project Planning and Design Guide – Stormwater Quality Handbook
PS&E	Plans, Specifications, and Estimate
RECPs	Rolled Erosion Control Products
RUSLE2	Revised Universal Soil Loss Equation
RVTS	Roadside Vegetated Treatment Sites Study
RWQCB	Regional Water Quality Control Board
sec	second
SQFT	square feet
SQYD	square yard
SRE	Soil Resource Evaluation
SSHM	Small Storm Hydrology Method
SSP	Standard Special Provision
SWDR	Stormwater Data Report
TBMP	Treatment Best Management Practice
TRM	Turf Reinforcement Mat
TSS	total suspended solids
USDA	United States Department of Agriculture
WQ	water quality
WQF	Water Quality Flow
WQV	Water Quality Volume

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Section 1

Introduction

This document provides guidance to Caltrans Designers for incorporating Biofiltration Swale Treatment Best Management Practices (TBMPs) into projects during the planning and design phases of Caltrans highways and facilities. Biofiltration Swales are a soil based Low Impact Development (LID) TBMP approved for use on Caltrans facilities. Biofiltration Swales are open channels that convey highway drainage and are designed to treat water quality volume and flow. A Biofiltration Swale may also be known as a bioswale, swale, biofilter, and vegetated swale. The primary functions of this document are to:

1. Describe a Biofiltration Swale
2. Provide design guidance
3. Review the required elements for implementing a Biofiltration Swale into Plans, Specifications, and Estimates (PS&E) packages

It is assumed that the need for post construction TBMPs has already been determined in accordance with the guidelines and procedures presented in the Project Planning and Design Guide (PPDG; Caltrans 2019b).

The following guidance is provided based on Caltrans pilot studies and professional design experience. Designers may utilize alternatives to the calculation methodologies presented in this guidance. Alternative calculations and design decisions must be documented in the project Stormwater Data Report (SWDR) or the Project File. The SWDR template can be found in the PPDG.

1.1 Design Responsibility

The Project Engineer (PE) is responsible for the design of Biofiltration Swale hydrology, hydraulics, grading, and traffic because they are part of the highway drainage system. The designer must consider the highway grading plans and the impacts stormwater infiltration may have on the roadway especially in consideration of the Clear Recovery Zone (CRZ). Coordinate with other functional experts to implement successful and functioning Biofiltration Swales.

Refer to Chapter 800 of the Highway Design Manual, the Headquarters (HQ) Office of Hydraulics and Stormwater Design (OHSD), and District Hydraulics for project drainage requirements. Contact District Landscape Architect for appropriate plant selection based on the physiographic region and the purpose of the BMP. To achieve sustainability requirements, the Project Development Team (PDT) is encouraged to use native and climate appropriate vegetation that does not require irrigation and requires the least amount of maintenance.

1.2 Biofiltration Swales

Biofiltration Swales are a type of biofiltration system with vegetated channels, typically configured as trapezoidal or v-shaped, that receive and convey stormwater flows while meeting water quality criteria and other flow criteria. Biofiltration Swales are a TBMP used for treating stormwater runoff from project areas that are anticipated to produce pollutants of concern (e.g., roadways, parking lots, maintenance facilities). Pollutants are removed by filtration through the vegetation, uptake by plant biomass, sedimentation, adsorption to soil particles, and infiltration through the soil. Pollutant removal capability is related to channel dimensions, longitudinal slope, soil gradation, soil composition, soil compaction, and type of vegetation.

Biofiltration Swales are effective at removing total suspended solids (soil particles), metals, oil and grease, organics, nutrients, trash, and bacteria as noted in the PPDG and TC-30 of the California Stormwater Quality Association (CASQA) manual (CASQA 2003). The effectiveness of Biofiltration Swales can be improved by increasing the amount of water quality volume (WQV) infiltrated, so the total load removed (i.e., infiltrated) is higher (Caltrans 2017a). When site conditions allow, consider amending the TBMP underlying soils to increase infiltration.

The following list demonstrates some advantages of utilizing a Biofiltration Swale as a treatment control BMP.

1. The Caltrans Permit requires PEs to prioritize first infiltration and then flow through TBMPs. Biofiltration Swales can be designed to fulfill both permit requirements.
2. Biofiltration Swales were determined to be an effective TBMP in reducing sediment and heavy metals, as described in the BMP Retrofit Pilot Program Final Report (Caltrans 2004).
3. In the BMP Retrofit Pilot Program Final Report Biofiltration Swales were determined to be cost effective and feasible for highway use. Life cycle costs for Biofiltration Swales were found to be lower than many other BMPs.
4. Biofiltration Swales mimic natural processes that result in infiltration and biofiltration of stormwater runoff close to its source and are therefore considered a LID BMP. LID is a prioritization goal of the Caltrans Permit.
5. Biofiltration Swales may be used alone or at locations upstream of other TBMPs as pretreatment, or as part of a treatment train.

Figure 1-1 is a schematic of a Biofiltration Swale adjacent to a Biofiltration Strip, Figure 1-2 is a photo of Biofiltration Swale constructed to receive runoff from a State highway. Consult with Geotechnical Design, Hydraulics, and Traffic Safety if within the CRZ.

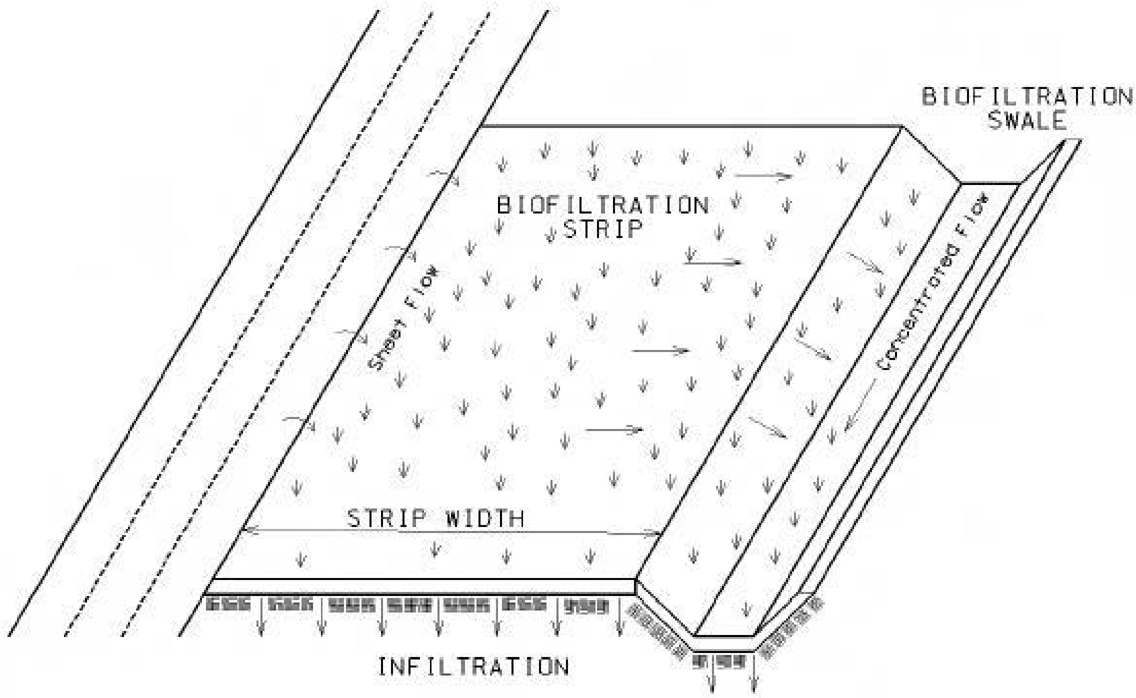

Figure 1-1. Schematic of Biofiltration Swale and Strip

Figure 1-2. Biofiltration Swale (SR-78/Melrose Drive)

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Section 2

Basis of Biofiltration Swale Design

Biofiltration Swales may be considered whenever site conditions and climate allow vegetation to be established, safety criteria are met, and where flow velocities can be mitigated to prevent scour. Biofiltration Swales can also be considered upstream of other TBMPs as either pretreatment or as part of a treatment train.

Checklist T-1, Part 3 in the PPDG, assists in evaluating the initial feasibility of Biofiltration Swales for a project. The checklist identifies design elements that should be considered during the design of Biofiltration Swales. Once the feasibility of the device has been confirmed using Checklist T-1, Part 3 in the PPDG, use the following subsections to further understand the design elements of a Biofiltration Swale for a given site.

2.1 Preliminary Design Criteria

Biofiltration Swales must meet certain design criteria to perform as an effective TBMP. The primary factors to be incorporated into the design are found below in Table 2-1.

Table 2-1. Biofiltration Swale Design Criteria

Parameter	Min. Value	Max. Value
Flow Rate[1]	For water quality treatment: WQF, or portion thereof	For roadway drainage, use the Design Storm (HDM Topic 831)
Bottom Width[2]	0 ft, as v-ditch 2 ft, as trapezoid Consult with District Maintenance	Up to 10 ft for trapezoidal. Consult with District Hydraulics and District Maintenance for v-ditch.
Side Slope (sides of the Biofiltration Swale, in cross section)	No minimum	4H:1V, discuss other side slopes with District Maintenance
Longitudinal Slopes	0.25%	1% to 2% preferred, 6% maximum. The resulting depth, velocity, and HRT must meet the Interrelationship formula
Hydraulic Residence Time (HRT) at WQF	5 minutes	No maximum
Length of flow path	As required by minimum HRT	No maximum
Flow Depth during WQF	No minimum	6 inches[3]
Freeboard	Refer to HDM Topic 868 Freeboard Considerations	Refer to HDM Topic 868 Freeboard Considerations
Velocity	No minimum	During WQF[3]: 1.0 ft/s During Design Storm: Refer to HDM Table 865.2

Table 2-1. Biofiltration Swale Design Criteria		
Interrelationship Formula for HRT, depth, and velocity	1300 sec^2/SQFT	No maximum
Manning's *n* value	During WQF: 0.24 recommended[4] During Design Storm: 0.05 (HDM Table 866.3A)	During WQF: 0.24 recommended[4] During Design Storm: 0.05 (HDM Table 866.3A)
Vegetative Coverage and Type	65% minimum coverage[5] Type - See Appendix A	65% minimum coverage[5] Type - See Appendix A

1. Biofiltration Swale should be designed based on both the WQF and peak flow of the Design Storm, unless bypass of the larger flows is made.
2. Consult with District Maintenance on proposed bottom width to ensure maintenance feasibility. For example, if the smallest mower on hand in the District is 4-feet wide the Biofiltration Swale minimum bottom width is 4-feet.
3. Maximum value may be limited if HRT less than 10 minutes, use the Interrelationship Formula. Values may be higher if protected from erosion, refer to HDM Table 865.2.
4. Refer to HDM Table 816.6A. If the proposed grass type or its conditions are not known, use n = 0.24. If the grass condition is known, refer to Federal Highway Administration (FHWA) Hydraulic Engineering Circular (HEC) No. 15, Chapter 4.1 (FHWA 2005). The use of 0.24 is adequate for almost all situations, as Manning's Equation would be used to calculate the velocity and the depth, and these parameters seldom control the design. Soil amendments (such as compost material) may increase Manning's n value; substantiate use of any higher value in the SWDR.
5. Vegetative cover is the percentage of soil surface in contact with plant stems and leaves, including the area covered by leaves, stems, or other plant parts that extend no more than 12 inches above the ground surface.

2.2 Site Soils and Infiltration

The amount of runoff infiltrated by Biofiltration Swales should be calculated and documented as this provides a treatment train BMP benefit. Since Biofiltration Swales are flow based BMPs and infiltration is a volume based BMP, percentages of each amount can be calculated to determine total treatment.

When infiltrative type BMPs are proposed, infiltration testing and depth to seasonal high groundwater may be needed for the project. At the PID phase, use historic soil information or previous geotechnical reports from projects within the area to determine existing soil types and infiltration rates. Designers can use the Digital Archive of Geotechnical Data, (GeoDOG) to search archived geotechnical information at this location; https://geodog.dot.ca.gov/

The minimum effort required to determine infiltration rates may be obtained using Caltrans Water Quality Planning Tool (http://svctenvims.dot.ca.gov/wqpt/wqpt.aspx) using the NRCS maps layer (use the Soil Details layer under the Risk Level Determination subsection) to determine the Hydrologic Group at the location of the Treatment BMP. The Hydrologic Group can be input into Caltrans Infiltration Tool and the tool defaults to typical infiltration rates for each type of soil (A, B, C or D), bulk density, specific gravity and void ratios. Note this methodology is less desirable because soils most likely have been disturbed within the highway prism. It is up to the PE to determine the level of effort (including cost, schedule and scope issues) to determine the inputs into the Caltrans Infiltration Tool or other infiltration calculation methodology.

Coordination of geotechnical tests required for inputs to the Caltrans Infiltration Tool IT4 are recommended to be requested at the 0 phase while other soil testing is normally being conducted. The IT4 excel spreadsheet tool can be used to model the biofiltration swale's infiltration performance for the water quality storm event. Grain Size Curves will help determine the suitability of an area for infiltration. Locations that contain large fractions of silt and clay where the D_{10} > 0.02mm and D_{20}> 0.06mm may indicate slow infiltration rates.

At the PA/ED phase, preliminary geotechnical or site investigation studies are typically prepared and are used to further develop the discussion of the geotechnical features within the project. Well records can provide information regarding the depth from surface to seasonal high groundwater.

At the PS&E phase, the locations and details of the TBMPs are known and the project-specific Geotechnical Design Report is typically finalized. The Geotechnical Design Report should generally describe features that relate to stormwater quality design (e.g., types of soils, groundwater depth and conditions) and may include infiltration rates and the detailed soil testing performed at proposed stormwater TBMP locations. The findings of the report are used to update the BMP design assumptions.

Specific soils testing to be reported in the Geotechnical Design Report must be carefully considered. Soil testing, including determining the infiltration rate of site soils, should be completed as part of the Geotechnical request. The infiltration and soil property tests that may be considered for inclusion in the Geotechnical request are listed in Tables 2-2 and 2-3. See Appendix A for additional soils tests.

Table 2-2. Infiltration and Soil Properties Testing Table for Input into the Caltrans Infiltration Tool	
Parameter	Test method(s)
Infiltration Rate, in/hr	CTM 750 (modified for shallow depth) ASTM D5126 (Single-Ring/Infiltrometer) ASTM D3385 (Double-Ring/Infiltrometer) ASTM D8152-18 (Modified Philip Dunne/Infiltrometer) CTM 220
Bulk Density, Dry Density, Water Content	ASTM D7263-09 ASTM D1557 CTM 216 – compaction behavior
Specific Gravity	CTM 209 – specific gravity of the soil ASTM D1557 ASTM D854
Void Ratio	ASTM D1556

Table 2-3. Other Possible Soil Tests	
Parameter	Test method(s)
Hydraulic Conductivity, Saturated	ASTM D5856
Soil Classification	AASHTO M145 ASTM D2487
Particle Size Distribution	CTM 202 - sieve analysis CTM 203 - hydrometer
Remolded Moisture Curve	ASTM D698 ASTM D1557

In addition to the soil tests listed above there may be additional effort to ensure the effectiveness of infiltration:

- Which project phase the tests are completed in, as some preliminary information may be needed prior to PS&E
- The number of tests needed and spacing of the tests (i.e., if the BMP is 50 ft long vs. 0.25-mile-long) to adequately categorize conditions
- Shallow depth of geotechnical tests to estimate infiltration rates

2.3 Soil Amendment Consideration

This section focus is soil amendments for infiltration and WQV storage. Soil compaction requirements in the Caltrans Standard Specifications section 19 should be followed or use an NSSP from OHSD for changes to the compaction.

If testing shows that the existing site soils have low infiltration, consider incorporating soil amendments to increase storage and infiltration capabilities of the WQV. A schematic of an amended embankment is shown in Figure 2-1. Amended soils may be considered for the invert of the TBMP when the native soils have low infiltration rates. The Caltrans Infiltration Tool may be used to help design amendments and to determine storage capacity and infiltration capabilities.

The primary purpose for soil amendments are for infiltration and WQV storage in accordance with the Caltrans NPDES permit for TBMP sizing. Soil amendments may have other purposes depending on the site design (e.g., scour protection, bearing strength, erosion control, vegetation establishment) and should be designed accordingly. Design of soil amendments should be carefully considered and coordinated with other functional experts such as District Hydraulics, District Traffic Operations, District Landscape Architecture, Geotechnical Design, Traffic Safety, and OHSD. See Appendix A for additional information on soil amendments for Biofiltration TBMPs.

2.4 Safety Considerations

Biofiltration Swale BMPs should be located using the general roadway drainage considerations for safety and CRZ concept in the AASHTO manual (AASHTO 2011). Traffic safety is an important part of highway drainage facility design. The roadside Biofiltration Swale should provide a traversable section for errant traffic leaving the traveled way within the CRZ (HDM Topics 304, 309, and 861.4). Coordinate with other functional experts such as District Traffic Operations, District Maintenance, District Hydraulics, Geotechnical Design, and Traffic Safety as applicable.

2.5 Restrictions/Coordination

Successful implementation and utilization of a Biofiltration Swale as a TBMP will require proper siting by the PDT with coordination of District Hydraulics, District Maintenance, District Landscape Architecture, Geotechnical Design, and Traffic Safety, as applicable. Biofiltration Swale design decisions and coordination must be documented in the SWDR and project file.

Additional design criteria applicable to the use of the Biofiltration Swale BMP are as follows:

1. Caltrans Water Conservation Requirements: Limit planting to native and non-native plants appropriate for the project micro-climate so no water beyond natural rainfall is required for healthy plant survival after the plant establishment

period. Limit supplemental water provided by irrigation to non-potable, unless not practical.

2. Biofiltration Swales in arid regions are not recommended because it will require installation of a temporary (or permanent) irrigation system to ensure 65 percent vegetative coverage, and/or must be planted with vegetation that will go dormant outside of the rainy season. Consult with the District Landscape Architect to verify that recycled water is available for irrigation. If no recycled water is available and PDT determines that vegetation is unlikely to be successful, then non-vegetated BMPs (e.g., DPPIAs) are recommended.
    a. Caltrans Water Quality Planning Tool may be used to determine arid and semi-arid regions at: http://www.owp.csus.edu/WQPT/wqpt.aspx
    b. In extremely arid places where permanent irrigation would be required, Biofiltration Swales would not generally be recommended.
3. When irrigation is required, the District Landscape Architect will comply with the California Department of Water Resources Model Water Efficient Landscape Ordinance (MWELO). Guidance on water conservation and the MWELO is available at: http://www.dot.ca.gov/design/lap/landscape-design/irrigation/irrigation-mwelo.html
4. There may be locations, especially in an urban environment, where infiltration is not allowed. Consult with District Hazardous Waste Coordinator and District/Regional National Pollutant Discharge Elimination System (NPDES) Coordinator if Biofiltration Swales are proposed at locations having contaminated soils or above contaminated groundwater plumes. Coordinate with the Regional Water Quality Control Board (RWQCB) to discuss feasibility and design options in these locations.
5. Biofiltration Swales can be used to effectively attenuate some flows depending on the site conditions and site hydrology. Amended soils and vegetation seeding, with correctly designed Biofiltration Swales, help in the attenuation of flows.
6. Biofiltration Swales are not generally subject to setback restrictions; however, if unusual geotechnical conditions exist, or if a Biofiltration Swale is proposed above a retaining wall and the soils are known to be especially erodible or permeable, consult with Geotechnical Design.
7. Soil testing and a percolation test is recommended. Soil amendments should be considered by the PDT to increase infiltration and vegetation establishment success.
8. Design the grading plans and temporary BMPs to stabilize slopes during the transition period until vegetation is established.

Section 3

Getting Started

Site conditions are evaluated to obtain the design parameters that will be used to determine if a Biofiltration Swale is suitable based on the Feasibility Criteria described in Section 2, and in the PPDG. First, determine the portion of WQV infiltrated by the BMP then verify that the Biofiltration Swale can convey the Design Storm[1] flows. Obtain values for contributing drainage area (CDA) length, longitudinal slope, and length of flow path from the project design information. An example of these calculations is not provided.

3.1 Preliminary Design Parameters

The calculations in this guidance assume instantaneous runoff to the BMP (i.e., 'slug-flow') which does not consider active treatment during the event, leading to conservative sizing designs. A sizing alternative to account for timing of runoff is to perform rainfall-runoff and unsteady-flow storage routing computations for the BMP. When the runoff is distributed over the duration of an event, early-event runoff can be treated and released before the peak runoff arrives. Using these calculations, the BMP does not need to be sized to store the entire runoff volume at once (i.e., 'slug-flow'), leading to smaller designs. By accounting for active treatment occurring during the event, an increase in the treated WQV can be expected. Details of this methodology and findings are discussed in the Review of Design Guidance for Sizing Media Filters for Stormwater Quality Treatment (Caltrans 2019d).

Additionally, when an infiltrative BMP is installed in a Type A or Type B soil the BMP footprint can be reduced while treating the same WQV. The following figure shows an example of how accounting for active treatment and native soil type using the Caltrans Infiltration Tool IT4 tool impacts BMP size. The example shows that in a Type A soil a BMP can be 60% smaller than if it were installed in Type C or Type D soils.

[1]The Design Storm flow is described in HDM Chapter 830, Transportation Facility Drainage. Design Storm is typically the 25-year storm; confer with District Hydraulics.

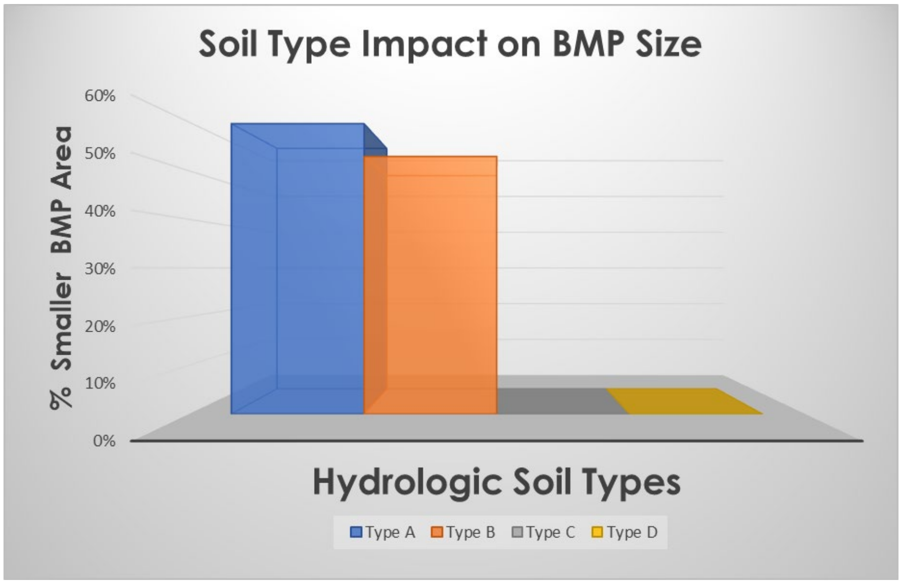

Figure 3-1. BMP Size Reduction Based on Soil Type

Alternative calculations may be used by the PE for a specific project and must be developed by a qualified professional in consultation with the District/Regional Design Stormwater Coordinator and documented in the SWDR. Consult with DEA and OHSD for design approval or to determine if a Special Design or pilot is required.

3.1.1 Contributing Drainage Area and WQV

The WQV generated by the BMP CDA is calculated using the Small Storm Hydrology Method (PPDG Section 5.3). The Caltrans Infiltration Tool version IT4 can also be used when this BMP site has infiltration capacity. An explanation of CDA delineation and WQV calculation and example can be found in Section 3 of the current DPPIA Design Guidance (Caltrans 2019a).

3.1.2 Water Quality Flow

Biofiltration Swales are designed to treat water quality runoff by flow based treatment. The TBMP can be designed using the Caltrans Infiltration Tool version IT4 hydrograph methodology, or other simulation methodology, if infiltration is also being included. Another option is to use Caltrans Bioswale Calculator (Caltrans 2020b) or Caltrans Bioswale Spreadsheet (Caltrans 2020c) or other hydraulic design tools that use the Rational Method to calculate the runoff as WQF. Calculate the WQF generated by the entire BMP CDA to size the Biofiltration Swale when the site has negligible infiltration. When infiltration is feasible, the BMP CDA should be reduced. Obtain the WQF runoff coefficient for use in the Rational Method from Table 5-3 in the PPDG. Obtain the rainfall intensity from Section 5.3 in the PPDG for use in the following equation:

WQF = C x i x A

where

WQF = runoff rate generated by the 85th percentile 24-hour storm event (cfs)

C = runoff coefficient – from PPDG Section 5.3

i = WQF rainfall intensity (in/hr) – from PPDG Section 5.3

A = portion of the CDA to the Biofiltration Swale not infiltrated (acres)

The following hypothetical project example uses the flow-based runoff coefficients to determine the amount of WQF generated by the potential BMP CDA. This example assumes negligible infiltration therefore the area is equal to the entire BMP CDA.

Given:

- Sacramento County
- Potential drainage (Figure 3-2) is 0.3-mile (1,633 ft) long with 2 new lanes, a shoulder, and an embankment
- Average overland slope of the flow path is 1 percent
- None of the runoff is infiltrated by the pervious portion of the CDA
- Rainfall intensity is 0.16 in/hr
- Potential BMP requires flow-based sizing

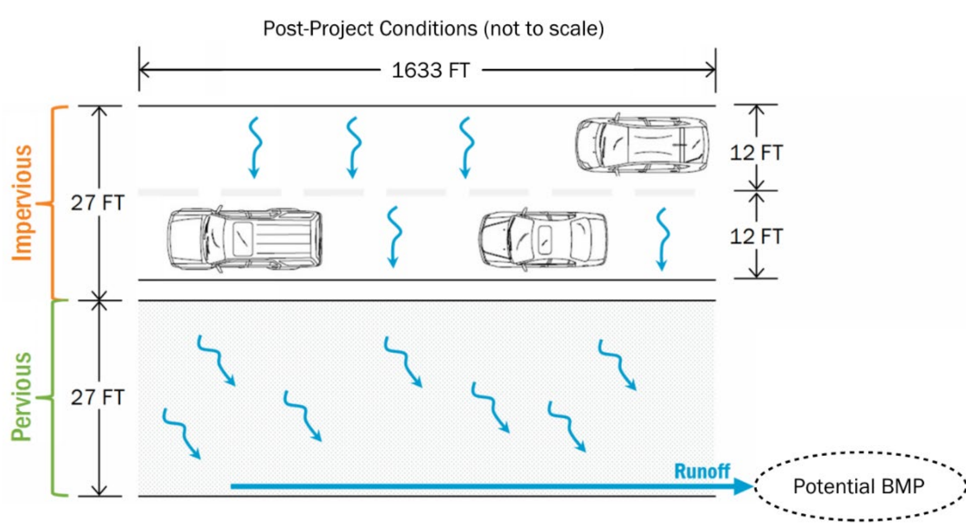

Figure 3-1. Hypothetical Project Scenario, WQF

Step 1: Calculate the impervious and pervious portions of the CDA

The impervious CDA consists of 2 travel lanes and a shoulder

CDA = (12 ft + 12 ft + 3 ft) x 1,633 ft (1 acre / 43,560 SQFT) = 1 acre

The pervious CDA consists of the embankment

CDA = (27 ft) x 1,633 ft (1 acre / 43,560 SQFT) = 1 acre

Note: None of the runoff is infiltrated per the problem statement therefore, no reduction to the CDAs calculated above.

Step 2: Determine the flow-based runoff coefficient

Select Asphalt and Grass from Table 5-3 in the PPDG as shown in Figure 3--3.

Table 5-3. Flow-Based Runoff Coefficients

Surface Type	Runoff Coefficient (C)
Roofs	0.90
Concrete	0.80
Stone, brick, or concrete pavers with mortared joints and bedding	0.80
Stone, brick, or concrete pavers with sand joints and bedding	0.10 – 0.70
Asphalt	0.70
Pervious concrete	0.10 – 0.60
Porous asphalt	0.10 – 0.55
Grid pavements with grass or aggregate	0.10
Crushed aggregate	0.10
Grass	0.10

Figure 3-2. Hypothetical Project Flow-Based Runoff Coefficient

Calculate a composite runoff coefficient

$$C = \frac{C_1A_1 + C_2A_2 + C_3A_3 \ldots + \ldots C_nA_n}{A_1 + A_2 + A_3 \ldots + \ldots A_n}$$

$$C = \frac{(0.10 \times 1\ ac) + (0.70 \times 1\ ac)}{1\ ac + 1\ ac} = 0.40$$

Step 3: Calculate WQF

WQF= C x i x A

Where:

WQF = runoff rate generated by the 85th percentile 24-hour storm event

C = 0.40 (Step 2)

I = 0.16 in / hr (given in problem statement)

A = 2 acres (Step 1)

WQF = 0.40 x 0.16 in / hr x 2 acres = 0.13 cfs

3.1.3 Design Storm Event

When placed in an inline configuration, the Design Storm event will typically govern the Biofiltration Swale design regarding shear stress and erosion. An explanation of Design Storm peak flow determination and an example calculation can be found in Section 3 of the DPPIA Design Guidance (Caltrans 2019a).

3.2 Calculations

3.2.1 BMP Sizing

The flow calculated for the WQF in Section 3.1.2 and the Design Storm in Section 3.1.3 should be used to size the Biofiltration Swale using Manning's Equation. The Caltrans Bioswale Calculator (Caltrans 2020b) may be used to size the TBMP.

An example sizing calculation is shown below. For this example, the Design Storm is assumed to be the 25-year event. Refer to Figure 3-4 for a typical Biofiltration Swale cross section.

$$Q = (^{1.49}/_{n}) \times A \times R^{2/3} \times S^{1/2}$$

where

Q = flow at defined event, Q_{WQF} or Q_{25}, (cfs)

n = Manning's coefficient; recommend using "n" = 0.24 for Q_{WQF} and 0.05 for Q_{25}

A = Cross-sectional area of the flow in the channel

R = Hydraulic Radius = "A" / Wetted Perimeter ("P")[2]

S = longitudinal slope (ft/ft)

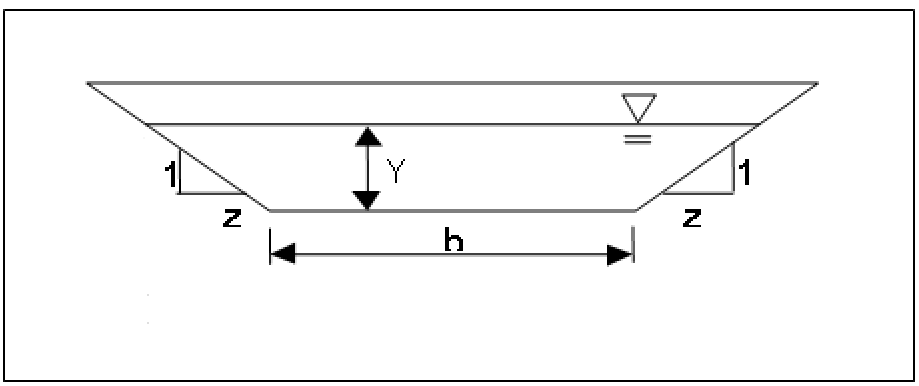

Figure 3-3. Biofiltration Swale Typical Cross Section

[2] The depth of flow is shown in various sources as "y" or "d", but with no difference in meaning.

While Q, n, and S are known values in the equation based on the project's specifics, the area and wetted perimeter are unknowns. For this reason, it is easier to set up as a spreadsheet and assign various flow depths to the swale, which allows the area, the wetted perimeter, and the hydraulic radius to be solved. From these values, Q can be calculated for each of the depths. This process is illustrated for the Design Storm event on Tables 3-1 and 3-2, which were generated using the bioswale spreadsheet available upon request of OHSD (Caltrans 2020c). The row that represents the site has the Q nearest to the flow calculated to enter the Biofiltration Swale during the Design Storm. From this table, the trial values for depth and velocity are obtained. Various hydraulic references present such parametric tables for trapezoidal cross-sections.

For example, with the site parameters shown in Table 3-1 (note that Manning's n is for the Design Storm condition), and with the Q_{25} as 2.10 cfs, using Table 3-2 the depth in the Biofiltration Swale is determined to be 3.6 in, and the velocity is 1.18 ft/s.

Table 3-1. Biofiltration Swale Parameters, Q_{25} Condition

b (ft)	z (side slope)	n	S (ft/ft)	Length (ft)
5.0	4.0	0.05	0.010	150

Table 3-2. Q_{25} Condition– Depth and Velocity

Depth (in) max = 6 in	A (SQFT)	P (ft)	R (ft)	Q_{25} (CF/sec)	Velocity (ft/s) max = 4.0 ft/s
1.20	0.54	5.82	0.09	0.33	0.61
1.80	0.84	6.24	0.13	0.66	0.78
2.40	1.16	6.65	0.17	1.08	0.93
3.00	1.50	7.06	0.21	1.59	1.06
3.60	1.86	7.47	0.25	2.19	1.18
4.20	2.24	7.89	0.28	2.88	1.28
4.80	2.64	8.30	0.32	3.66	1.38
5.40	3.06	8.71	0.35	4.53	1.48
6.00	3.50	9.12	0.38	5.49	1.57

The geometric parameters set during this step, the base width, side slope ratio, and longitudinal slope, are accepted at the trial values. Next, check these trial values against the sizing for WQF and verify that the design meets the criteria for Hydraulic Residence Time and the Interrelationship Formula.

3.2.2 Hydraulic Residence Time

The minimum travel time within the Biofiltration Swale, termed the Hydraulic Residence Time (HRT) is 5 minutes. This can be checked after the proposed Biofiltration Swale site is analyzed using Manning's Equation, as discussed above. The velocity associated with the Q_{WQF} is determined and the HRT is calculated using the proposed length of the Biofiltration Swale:

$$HRT = L / (60 \times V_{WQF})$$

where

L = proposed length of the Biofiltration Swale (ft)

HRT = Hydraulic Residence Time (minutes)

V_{WQF} = velocity at Q_{WQF} (ft/s)

60 = conversion from seconds to minutes

The HRT can also be obtained from the same design spreadsheet. Continuing with the previous example, using the site parameters for the WQF conditions and with the Q_{WQF} as 0.20 cfs, using Table 3-4 the Biofiltration Swale HRT is determined to be 12.94 minutes, which is valid.

Table 3-3. Biofiltration Swale Parameters, Q_{WQF} Condition

b (ft)	z (side slope)	n	S (ft/ft)	Length (ft)
5.0	4.0	0.24	0.010	150

Table 3-4. Q_{WQF} Condition – Hydraulic Residence Time Check

Depth (in) max = 6 in	A (SQFT)	P (ft)	R (ft)	Q_{WQF} (CF / sec)	Velocity (ft/s) max = 1.0 ft/s	HRT (minutes) min = 5 minutes
1.20	0.54	5.82	0.09	0.07	0.13	19.73
1.80	0.84	6.24	0.13	0.14	0.16	15.38
2.40	1.16	6.65	0.17	0.22	0.19	12.94
3.00	1.50	7.06	0.21	0.33	0.22	11.35
3.60	1.86	7.47	0.25	0.46	0.24	10.21
4.20	2.24	7.89	0.28	0.60	0.27	9.35
4.80	2.64	8.30	0.32	0.76	0.29	8.67
5.40	3.06	8.71	0.35	0.94	0.31	8.11
6.00	3.50	9.12	0.38	1.14	0.33	7.65

If the HRT is less than 5 minutes, the length of the Biofiltration Swale should be increased or the velocity at Q_{WQF} should be decreased by either increasing the bottom width or by decreasing the slope.

3.2.3 Interrelationship Formula during WQF

Upon determining that the HRT, d_{WQF}, and V_{WQF} meet their respective design criteria, the Interrelationship Formula shown below also must be satisfied, as the maximum allowed depth of flow and velocity may be restricted if the HRT is less than 5 minutes.

$$(HRT \times 60)/(d_{WQF} \times V_{WQF}) \geq C$$

where:

HRT = Hydraulic Residence Time during Q_{WQF} (minutes)

60 = conversion factor from minutes to seconds

d_{WQF} = depth of flow at Q_{WQF} (ft)

V_{WQF} = velocity of flow at Q_{WQF} (ft/s)

C = constant: 1,300 (sec^2/SQFT)

Validation of the Interrelationship Formula can also be obtained from the design spreadsheet. Continuing with the previous example, using the site parameters shown in Table 3-3 (note that Manning's n is for the WQF conditions), and with the Q_{WQF} as 0.20 cfs, using Table 3-4 the Biofiltration Swale Interrelationship Formula is determined to be 20,093 sec^2/SQFT, which is valid.

Table 3-5. Q_{WQF} Condition– Interrelationship Formula Check

Depth (in) max = 6 in	A (SQFT)	P (ft)	R (ft)	Q_{WQF} (CF / sec)	Velocity (ft/s) max = 1.0 ft/s	HRT (minutes) min = 5 minutes	HRT Criteria Met (sec^2/ft^2) HRT*60/(y*V)≥ 1300
1.20	0.5400	5.82	0.093	0.068	0.13	19.73	93,396
1.80	0.8400	6.24	0.135	0.137	0.16	15.38	37,834
2.40	1.1600	6.65	0.174	0.224	0.19	12.94	20,093
3.00	1.5000	7.06	0.212	0.330	0.22	11.35	12,361
3.60	1.8600	7.47	0.249	0.455	0.24	10.21	8,339
4.20	2.2400	7.89	0.284	0.599	0.27	9.35	5,992
4.80	2.6400	8.30	0.318	0.761	0.29	8.67	4,508
5.40	3.0600	8.71	0.351	0.943	0.31	8.11	3,510
6.00	3.5000	9.12	0.384	1.144	0.33	7.65	2,809

Note: The higher of the two flow depths calculated should be used to set the design depth of the Biofiltration Swale, including any freeboard that may be required. For the example above, the Design Storm depth is higher.

3.3 Other Comments

1. In general, the flatter the slope the shorter the Biofiltration Swale length required to meet TBMP requirements.
2. The width of the Biofiltration Swale is often the most easily changed site variable if the original proposed dimensions do not satisfy depth, velocity, and HRT criteria at WQF. Sometimes the slope may be reduced.
3. Calculations for the Biofiltration Swale are easier if most or all the Q_{WQF} enters at a discrete location at the upstream, rather than at distributed locations along the length of the Biofiltration Swale. However, if the flow enters the Biofiltration Swale continuously along the length of the swale or at multiple discrete locations, other rational methods should be employed. In the case of continuous flow entering the swale, the PE may wish to initially calculate the depths and velocities at selected points along the swale to verify they have not exceeded the maximum allowed values. This same calculation could be used if there is a grade change. The length of the swale that would qualify as a Biofiltration TBMP must be upstream of the location where either the maximum depth or velocity was exceeded. The calculation of the HRT when the WQF enters at multiple entry points could be done by calculating the HRT for the flow from each of the discrete entry points, and then taking a weighted average of the HRTs for the entire flow over the length that qualifies as a Biofiltration TBMP. Velocity and depth criteria must still be met.
4. To provide adequate hydraulic function, a swale must also be sized as a conveyance system calculated according to criteria and procedures for conveyance of Design Storm flows and scour associated with the peak drainage facility Design Storm.
5. Check dams within the Biofiltration Swale may be considered if the HDM criteria are met, but the HRT, velocity, or length requirements are not met due to the steepness of the proposed Biofiltration Swale. Follow the guidance for Temporary Check Dams located in the Caltrans Construction Site BMP Manual (http://www.dot.ca.gov/hq/construc/stormwater/CSBMP-May-2017-Final.pdf). Additionally, check dams should be constructed of rock or compost socks, placed a maximum of 20 ft apart, have 3H:1V side slopes, and be a maximum height of 9 in. Placement should not impede the flow of the Design Storm. If the TBMP is within the CRZ, consult with Traffic Safety. Consult with District Maintenance as check dams must be maintained: http://www.dot.ca.gov/hq/esc/oe/project_plans/highway_plans/stdplans_US-customary-units_10/viewable_pdf/t57.pdf
6. Temporary fiber roll check dams can be used in final channels with non-erosive flows to slow the water and create a series of micro-pools to promote vegetative growth. The check dams have the potential to create erosion if the permitted flow velocities are exceeded or scour prevention is not installed. While

check dams can be beneficial in promoting vegetation and minimizing erosion, their use must be coordinated with District Maintenance. Consult District Hydraulics engineer or HQ Drainage for appropriate applications.

7. In steep locations where concentrated flow velocities may cause erosion with long term vegetation or exposed bed materials, consider using Turf Reinforcement Mat (TRM). See HDM Chapter 860 for methods to calculate shear stresses.

Section 4

BMP Layout and Design

This section includes considerations for the layout and specific design elements of a Biofiltration Swale.

4.1 Layout

4.1.1 Location

Biofiltration Swales can be used as a stand-alone device or can be placed upstream of other TBMPs as pretreatment. They perform well upstream of other TBMPs that benefit from pretreatment to reduce sediment loading, such as Infiltration Devices, Detention Devices, and Media Filters. Biofiltration Swales can also be considered as part of a treatment train.

To provide effective treatment of runoff, the proposed location must be able to support the chosen vegetation. Locations should be sought that have sufficient open space, adequate sunlight for vegetation growth, and topography to meet the hydraulic requirements. If right-of-way is available and the location can support the chosen vegetation, then Biofiltration Swales are a good solution for permit compliance.

4.1.2 Maintenance

Biofiltration Swales need sufficient space for maintenance and inspections along the roadways. There should be enough space for maintenance vehicles and all equipment necessary for cleaning, repair, or inspection. District Maintenance must concur with the proposed Biofiltration Swale location and configuration.

4.2 Site Specific Design Elements

4.2.1 Turf Reinforcement Mat

A turf reinforcement mat (TRM) is a geotextile that may be used to prevent scour of the Biofiltration Swale when concentrated flows are expected. A TRM is a permanent, rolled erosion control product composed of non-degradable synthetic fibers, filament, nets, wire mesh, and other material processed into a three-dimensional matrix. Use of TRMs for Biofiltration Swales should be discussed with District Maintenance and District Biologist. Refer to HDM Chapter 860.

4.2.2 Soil Modification

When project soils are modified to improve infiltration, the PE may use organic or non-organic amendments for vegetated BMP surfaces. Design of soil amendments should be coordinated with other functional experts such as District Hydraulics, District Traffic Operations, District Landscape Architecture, Geotechnical Design, Traffic Safety, and OHSD, as applicable. When needed, a geotextile can be used to enhance the subgrade stability. Coordinate with Geotechnical Design when considering geotextiles or geogrids including for use in embankments to help with slope stability.

4.2.3 Energy Dissipation

Entry of runoff into a Biofiltration Swale may enter as sheet flow along its length, and/or from a concentrated conveyance. Consider designing energy dissipation devices where concentrated flow enters a Biofiltration Swale to prevent erosion. Refer to HDM Chapter 860.

4.2.4 Excessive Flows

Flow splitters are upstream drainage bifurcation structures designed to direct water quality flows to BMPs and to divert Design Storm flows. Possible conditions requiring the implementation of a flow splitter are:

- Backwater effect in the BMP
- Large Design Storm flows that create negative effects on the BMP
- Downstream effects

A detailed hydraulic analysis is required to properly size and design the flow splitter structure and overflow pipe, which are covered in the guidance document, Flow Splitters Design Guidance (Caltrans 2020e).

In cases where the WQV of a drainage area would require a BMP footprint larger than what is available, in addition to implementing flow splitters consider splitting a large drainage area into smaller subareas and using additional BMPs.

4.2.5 Concentrated Runoff at the End of a Bridge

Consider using drainage inlets to capture runoff from portion of bridge approaches and deck that drain to each end of a bridge structure. This runoff should be brought to the base of the embankment and directed into a Biofiltration Swale using an energy dissipation device. The remaining portion of the bridge approach would then be allowed to convey runoff as sheet flow onto Biofiltration Strips. Refer to Biofiltration Strip Design Guidance (Caltrans 2020d) for design elements necessary for siting this BMP. Coordinate with Geotechnical Design when infiltration into structural backfill is proposed and on the need for diversion. Runoff from the end of a bridge should not be allowed to cause erosion.

4.2.6 Use of Dikes Within the Roadway Cross Section

Dikes should be designed so that drainage and slope stability is achieved, but with consideration for allowing sheet flow to Biofiltration Swales or other TBMPs. Coordination with District Hydraulics, District Maintenance, District Traffic Operations, Geotechnical Design, and Traffic Safety may be required. A further discussion about the use of curbs and dikes is found under HDM Topic 303 - Curbs, Dikes, and Side Gutters.

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Section 5

PS&E Preparation

This section provides guidance for incorporating Biofiltration Swales into the PS&E package, discusses the typical specifications that may be required, and presents information about estimating construction costs.

While every effort has been made to provide accurate information here, the PE is responsible for incorporating all design aspects of Biofiltration Swales into the PS&E in accordance with the requirements of Section 2 of the Construction Contract Development Guide (Caltrans 2019c).

5.1 PS&E Drawings

Biofiltration Swale TBMPs do not have standard drawings but there are example drawings available at the OHSD website: http://www.dot.ca.gov/hq/oppd/stormwtr/bmp-examples.htm. The PS&E drawings for most projects having Biofiltration Swales may include:

- Layout(s): Show location(s) of the Biofiltration Swales. This will aid in recognizing, both within and outside Caltrans, that Biofiltration Swales were placed within the project limits.
- Drainage Plan(s), Profiles, Details, and Quantities:
  - Drainage Plan sheets should show each Biofiltration Swale in plan view, along with other existing (or proposed) drainage conveyance devices that direct runoff into the device. Biofiltration Swales are shown on drainage sheets so that they are recognized as a TBMP for Post Construction and TMDL compliance unit (CU) tracking for the NPDES permit compliance. The drainage sheet locations should also be shown in the SWDR tracking sheet.
  - Drainage Profile sheets should show the Biofiltration Swale in profile within the drainage conveyance system. These sheets should provide inlet and outlet flow line (surface) elevations.
  - Drainage Detail sheets should show detailing needed for the construction of the Biofiltration Swale not provided elsewhere in the contract plans, (i.e., Planting Plans). Inflow and outflow detailing should be shown (e.g., a lined channel used at the upstream or downstream end of the Biofiltration Swale).
- Planting Plans/Erosion Control Plans: These sheets are used to show incorporated materials and vegetative portion of the BMP. Planting quantities (e.g., hydroseed) for each Biofiltration Swale should be provided.

- Temporary Water Pollution Control Plans: These sheets are used to show the temporary BMPs used to establish the Biofiltration Swale BMPs and compliance with the Construction General Permit.

5.2 Specifications

Contract specifications for Biofiltration Swale Treatment BMP projects will include Standard Specifications and may include Standard Special Provisions (SSPs) and nSSPs.[3]

If special provisions are needed for the various items of work to construct the Biofiltration Swale, they could be organized under the blanket heading of 'Biofiltration Swale' with some or all of these items listed as subheadings. Payment would be made for 'each' Biofiltration Swale. Optionally, separate listings could be made for each contract item of work, with separate measurements and payments. The PE and the District Office Engineer should consider which method would better serve the project.

5.2.1 Standard Specifications

Standard Specifications are to be used for a project that constructs a Biofiltration Swale TBMP. Consider the construction of Biofiltration Swales in the context of the entire project to determine what Standard Specifications are applicable. Within the Standard Specifications, these are the sections that will typically be applicable:

13 Water Pollution Control

17 General (Earthwork and Landscape)

19 Earthwork

20 Landscape

21 Erosion Control

68 Subsurface Drains

70 Miscellaneous Drainage Facilities

71 Existing Drainage Facilities

72 Slope Protection

96 Geosynthetics

[3] Standard Specifications will not be included but merely referenced in the contract's special provisions.

5.2.2 Standard Special Provisions

SSPs are not typically used for a project that constructs a Biofiltration Swale TBMP. Consider the construction of Biofiltration Swales in the context of the entire project to determine if SSPs are required or if they can enhance the overall design.

5.2.3 Non-Standard Special Provisions

Typical placement of Biofiltration Swales will not require nSSPs. However, if the PE and PDT deem them necessary, coordinate with the OHSD or other appropriate office.

5.3 Project Cost Estimates

Project Cost Estimates are required at every phase of the project - Project Initiation Document (PID), Project Approval/Environmental Document (PA/ED), and PS&E. The Caltrans Division of Design has developed the following website to assist in the development of cost estimates:

http://www.dot.ca.gov/hq/oppd/costest/costest.htm

This website includes links to Chapter 20 Project Development Cost Estimates of the Project Development Procedures Manual and Caltrans Cost Estimating Guidelines. In addition to Chapter 20, this website includes other useful cost estimating information on project cost escalation, contingency and supplemental work, and cost estimating templates for the planning and design phases of the project. These templates may be used to track estimates relating to costs for incorporating TBMPs.

5.3.1 PID and PA/ED Phases

Project planning cost estimates typically proceed as: project feasibility, project initiation, draft project report, and project report. A refined version of the cost estimate is the project report cost estimate and is developed in the PA/ED phase. For details on what needs to be included in the TBMP cost estimate refer to Appendix F of the PPDG. This estimate must be modified as the project progresses.

At the PID phase of the project, the construction cost for Biofiltration Swales could be estimated based on the findings of the BMP Retrofit Pilot Program Final Report (Caltrans 2004), which was $34/CF of WQV treated, exclusive of right of way.[4]

To determine an initial cost estimate using this value simply use the following equation:

[4] In 2021 dollars inflated from 1999; contact District Office Engineer for appropriate run-up factors based on local experience. Note that costs were given in units more appropriate for a volume-based TBMP, for the comparison purposes within that report. The formula shown has been modified slightly to account for the otherwise incorrect units and should only be used for estimating purposes in these phases of the project.

Initial construction cost = ($34/CF x run-up factor) x WQV

This estimate will need to be modified as the project progresses. If some design is conducted during the PA/ED phase of the project, it is possible that a more refined estimate could be made using the methods in Section 5.3.2. A cost escalation should be added for projects that are anticipated to advertise more than a year after the date of the estimate.

5.3.2 PS&E Phase

Preliminary Engineer's Cost Estimates (PECE) are initiated at the beginning of PS&E and are updated until the completion of PS&E phase of the project. PECEs focus on the construction costs of the project and the stormwater BMPs and are inputs to the Basic Engineering Estimating System (BEES). Verify the quantities for inclusion in the project cost estimate to identify which should be considered Final Pay items, and to determine appropriate unit prices for each. Develop all necessary earthwork quantities for each specific Biofiltration Swale location and determine limits of excavation and backfill.

5.4 Developing Biofiltration Swale Cost Estimates

Develop a quantity-based cost estimate, regardless of availability of specific unit cost or quantity data. As the design process proceeds, the project cost estimate should be updated as new data becomes available. Identify the contract items required to construct the Biofiltration Swale. Table 5-1 includes typical contract items that may be included in the unit cost (CY and SQFT) estimate if they are required for the Biofiltration Swales. Table 5-1 is not a complete list and must be modified on a project-specific basis to accommodate all aspects of design.

Table 5-1. Example Biofiltration Swale Estimate

Contract Item	Type	Unit	Quantity	Price	Amount
Ditch Excavation		CY			
Soil Amendment		CY			
Permeable Material		CY			
Subgrade Enhancement Geotextile		SQYD			
Subgrade Enhancement Geogrid		SQYD			
Class D Filter Fabric		SQYD			
Erosion Control (Dry Seed)		SQFT			

When developing costs based on unit quantities, the unit costs should be based upon the most recent Caltrans Contract Cost Data Book or District 8 Cost Data Base for current similar projects in the District:

https://sv08data.dot.ca.gov/contractcost/

Use the project specifications, SSPs, and nSSPs to develop a list of items for which unit costs should be supplied. Carefully check that all items of work are accounted for either as pay or non-pay items.

Watch for the costs associated with earthwork for each specific Biofiltration Swale location, as that item of work will have the most variable costs for this TBMP. For Biofiltration Swale earthwork, use Section 19-2 Roadway Excavation of the Standard Specifications.

Estimate the total cost of each Biofiltration Swale used on the project for tracking TBMP costs at PS&E. Document all BMP costs in the project SWDR at PS&E. Some Biofiltration Swale features may be required for drainage or other project features and should not be double counted. Cost items will vary by project.

OHSD is developing specifications and cost estimates for Biofiltration Swales so the entire cost for the TBMP can be tracked as each. This will allow Caltrans to calculate the cost of TBMPs more accurately.

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Section 6

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Appendix A: Biofiltration Guidance Vegetation

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Appendix A: Biofiltration Guidance-Vegetation

A.1 Overview

This Appendix provides design guidance for the vegetative cover component of Biofiltration BMPs (i.e., Biofiltration Swales and Biofiltration Strips). For Biofiltration BMPs, District Landscape Architecture is responsible for selecting vegetation, and developing the appropriate plans, specifications, details, and estimates for contract documents. Incorporation of other improvements such as soil amendment and irrigation may be required to satisfy site conditions. For Biofiltration BMPs to be effective, it is necessary to establish a healthy, sustainable vegetative cover.

The District Landscape Architect or delegated representative is to verify that specific project requirements, necessary to provide vegetative cover for the Biofiltration BMPs, are documented in the SWDR and prepared for PS&E.

A.2 Soil Testing & Investigation

It is important to identify roadside soil characteristics of a site to determine its erosion potential, infiltration qualities, and ability to establish vegetative cover.

In addition to tests listed in Tables 2-2 and 2-3, when analyzing soils information for Biofiltration BMPs the soils test should report the following:

- Organic matter percentage – ASTM D2974-07a
- pH
- Salinity
- Sodium (Na)
- Boron (B)
- Nitrogen (N)
- Phosphorus (P)
- Potassium (K)

Information on soils should be requested as part of the geotechnical investigation. Soils characteristics such as USDA Soil Group, USDA-NRCS particle distribution (soil texture), organic matter percentage, and infiltration rate (see Section 2.2) should be requested. If the approved project Geotechnical Design Report has been completed without soils information, or if no Geotechnical Design Report is prepared for the project, then the Landscape Architect should collect soil samples and submit them to a soils testing lab for processing.

If soils information cannot be obtained for the project site, then soils information from a reference site should be evaluated. To be valid, the reference site must have characteristics similar to the project site such as slope aspect (north-facing, etc.) topography (cut or fill slopes), climate, geology, and existing vegetation.

A.3 Soil and Planting Area Preparation

Roadway construction that requires excavation or embankment work typically results in soils unable to support desirable vegetation. Grading operations, including compaction, produce soils of pulverized parent material with inverted soil horizons that lack nutrients, organic matter, rooting depth, and pore space. When these site conditions are anticipated, an assessment should be made by District Landscape Architecture to determine the level of treatment necessary to support vegetation. Coordination with the PE is recommended to ensure harvesting of suitable roadside soils within the project limits is considered.

Compost and organic slow-release fertilizers provide a better method to provide nutrients for desirable plant species than conventional commercial fertilizer. Because commercial fertilizers provide nutrients that are readily available, the germination and growth of invasive weeds is encouraged rather than desirable slower growing species. Incorporating compost and applying organic slow-release fertilizer releases nutrients gradually, thereby promoting the germination and establishment of perennial grasses and woody shrubs. In addition to providing long-term nutritional benefits as a soil amendment, compost can be applied as a 1 in to 2 in mulch layer to prevent the germination of most invasive annual weed species. When a compost mulch layer is specified, apply the seed on top of the compost to ensure that desirable seed species will germinate.

The following should be considered when preparing soil for biofiltration BMPs:

1. The soils in areas designated for Biofiltration BMPs should be ripped and cultivated to relieve surface compaction when feasible. Final grading must be coordinated with the PE. For slopes steeper than 4:1 (H:V), coordinate with the geotechnical engineer, District Maintenance, District/Regional Design Stormwater Coordinator. Deeper ripping may provide long term treatment benefits by increasing infiltration and water holding capacity, especially where soils are shallow. Deeper ripping for grading for soil-based BMPs must be approved by the PE for slope stability, traffic safety, and hydrology calculations.
2. Compost can be used to boost soil nitrogen and organic matter percentage if a soils report indicates a deficiency of these. A minimum of 1100 lb. total N/acre distributed throughout the top 12 in of soil is the end goal. For poor soils, compost should be incorporated at a minimum rate of 400 CY/acre to a minimum depth of 12-in to help restore soil organics, rooting depth, porosity and nutrients (carbon and nitrogen). Compost should be specified as, per Standard Specification 21-2.02K Compost.

3. Harvest topsoil from areas to be graded. Compost use may not be required if topsoil has an acceptable level of organic matter. Designate topsoil harvest and stockpile locations on the plans. Plant harvested topsoil with a temporary vegetative cover of appropriate native species to maintain microbial soil health. Include details for re-application and placement of topsoil. Coordination with the PE is recommended to ensure staging requirements and environmental issues are considered.
4. Where invasive weeds are pervasive, specify that weed seeds be germinated and resulting weeds killed or include mulch for weed control. Germination of an existing seed bank is a very effective method for controlling weeds. Planting by hydroseeding or other methods should be done after one or more weed germination cycles. Weed germination is only practical when temporary irrigation is employed. A 1 in-2 in layer of compost mulch is also an effective method to prevent germination and competition from annual weeds. Keep mulch clear of flow lines for Biofiltration Swales.
5. Incorporate amended soil as part of slope construction when specifying Mechanically Stabilized Embankments (MSE) for steep embankments. Placing amended soil at the proposed slope face can be done as part of placing each geotextile reinforced lift. Geotextiles and grading must be approved by the PE and must be in accordance with the approved project Geotechnical Design Report recommendations.

A.4 Irrigation Strategies

California's diverse microclimates make establishing vegetation difficult and sometimes impossible without supplemental irrigation. Harsh site conditions often limit the ability of the plantings to survive and thrive to the extent necessary for successful treatment. Under these conditions, irrigation should be provided when connecting to a water source is practicable.

Design landscapes to comply with the California Department of Water Resources Model Water Efficient Landscape Ordinance (MWELO). Guidance on water conservation and the MWELO is available at: http://www.dot.ca.gov/design/lap/landscape-design/irrigation/irrigation-mwelo.html

The following criteria should be considered when designing Biofiltration BMPs:

1. If vegetative cover goals (minimum 65%) are not achievable under normal rainfall, a temporary irrigation system will be required until plants are established.
2. If establishment of vegetative cover is required prior to normal rainfall, or the anticipated contract schedule necessitates germination prior to winter, then the use of a temporary irrigation system to establish the vegetation prior to the rainy season is recommended.

3. If the proposed Biofiltration BMP is adjacent to or within a recycled water irrigated landscape then utilization of the existing water service for permanent irrigation is recommended to ensure design compatibility with existing highway planting.

A.5 Planting Strategies

The following criteria should be used as a general measure of successful Biofiltration BMP installation:

1. Within the first year, a minimum of 65 percent vegetative cover is achieved.
2. The Biofiltration BMP does not exhibit rills, gullies, or visible erosion that is contributing to the export of sediment.
3. Biofiltration BMPs located within a landscaped urban interchange should be designed to complement the adjacent existing highway planting.

California's diverse microclimates require equally diverse strategies for successfully establishing vegetation. The following planting strategies have been successfully used for roadside revegetation and should be considered for Biofiltration BMPs where appropriate:

1. Provide temporary cover until the desired percent cover of vegetation is achieved. For challenging sites, it may take more than one growing season to establish adequate vegetative cover. This is especially true for shrubs and woody perennials on harsh sites. Temporary cover is usually provided through the use of short-term, degradable erosion control products such as rolled erosion control products (RECPs), wood chips and compost, and straw. These products vary in how long they will last. For example, straw can be expected to last through a single rainy season while a high-quality coconut fiber erosion control blanket will usually function for 3 years.
2. Strive for cost effective solutions. In most cases, the temporary cover product with the greatest longevity will also be the most expensive. While plant performance, slope steepness, slope inclination, slope aspect, and soil characteristics must be considered, avoid over-design. Specify materials as warranted by specific project conditions. For example, a cost-effective project design may use straw and hydroseed on areas of good soil and gentle slopes, reserving compost and coir netting for steep, cut slopes.
3. Specify drought tolerant grasses, with a goal to use as many appropriate local native species as possible. Species that become dormant during the dry season are acceptable as long as biofiltration performance is not affected. In Southern California, it is preferable to select plant species that are not dormant during the winter and spring (wet season).
4. Combine hydroseeding and direct planting. Some plant species favor particular planting methods, so special provisions may need to be made if these species are to be used. Many plant species can be applied by hydroseeding. Other

plants are better established as liner, container, or plug plant material and can be installed in previously seeded areas, following germination. This method can be effective for Biofiltration Swales when the upland zone on the banks is hydroseeded and the hydrophilic zone in the bed is planted with sedge, grass, and rush liners.

5. Specify erosion control blankets or other RECPs in areas that will receive concentrated flow. Although hydroseeding may be appropriate for planting portions of Biofiltration Swales, it should not be used in locations that will receive concentrated runoff. Liner, container or plug plant material is a better choice in these areas.

A.6 Restrictions for Plant Selection

Nearly half of the bulk solids collected in structural TBMPs consist of plant litter such as leaves and twigs. However, trees and shrubs provide both functional and aesthetic benefits to highway roadsides. To limit maintenance requirements of downstream TBMPs and especially basins and trash BMPs such as Gross Solid Removal Devices (GSRDs), trees and shrubs selected for banks of Biofiltration Swales (above Q100 depth as determined by PE) should not contribute large amounts of plant litter (e.g., bark, leaves, flowers or seeds) to the BMP.

A.7 Drainage Facilities

Accommodations for drainage facilities upstream and downstream from Biofiltration BMPs (e.g. flared end sections, scour protection) should be considered and, as determined by the PE, shown on drainage plans.

A.8 Plant Establishment Period

A Plant Establishment Period (PEP) ensures project success by maintaining plants during a period when mortality rates tend to be high. This is true for Highway Planting as well as for revegetation planting that includes grasses and forbs, and especially native grasses.

The following should be considered when requiring PEP for Biofiltration BMPs:

1. Biofiltration BMPs that are graded, constructed and planted as part of a roadway construction contract should have a 1-year PEP. Depending upon the type of construction and order of work, the PEP may run concurrently with other work.
2. Work to be performed during the PEP should include the following when applicable for the project:
   a. Weed control and removing inappropriate plant species (as field identified by a qualified specialist)
   b. Watering plants as necessary

c. Mowing and other vegetation management
d. Repairing rills, gullies, and other damage caused by erosion and scour
e. Reseeding bare or repaired areas
f. Replacing liner, container, or plug planting
g. Monitoring and repairing irrigation system (permanent or temporary)
h. Removing accumulated sediment and debris
i. Removing temporary irrigation system at end of PEP

3. The following activities may be performed during the PEP and done as extra work:
   a. Additional planting
   b. Additional irrigation
   c. Monitoring plant growth and establishment
4. Ideally, a 3-year contract to perform plant establishment work should follow immediately after completion of the roadway contract that installed the Biofiltration BMPs. If practical, the follow-up contract may include the Biofiltration BMPs of several construction projects in proximity of each other.

A.9 Definitions:

Vegetative Cover: Actively growing plant matter that is uniform, self-sustaining (perennial) and in contact with the soil. Live perennial vegetation may include grasses, grass like species, forbs, and some broad leaf species that are ground covers, low shrubs, or a combination. The area shall have a minimum vegetative cover of 65% within the first growing season. The remaining 35% shall be covered by fallen plant litter, standing dead plant material, or mulch.

Temporary Cover: Temporary cover consists of erosion control materials that provide short-term, interim protection of disturbed soil areas. Temporary cover products include erosion control blankets and other RECPs, straw, composts, and mulches. These products are generally composed of biodegradable and photodegradable materials with variable longevity.

A.10 Additional Resources

See locations below for additional information regarding planting methods and strategies for slope stabilization:

- Several studies on Biofiltration BMPs, erosion control, and revegetation can be found on the Caltrans Department of Environmental Analysis webpage at:

  http://www.dot.ca.gov/hq/env/stormwater/special/newsetup/index.htm

- The Caltrans Revised Universal Soil Loss Equation (RUSLE2) and the Erosion Prediction Procedure (EPP) provide a software tool and guidance for predicting surface erosion and selecting BMPs. The EPP appendices include information on collecting and processing soil samples.

- The Erosion Control Technology Council (ECTC) is a non-profit organization dedicated to developing performance standards, uniform testing procedures, and guidance on the application and installation of rolled erosion control products (RECPs). Information for selection and installation of RECPs based upon longevity, slope inclination, C-factor, and shear strength is given for various classes of products. Access their webpage at:

  http://www.ectc.org/

- The Soil Resource Evaluation (SRE) provides a stepwise process for regeneration and re-vegetation of drastically disturbed soils. Information on plant rooting depth, plant available water, soil nutrient levels, etc. can be found here. This information can be found on the HQ Landscape Architecture Program webpage at:

  http://www.dot.ca.gov/hq/LandArch/16_la_design/research/soils.htm

- The Erosion Control Toolbox developed by the Landscape Architecture Program provides information for erosion control standards and guidance. The toolbox identifies appropriate applications for erosion control materials, including erosion control blankets or other RECPs, hydroseed, and compost. The TransPlant Application is also accessible from the toolbox, which can be used to identify general regionally appropriate plant species for erosion control, revegetation, biofiltration, and other highway planting situations. The toolbox can be accessed at:

  http://dot.ca.gov/hq/LandArch/16_la_design/guidance/ec_toolbox/index.htm

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