Biofiltration Strip

Design Guidance

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California Department of Transportation
HQ Division of Design

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List of Abbreviations

AASHTO	American Association of State Highway and Transportation Officials
ASTM	American Society of Testing and Materials
BEES	Basic Engineering Estimating System
BMP	Best Management Practice
CASQA	California Stormwater Quality Association
CDA	contributing drainage area
CF	cubic feet
cfs	cubic feet per second
CGP	Construction General Permit
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 Study
RWQCB	Regional Water Quality Control Board
sec	second
SQFT	square feet
SQYD	square yard
SRE	Soil Resource Evaluation
SSHM	Small Storm Hydrology Method
SSIT	Strip and Swale Infiltration Tool
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 for Caltrans Designers for incorporating Biofiltration Strip Treatment Best Management Practices (TBMPs) into projects during the planning and design phases of Caltrans highways and facilities. Biofiltration Strips are a Caltrans approved soil-based Low Impact Development (LID) TBMP. A Biofiltration Strip may also be known as a biostrip, biofilter, grassed/vegetated buffer strip, vegetated filter strip, grassed filter, and filter strip. The primary functions of this document are to:

1. Describe a Biofiltration Strip
2. Provide design guidance
3. Review the required elements for implementing a Biofiltration Strip 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) and 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 the Biofiltration Strip 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 Strips.

Refer to Chapter 800 of the Highway Design Manual (HDM), 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 Strips

Biofiltration Strips are a type of biofiltration system with sloped vegetated land areas located adjacent to impervious areas, over which stormwater runoff flows as sheet flow. Biofiltration Strips are a TBMP used for treating stormwater runoff from project areas (e.g., roadways, parking lots, maintenance facilities) that are anticipated to produce pollutants of concern. Infiltration is the primary means for pollutant removal of the water quality volume, but may also include additional removal by sedimentation, adsorption to soil particles, and vegetation.

Biofiltration Strips are highly effective at removing sediments, metals, and oil and grease as noted in the PPDG and TC-31 of the California Stormwater Quality Association (CASQA) manual (CASQA 2003). They are in the medium effective range for organics and trash, and in the low effective range for nutrients and bacteria (CASQA 2003, TC-31). The effectiveness of Biofiltration Strips can be improved by increasing the amount of WQV infiltrated, so the total load removed (i.e., infiltrated) is higher (Caltrans 2017a). When site conditions allow, consider amending the BMP underlying soils to increase infiltration. Biofiltration Strips may be called other names by other agencies but are generally the same BMP with a few detail differences.

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

1. The Caltrans Permit prioritizes infiltration and then flow through TBMPs. Biofiltration Strips can be designed to fulfill both permit requirements.
2. Biofiltration Strips 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 Strips were determined to be cost effective and feasible for highway use. Life cycle costs for Biofiltration Strips were found to be lower than many other BMPs
4. Biofiltration Strips were further demonstrated to be effective for erosion control and other pollutants by the Roadside Vegetated Treatment Study (RVTS; Caltrans 2003)
5. Biofiltration Strips 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
6. Biofiltration Strips 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 Strip adjacent to a Biofiltration Swale, and Figure 1-2 is a photo of a Biofiltration Strip constructed along a highway.

Consult with Geotechnical Design, Hydraulics, and Traffic Safety if within the CRZ.

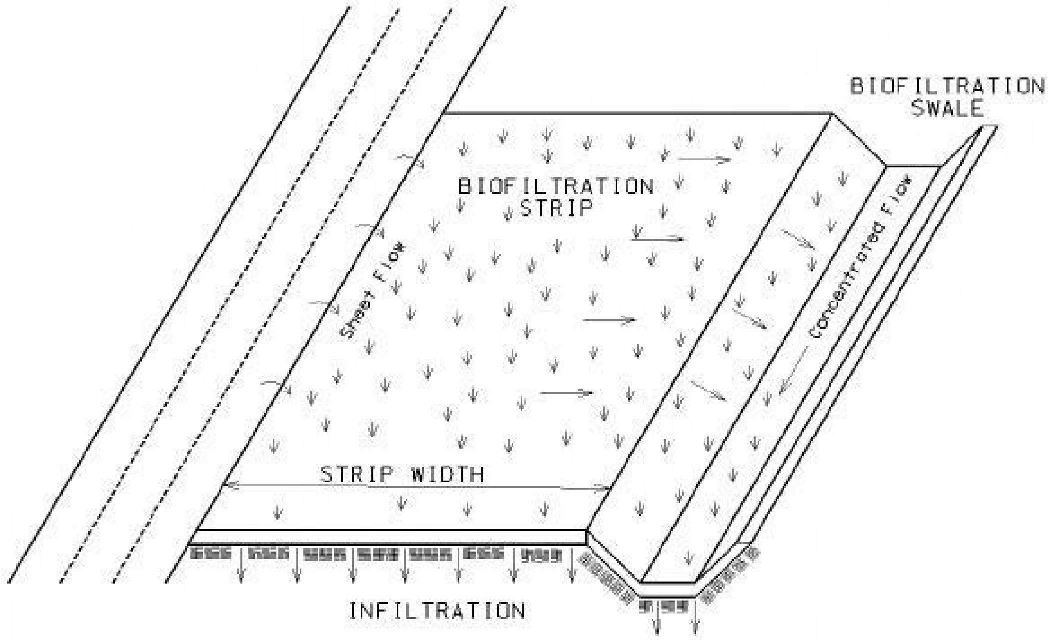

Figure 1-1. Schematic of Biofiltration Swale and Strip

Figure 1-2. Biofiltration Strip (District 7, I-605/SR-91)

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Section 2

Basis of Biofiltration Strip Design

Biofiltration Strips 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 Strips 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 Strips for a project. The checklist also identifies design elements that should be considered during the design of Biofiltration Strips. Once the feasibility 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 Strip for a given site.

2.1 Preliminary Design Criteria

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

Table 2-1. Biofiltration Strip Design Criteria

Parameter	Min. Value	Max. Value
Flow Rate, cfs	For water quality treatment: WQF, or portion thereof	None, except that the site must not be considered erodible during larger rainfall intensities
Side Slope Ratio	Minimum must grade to drain; 4H:1V or flatter preferred (refer to HDM Topic 304.1 for further discussion of slopes).	2H:1V and slope must support required vegetation; see also see also Section 2.2
Tributary Area	No minimum length (length of flow path)	150 ft maximum, consult District/Regional NPDES Coordinator if longer
Biofiltration Strip Length (Direction of Flow), ft	15 ft unless supported by RVTS; see also Section 2.3	100 ft, longer lengths may still be considered if potential erosion issues have been addressed
Biofiltration Strip Width (perpendicular to flow, usually parallel with traffic)	No minimum value established, but should be considered in the context of the overall location; use of very short widths is discouraged, but any width can be considered; agreement with District Maintenance is required	No minimum value established, but should be considered in the context of the overall location; use of very short widths is discouraged, but any width can be considered; agreement with District Maintenance is required
Manning's n value	During WQF: 0.24 recommended.1	During WQF: 0.24 recommended.1
WQF Velocity, VWQF	No minimum value	1.0 ft/s, but seldom controls design
Flow Depth (WQF), dWQF	No minimum value	1.0 in., but seldom controls design
Vegetative Coverage and Type	65 percent minimum coverage2; Vegetative Type (See Appendix A, Biofiltration Swale Guide Caltrans 2020b)	65 percent minimum coverage2; Vegetative Type (See Appendix A, Biofiltration Swale Guide Caltrans 2020b)
Hydraulic Residence Time	No minimum required; the Biofiltration Strip Length controls	No minimum required; the Biofiltration Strip Length controls
Hydraulic conductivity (permeability) of the soils	No value set, but it is acknowledged that a percentage of the treatment is made via infiltration. Consider conductivity only in the context of vegetation purposes.	No value set, but it is acknowledged that a percentage of the treatment is made via infiltration. Consider conductivity only in the context of vegetation purposes.

1 *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.*

2 *Manning's n value; substantiate use of any higher value in the SWDR. 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. Minimum vegetative cover for treatment listed; minimum cover for CGP compliance may be greater.*

2.2 Site Soils and Infiltration

The amount of runoff infiltrated by Biofiltration Strips should be calculated and documented as this provides a treatment train BMP benefit. Since Biofiltration Strips 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 strip'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 D10 > 0.02mm and D20> 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 should 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. Also refer to Appendix A of the Biofiltration Swale Design Guide.

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 the infiltration areas:

- 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. Amended soils may be considered 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. Topics for discussion may include:

- Specific geotechnical tests required for the amended soils
  - Geotechnical properties of amended soils for BMP design
  - Permeability (infiltration rate), USCS classification, particle size distribution (gradation), HSG classification, organic matter, compaction, bulk density,
- Vegetation amendments
  - Organic amendments may also be added for vegetation success

2.4 Minimum Biofiltration Strip Length

Pollutants are removed in a Biofiltration Strip by filtration through the vegetation, uptake by plant biomass, sedimentation, adsorption to soil particles, and infiltration through the soil. The relative proportion of total treatment by sedimentation and infiltration can vary by site, but in terms of total pollutant load reduction (as opposed to concentration reductions), the role played by infiltration can be much more than 50 percent (Caltrans 2006, Figures 5 and 6). Using total suspended solids (TSS) as the key pollutant for this discussion, monitoring indicated a reduction in the TSS concentration of 50 percent or more can occur after as little as 12 ft of travel for a variety of side slope ratios, including slopes as steep as 2H:1V. As mentioned, the concentration reduction does not fully indicate the significant reduction in loading that occurred due to the large volume of runoff infiltrated. Based on the data presented, the minimum recommended slope length for Biofiltration Strips is 15 ft for any side slope ratio as long as the site supports the required 65-percent vegetation coverage without rills or gullies. A reduced minimum length can be considered as a design exception if supported by the RVTS study with respect to side slope ratio, percentage vegetation coverage, and soil type.

Findings of infiltration and reduction in concentration of TSS have been plotted in Figures 2-1 and 2-2, because they are critical to understanding the recommended minimum length criteria.

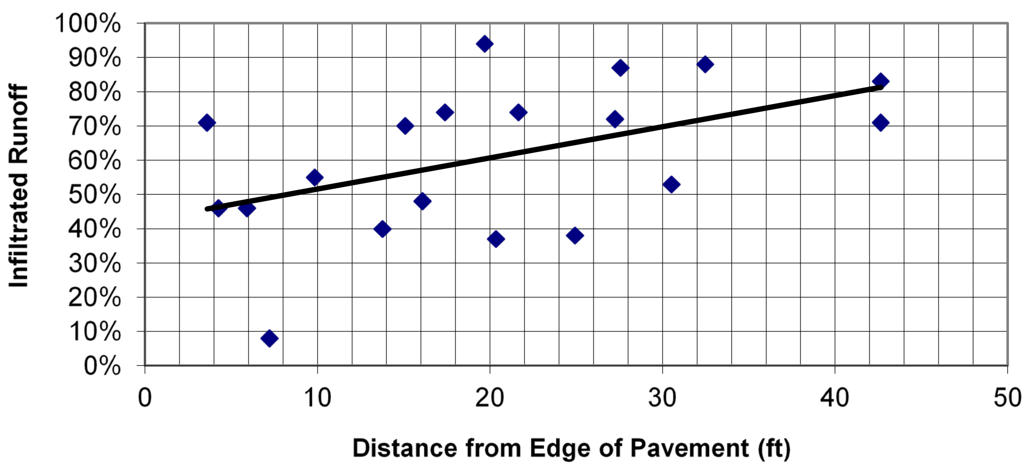

Figure 2-1. Percent of Runoff Infiltrated vs. Distance from Edge of Pavement
See Footnote 1

[1] Figures 2-1 and 2-2 are based on data presented in the RVTS Final Summary Report (Caltrans 2006). Figure 2-1 presents data from seven of the eight monitored sites, ignoring only Moreno Valley (which did not meet the minimum vegetation coverage percentage). Figure 2-2 presents data from six of the eight monitored sites (ignoring Yorba Linda, where gopher activity was high, Moreno Valley, which did not meet the minimum vegetation coverage percentage, and including only the first monitoring location at San Onofre, where gopher activity was low). For both: 100 percent value at the edge of pavement represents runoff directly from the road surface.

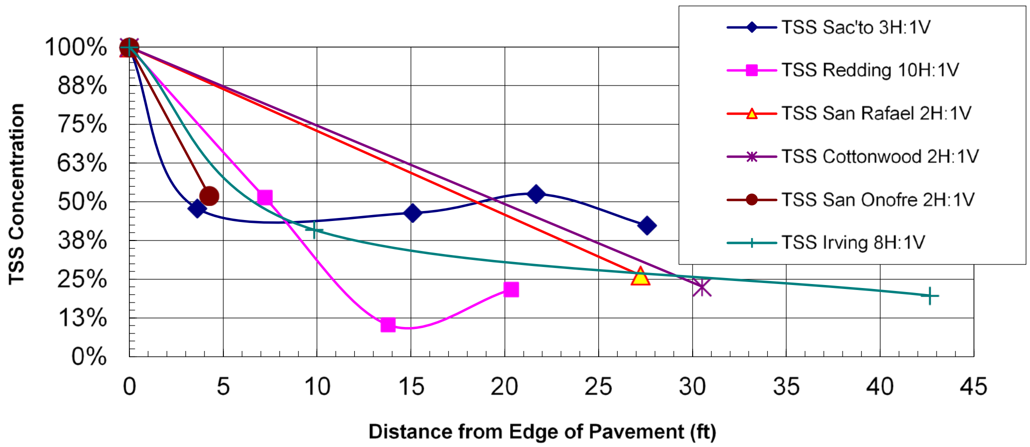

Figure 2-2. TSS Concentration Reduction Vs. Distance Edge of Pavement

See Footnote 1

2.5 Safety Considerations

Biofiltration Strip 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 Biofiltration Strip 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.

2.6 Restrictions/Coordination

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

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

- Biofiltration Strips 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.

- 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.
- 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
- There may be locations, especially in an urban environment, where infiltration is not allowed. Coordinate with the District Hazardous Waste Coordinator and District/Regional NPDES Coordinator if Biofiltration Strips are proposed at locations having contaminated soils or are above contaminated groundwater plumes. Coordinate with the Regional Water Quality Control Board (RWQCB) to discuss feasibility and design options in these locations
- Design slopes to be as flat as possible. For new construction, widening, or where slopes are otherwise being modified, embankment (fill) slopes should be 4H:1V or flatter (Refer to HDM Topic 304.1 for further discussion of slopes). If steeper slopes are used, consult with Geotechnical Design in regard to slope stability and impacts from the BMP
- Biofiltration Strips are not generally subject to setback restrictions. However, if unusual geotechnical conditions exist, or if a Biofiltration Strip is proposed above a retaining wall and the soils are known to be especially erodible or permeable, consult with Geotechnical Design.
- Soil testing and a percolation test is recommended. Soil amendments should be considered by the PDT for increased infiltration and for vegetation establishment success. Design 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 Strip is suitable based on the Feasibility Criteria described in Section 2 and in the PPDG. This section provides the calculations that are used to verify BMP feasibility. First, determine the portion of WQV infiltrated by the BMP, next verify that the Biofiltration Strip can convey the Design Storm[2] flows without causing erosion. Obtain values for contributing drainage area (CDA) length, length of Biofiltration Strip in the direction of flow, and surface slope of Biofiltration Strip in the direction of flow 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, may lead to smaller designs. By accounting for active treatment occurring during the event, an increase in the treated WQV can be expected for infiltrative TBMPs. 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.

[2]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.

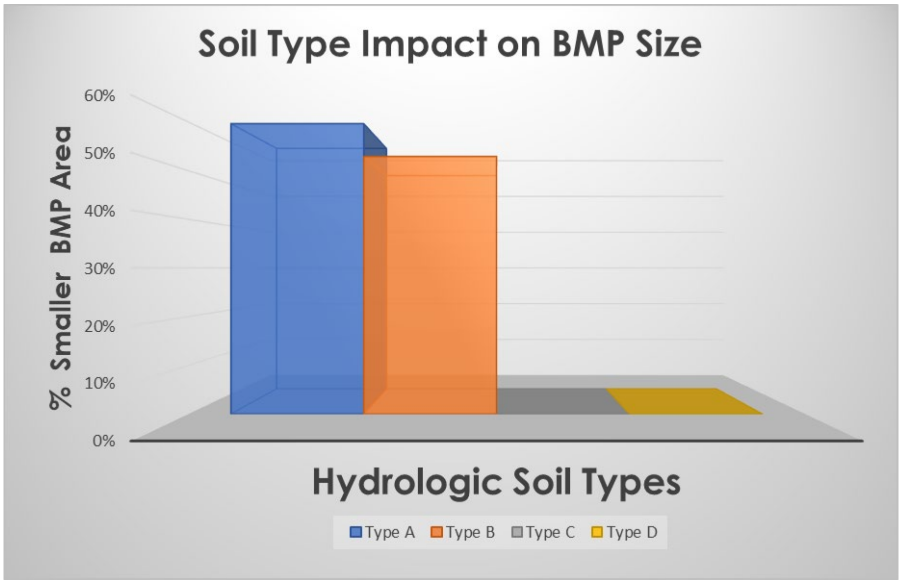

Figure 3-1. BMP Size Reduction Based on Soil Type

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 Strips 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. If infiltration is not determined to be suitable for the site, then calculate the WQF generated by the entire BMP CDA to size the Biofiltration Strip. An explanation of a WQF calculation and example can be found in Section 3 of the current Biofiltration Swale Design Guidance.

3.1.3 Design Storm Event

When placed in an inline configuration, the Design Storm event will typically govern the Biofiltration Strip 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 Hydraulic Calculations

Hydraulic calculations involve determining the flow depth and velocity during the water quality event. The BMP size must be verified to ensure it can convey the Design Storm peak flows, see HDM Topic 831, and to evaluate the need for erosion prevention measures, see HDM Chapter 860.

3.2.1 BMP Capacity

The Biofiltration Strip must be sized to convey the flow calculated for the Design Storm (± 5 percent) in Section 3.1.3. Use Manning's equation, or the simplified and rearranged version of Manning's equation as shown below, to calculate the BMP capacity. For this example, the Design Storm is assumed to be the 25-year event and the Manning's coefficient assumes the surface is vegetated.

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

where all units are English as follows:

Q = Design flow, (cfs)

n = Manning's coefficient for vegetated surface; use "n" = 0.24 for Q_{WQF} and "n" = 0.05 for Q_{25}

A = Cross-sectional area of the flow in the channel, unit width (ft)

R = Hydraulic Radius = "A" / Wetted Perimeter[3] ("P")

S = longitudinal slope (ft/ft)

If we neglect the flow contribution of the side slopes, the area, A, equals the depth times the unit width, and the wetted perimeter equals two times depth plus width. Therefore, the formula can be rewritten as:

$$Q = ({}^{1.49}/_{n}) \times (d \times w) \times ((d \times w)/(2d + w))^{2/3} \times S^{1/2}$$

where:

d = Design flow depth (ft)

w = Design flow width (ft) and all other terms as above

The flow depth should not exceed 1 in (Design Criteria). If it does, a reduced WQF intensity could be discussed with the District/Regional Design Stormwater Coordinator, an increased slope could be made (although this will increase the velocity, so it is not the ideal adjustment), or the area could be considered to also include infiltration treatment by way of DPPIA design.

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

3.2.2 Design Velocity

Using the design flow and design flow depth as calculated in the previous section, velocity equals:

$$V = Q / (d \times w)$$

where

V = Design flow velocity (ft/s)

d = Design flow depth (ft)

w = Design flow width (ft)

If the design velocity exceeds the permissible velocity of the lining (HDM Table 865.2), the slope can be rocked to provide higher shear stress protection, or the slope can be adjusted if there is enough right of way. If the slope cannot be adjusted, evaluate measures that will prevent erosion at the higher velocity without impeding infiltration. Designs with velocities over 1.0 ft/s must be discussed with the District/Regional Design Stormwater Coordinator.

3.2.3 Hydraulic Residence Time

While there is no minimum travel time, (termed the Hydraulic Residence Time [HRT]), required within the Biofiltration Strip, it may need to be calculated for other reasons. This calculation would be made after the proposed Biofiltration Strip was analyzed using Manning's Equation, as discussed above. The velocity associated with the Q_{WQF} is determined, and the HRT calculated using the proposed length of the Biofiltration Strip:

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

where

HRT = Hydraulic Residence Time (minutes)

L = proposed length of the Biofiltration Strip (ft)

60 = conversion from seconds to minutes

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

3.2.4 Travel Time Using the Kinematic Wave Equation

An alternative formula that is sometimes used to calculate the HRT is the Kinematic Wave Equation as presented in HDM Topic 816.6 Time of Concentration (Tc) and Travel Time (Tt):

T_t= [0.93 x $L^{3/5}$ x $n^{3/5}$/ ($i^{2/5}$ x $S^{3/10}$)] See Footnote [4]

where

T_t = travel time [HRT] (minutes)

L = proposed length of the Biofiltration Strip (ft)

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

i = WQF rainfall intensity (in/hr)

S = longitudinal slope (ft/ft)

One advantage of this formula is that it allows the HRT to be calculated directly, without first calculating the unit width Q_{WQF}. Note that this formula will calculate a longer travel time than will Manning's Equation for the shorter lengths that are typical for Biofiltration Strips, because there are different assumptions made for each of these empirical equations.

[4] Using metric units: T_t= [6.92 x $L^{3/5}$ x $n^{3/5}$/ ($i^{2/5}$ x $S^{3/10}$)], with all terms the same, except that L is in meters, and intensity i is in mm/hr.

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Section 4

BMP Layout and Design

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

4.1 Location

A Biofiltration Strip 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 Strips can also be considered as part of a treatment train. If right of way is available and the location can support the chosen vegetation, then Biofiltration Strips are a good solution for permit compliance.

In highly urbanized areas, narrow shoulders and conflicts with sound walls and other structures may limit opportunities for retrofit with Biofiltration Strips on existing freeways.

4.2 Maintenance

Biofiltration Strips 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 should concur with the proposed Biofiltration Strip location and configuration. District Maintenance and Construction personnel should conduct a 90 percent complete walk-through for the proposed Biofiltration Strips during construction.

4.3 Turf Reinforcement Mat

A turf reinforcement mat (TRM) is a geotextile that may be used to prevent scour of the Biofiltration Strip due to velocity. 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 Strips should be discussed with District Maintenance and District Biologist.

If the flow characteristics do not require a TRM, a temporary erosion control blanket may still be needed for vegetated Biofiltration Strips to protect the soil from concentrated flow that may occur before vegetation can be established. Hydroseeding is not recommended for areas that will receive concentrated flows. Refer to HDM Chapter 860 and Table 865.2 for lining materials.

4.4 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.

4.5 Use of Level Spreaders

The BMP Retrofit Pilot Program Report discussed the use of flow spreading. Due to various difficulties, that report recommended against the use of concrete level spreaders to distribute runoff.

4.6 Use of Dikes Within the Roadway Cross-Section

When existing dike is to be removed to allow sheet flow to Biofiltration Strip TBMPs, use engineering judgement to ensure that highway safety, drainage, and slope stability is maintained. Erosion of the embankment area must not result from placement of Biofiltration Strips. Coordination with District Hydraulics, District Maintenance, District Traffic Operations, Geotechnical Design, and Traffic Safety is required. A further discussion about the use of curbs and dikes will be found under HDM Topic 303 - Curbs, Dikes, and Side Gutters.

Section 5

PS&E Preparation

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

While every effort has been made to provide accurate information here, the PE is responsible for incorporating all design aspects of Biofiltration Strips 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 Strip TBMPs do not have standard drawings but there are several sheets that should be placed in the PS&E package. The PS&E drawings for most projects having Biofiltration Strips may include:

- Layout(s): Show location(s) of Biofiltration Strips. This is a recommended option, as its use will aid in recognizing, both within and outside the Department, that Biofiltration Strips were placed within the project limits.

Drainage Plan(s), Profiles, Details, and Quantities:

  - Drainage Plan sheets should show each Biofiltration Strip in plan view. Biofiltration Strip are shown on drainage sheets so that they are recognized as a TBMP for Post Construction and TMDL compliance 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 Strip in profile within the drainage conveyance system. These sheets should provide flow line (surface) elevations.
  - Drainage Detail sheets should show detailing needed for the construction of the Biofiltration Strip not provided elsewhere in the contract plans, (i.e., Planting Plans). Outflow detailing should be shown (e.g., a lined channel used at the upstream or downstream end of the Biofiltration Strip).

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

5.2 Specifications

Contract specifications for Biofiltration Strip TBMP projects will include Standard Specifications and may include Standard Special Provisions (SSPs) and nSSPs.[5]

If special provisions are needed for the various items of work to construct the Biofiltration Strip, they could be organized under the blanket heading of 'Biofiltration Strip' with some or all project. of these items listed as subheadings. Payment could be made for 'each' Biofiltration Strip. 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 Strip TBMP. Consider the construction of Biofiltration Strips 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

71 Existing Drainage Facilities

72 Slope Protection

96 Geosynthetics

5.2.2 Standard Special Provisions

SSPs are not typically used for a project that constructs a Biofiltration Strip TBMP. Consider the construction of Biofiltration Strips 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 Strips will not require nSSPs. However, if the PE and PDT deem nSSPs necessary, coordinate with OHSD or other appropriate office.

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

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

A preliminary cost estimate, Project Planning Cost Estimate (PPCE), is required as an attachment of the SWDR during PID phase of the project. A refined version of the PPCE is developed in PA/ED phase. For details on what needs to be included in PPCE, refer to Section 6.4.9 and Appendix F of the PPDG.

At the PID phase of the project, the construction cost for Biofiltration Strips could be estimated based on the findings of the BMP Retrofit Pilot Program Final Report, which was at $34/CF of WQV treated, exclusive of right of way.[6]

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

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

[6] 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 Treatment BMP, for 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.

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 Strip location and determine limits of excavation and backfill.

5.4 Developing Biofiltration Strip 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 Strip. Table 5-1 includes typical contract items that may be included in the unit cost (CY and SQFT) estimate if they are required for Biofiltration Strips. 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 Strip Estimate

Contract Item	Type	Unit	Quantity	Price	Amount
Clearing and Grubbing		LS			
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 Strip location, as that item of work will have the most variable costs for this TBMP. For Biofiltration Strip earthwork, use Section 19-2 Roadway Excavation of the Standard Specifications.

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

Section 6

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