Design Pollution Prevention Infiltration Area

Design Guidance

April 2021

California Department of Transportation
HQ Division of Design

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Table of Contents

TABLE OF CONTENTS

List of Figures

List of Tables

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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
CTM	California Test Methods
CRZ	Clear Recovery Zone, (AASHTO Clear Zone)
CDA	contributing drainage area
CF	cubic foot
cfs	cubic feet per second
CY	cubic yard
DPPIA	Design Pollution Prevention Infiltration Area
ft	foot/feet
ft/s	foot/feet per second
FHWA	Federal Highway Administration
FP	Federal Project
HQ	Headquarters
HDM	Highway Design Manual
hr	hour
HRT	Hydraulic Residence Time
H:V	Horizontal:Vertical
HEC	Hydraulic Engineering Circular
in	inch
in/hr	inches per hour
LID	Low Impact Development
max	maximum
min	minimum
MWELO	Model Water Efficient Landscape Ordinance
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System
nSSPs	non-Standard Special Provisions
OHSD	Office of Hydraulics and Stormwater Design
PS&E	Plans, Specifications and Estimate
PA/ED	Project Approval/Environmental Document
PDT	Project Development Team
PE	Project Engineer
PECE	Preliminary Engineer's Cost Estimate
PID	Project Initiation Document
PPCE	Project Planning Cost Estimate
PPDG	Project Planning and Design Guide – Stormwater Quality Handbook
RECPs	Rolled Erosion Control Products
RSP	Rock Slope Protection
RWQCB	Regional Water Quality Control Board
sec	second
SF	safety factor
SQFT	square foot
SQYD	square yard
SSHM	Small Storm Hydrology Method
SSPs	Standard Special Provisions
SWDR	Stormwater Data Report
TRM	turf reinforcement mat
TOC	time of concentration
USCS	Unified Soil Classification System
WQF	Water Quality Flow
WQV	Water Quality Volume

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Section 1

Introduction

This document provides guidance for Caltrans Designers for incorporating Design Pollution Prevention Infiltration Areas (DPPIAs) as Treatment Best Management Practices (TBMPs) into projects during the planning and design phases of Caltrans highways and facilities. DPPIA TBMPs are stabilized pervious areas (new, modified, or existing) that infiltrate runoff. DPPIAs can be existing features within the right-of-way, including vegetated and non-vegetated features, which promote infiltration of stormwater runoff. When vegetated existing features are identified as DPPIA TBMPs, preserve the existing vegetation and protect it from construction disturbance using the DPP BMP: *Preservation of Existing Vegetation*. The primary functions of this document are to:

1. Describe a DPPIA
2. Provide design guidance
3. Review the required elements for implementing a DPPIA 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 2019a). DPPIA infiltration treatment is first in the "order of preference" for TBMPs as set forth in the NPDES Permit. The required volume to treat is the 85th percentile 24-hour storm event depth over the treatment area.

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 DPPIA 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). Coordination with other functional experts is necessary to implement successful and functioning DPPIAs.

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 and agronomic soil amendments based on the physiographic region and the purpose of the TBMP. 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 DPPIAs

DPPIAs are a type of treatment system consisting of vegetated and non-vegetated pervious areas that promotes infiltration of stormwater runoff. DPPIAs can be adjacent to impervious areas to allow stormwater runoff to flow over the infiltration area as sheet flow, and they can convey concentrated flows (e.g., rock lined ditch). DPPIAs are used for treating stormwater runoff from project pavement areas (e.g., roadways, parking lots, maintenance facilities, etc.) that contain 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.

The DPPIA TBMP (vegetated and non-vegetated) is highly effective at removing sediments, nutrients, pesticides, metals, pathogens, bacteria, and turbidity as noted in the PPDG. The TBMP effectiveness varies with the amount of infiltration. When site conditions allow, consider amending the TBMP underlying soils to increase infiltration.

DPPIAs can have many configurations. A section of a rock lined ditch is shown below (Figure 1-1), and a vegetated embankment slope (Figure 1-2) are shown below. Materials below the rock can vary based on site conditions and project goals. Consult with Geotechnical Design, Hydraulics, and Traffic Safety if within the CRZ.

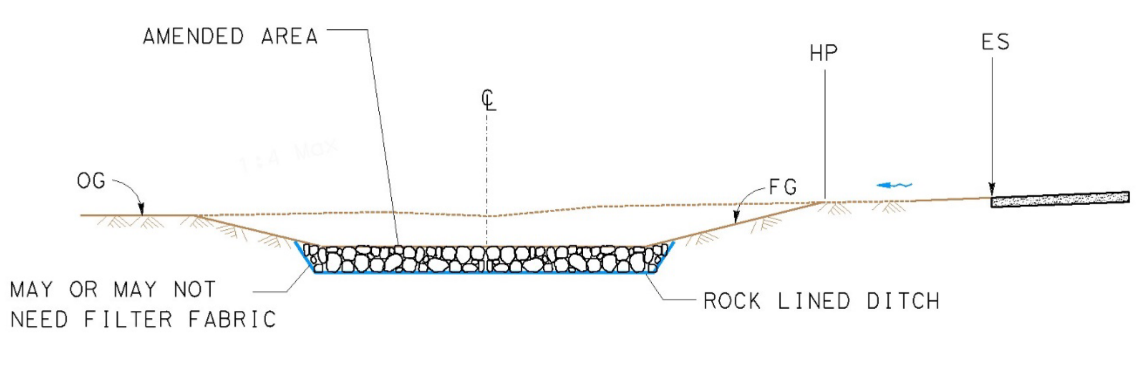

Figure 1-1. Typical Section of a Rock Lined DPPIA

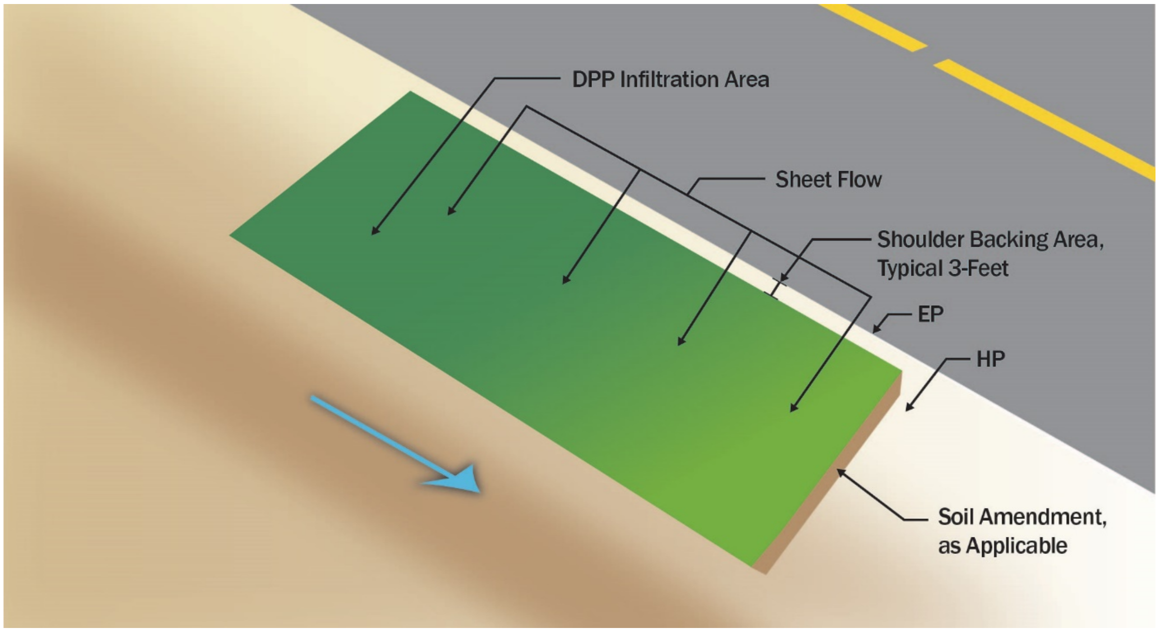

Figure 1-2. Typical Section of an Embankment DPPIA

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Section 2

Basis of DPPIA Design

DPPIAs may be considered whenever site soils provide infiltration or can be amended to enhance infiltration, safety criteria are met, and where flow velocities can be mitigated to prevent scour. DPPIAs can be considered upstream of other TBMPs as either pretreatment or as part of a treatment train.

Checklist T-1, Part 11 in the PPDG, assists in evaluating the initial feasibility of DPPIAs for a project. The checklist identifies design elements that should be considered during the design of DPPIAs. Once the feasibility has been confirmed using Checklist T-1, Part 11 in the PPDG, use the following subsections to further understand the design elements of a DPPIA for a given site.

2.1 Preliminary Design Criteria

DPPIAs must meet certain design criteria to perform as an effective TBMP. The primary factors to be incorporated in the design are found in Table B-1 of the PPDG. Additional criteria are listed in Table 2-1.

Table 2-1. DPPIA Design Criteria

Applications/Siting	Preliminary Design Factors
Existing areas (protected from construction disturbance) may be used for DPPIA.	Consider adding materials to increase infiltration, increase void space, and stabilize slopes.
The DPPIA should be designed to protect surface water and groundwater beneficial uses.	Concentrated flow areas prevent scour with appropriate lining materials for drainage and provide infiltration (rock, sand, soil, permeable material).
When soil amendments are proposed within the CRZ, compaction and stability of the soil must be considered and evaluated.	When using soil amendments within the CRZ, validate that the desired soil amendment can be structurally compacted and still provide enhanced infiltration.

2.2 Site Soils and Infiltration

When infiltrative type TBMPs 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 TBMP. The Hydrologic Group can be input into Caltrans Infiltration Tool IT4 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. Caltrans Infiltration Tool IT4 can be used to model the infiltration trench 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 $D_{10} > 0.02$mm and $D_{20} > 0.06$mm 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 TBMP 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.

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 TBMP 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 DPPIA 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. Soil amendments may either be organic or non-organic and may be used for TBMPs with vegetated and non-vegetated surfaces. Amended soils may also be considered for the invert of the concentrated flow path (rock lined ditch) 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 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 TBMP 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 Safety Considerations

DPPIA TBMPs 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 DPPIA 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 the DPPIA 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 per site design. DPPIA design decisions and coordination must be documented in the SWDR and project file.

Additional design criteria applicable to the use of the DPPIA TBMP are as follows:

- 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 - may not be allowed. Coordinate with the District Hazardous Waste Coordinator and District/Regional NPDES Coordinator if DPPIAs are proposed at locations having contaminated soils that could be mobilized or are above contaminated groundwater plumes that could be affected. Coordinate with the Regional Water Quality Control Boards 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 4:1 (H:V) or flatter (Refer to HDM Topic 304.1 for further discussion of slopes). If project slopes have stability issues, designating the slope as a DPPIA may negatively affect site stability. The PE must consult with Geotechnical Design for slopes steeper than 2:1 (H:V) as outlined in the PPDG.
- The TBMP geometry and location design should consider future impacts. Assure that the TBMP as designed (geometry and location), is maintainable and shown on project plans.
- Velocity of sheet flow coming off the roadway and onto the TBMP must not cause erosion.
- Soil amendments may be considered to increase infiltration when you know the native soils geotechnical properties.
- When vegetation is proposed for permanent TBMPs, include temporary BMPs to stabilize slopes during the transition period until vegetation is established.

- Soil amendments should be considered to increase vegetation establishment success.
- Infiltration TBMPs should not be located within 100 ft of a private well, septic tank, or drain field due to potential groundwater contamination concerns.
- Infiltration TBMPs must not present a potential hazard to structural foundations, and therefore should not be used within 10 ft down gradient or 100 ft up gradient of foundations. A project Geotechnical Design Report and approval are required if outside these criteria.

Section 3

Getting Started

This section presents the hydrologic and hydraulic calculations necessary to support the design of the DPPIA. It is assumed that the need for a DPPIA has already been determined in accordance with the guidelines and procedures presented in Section 2 and in the PPDG. It is further assumed that the specific site for the TBMP has been selected. As a result, no TBMP selection or site selection guidelines are provided herein.

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 TBMP. 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 2019c).

Additionally, when an infiltrative BMP is installed in a Type A or Type B soil the TBMP 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 TBMP 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.

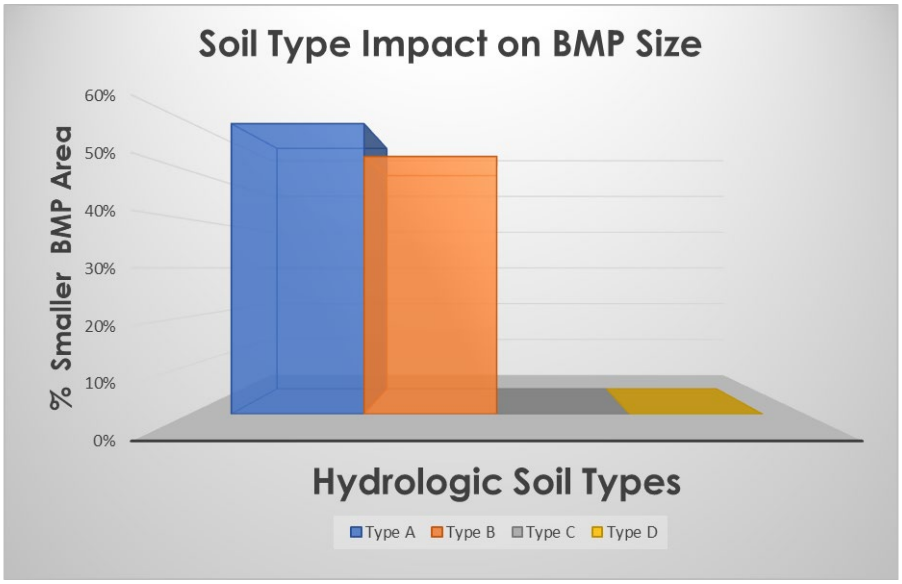

Figure 3-1. BMP Size Reduction Based on Soil Type

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.

3.2 Hydrology Calculations

The hydrology calculations include the following:

1. Calculate Contributing Drainage Area (CDA)
2. Estimate the Water Quality Volume (WQV) using Small Storm Hydrology Method (SSHM)
3. Determine the Design Storm peak flow generated by the CDA

The following subsections include details and examples of these calculations.

3.2.1 Contributing Drainage Area

TBMPs are sized to treat the runoff generated by the CDA. The CDA is dependent on the TBMP location and the surrounding topography. To calculate CDA, use the project topographic survey and contour mapping to determine the TBMP runoff generated. The CDA includes any area that drains to the TBMP.

For example, if the CDA flows down an embankment like Figure 1-2, the TBMP may be located at the edge of shoulder, at the bottom of the embankment, or as determined by the designer. If the TBMP is located at the edge of shoulder, then the CDA would include the road, and shoulder. If the TBMP is located at the bottom of the embankment, then the CDA would include the road, shoulder, and the portion of the embankment contributing to the TBMP.

When determining the TBMP location, coordinate with the District/Regional Design Stormwater Coordinator to understand the long-term goals of the project area. For instance, if the project area will be included in a future widening project that will modify the upper portion of the embankment only, consider locating the TBMP away from the top hinge point of the embankment to avoid having to remove and rebuild the treatment TBMP later.

Another consideration when locating the TBMP is the amount of impervious versus pervious surface in the CDA. In some cases, the pervious portion of the CDA can reduce the runoff coefficient used to calculate the WQV generated by the CDA. However, this smaller coefficient will be multiplied by the full CDA which can increase the required TBMP size. It should be noted that when the impervious area is less than 50 percent of the CDA, a composite WQV calculation will be required, see Example 3-2.

3.2.2 Water Quality Volume

This section explains how to calculate the volume of runoff to be treated (WQV). To calculate the WQV generated by the CDA, use the Small Storm Hydrology Method (SSHM) and obtain the 85^{th} percentile, 24-hour storm event precipitation depth from the Caltrans tab in the Basin Sizer program (CSUS 2013). An explanation of the calculation methodologies is included in the Basin Sizer guidance.

http://svctenvims.dot.ca.gov/wqpt/basinsizer.aspx

Below are hypothetical project examples that use the SSHM to determine the amount of WQV generated by the potential CDA upstream of the DPPIA.

Example 3-1 (more than 50% impervious)

Given:

- Sacramento County, Clarksburg Station
- Potential drainage (Figure 3-2) is 0.3-mile (1,633 ft) long with 2 new lanes, a shoulder, and an embankment.
- 85th percentile, 24-hour rainfall depth is 0.64 in
- TBMP located at the toe of the embankment, 15 ft away from the edge of shoulder
- Potential TBMP receives sheet flow only and requires volume-based sizing

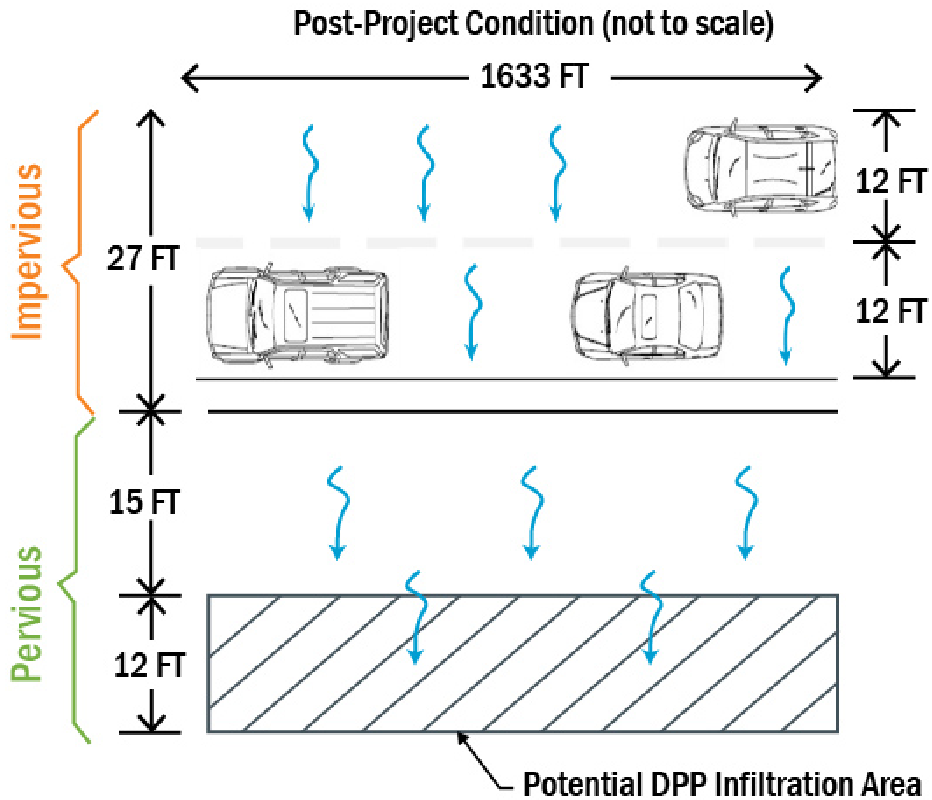

Figure 3-2. CDA with more than 50% Impervious

- **Step 1:** Calculate the CDA upstream of the TBMP to determine percent impervious
- The CDA consists of 2 travel lanes, a shoulder, and the embankment.
- CDA = (27 ft + 15 ft) x 1,633 ft = 68,586 ft^2
- Calculate the percent impervious for the CDA:
- Percent Impervious = (Impervious Area / CDA) x 100
- Percent Impervious = (27 ft x 1,633 ft) / 68,586 ft^2) x 100 = 64 percent
- The CDA has over 50% impervious surfaces and the CDA drains the impervious area to the pervious area therefore, use a single calculation for the entire CDA using a composite volumetric runoff coefficient (R_v).
- **Step 2:** Determine the volumetric runoff coefficient (R_v)
- 64 percent impervious area is not included in Table 5-2 of the PPDG as shown in Figure 3-3.

Table 5-2. Volumetric Runoff Coefficients	
Description	Volumetric Runoff Coefficient (R_v)
100% Impervious	0.89
90% Impervious	0.73
80% Impervious	0.60
70% Impervious	0.49
60% Impervious	0.41
50% Impervious	0.34
Clayey Soils[1]	0.22
Sandy Soils[1]	0.03

[1]*Value for an average California 85th percentile, 24-hour storm event depth of 1.26 inches*

Figure 3-3. Hypothetical Project R_v

Interpolate using Table 5-2 or use the Urbonas equation to determine the volumetric runoff coefficient (R_v):

$R_v = 0.8581I^3 - 0.781I^2 + 0.7741I + 0.04$

Where:

I= fraction of area that is impervious (Percent Impervious (%)/100)

$R_v = 0.8581(0.64)^3 - 0.781(0.64)^2 + 0.7741(0.64) + 0.04 = 0.44$

Step 3: Calculate WQV

$WQV = R_v(P/12)A$

Where:

WQV = Runoff volume generated by the 85th percentile 24-hour storm event (CF)

R_v = 0.44 (Step 2)

P = 0.64 in – given in problem statement

A = 68,586 ft^2 (Step 1)

WQV = 0.44 x 0.64 in (1 ft /12 in) x 68,586 ft^2= 1,609 CF

Example 3-2 (less than 50% impervious)

Given:

- Sacramento County, Clarksburg Station
- Potential drainage (Figure 3-4) is 0.3-mile (1,633 ft) long with 1 lane, a shoulder, and an embankment.
- Site soils are clayey
- 85th percentile, 24-hour rainfall depth is 0.64 in
- TBMP located at the toe of the embankment, 17 ft away from the edge of shoulder
- Potential TBMP receives sheet flow only and requires volume-based sizing

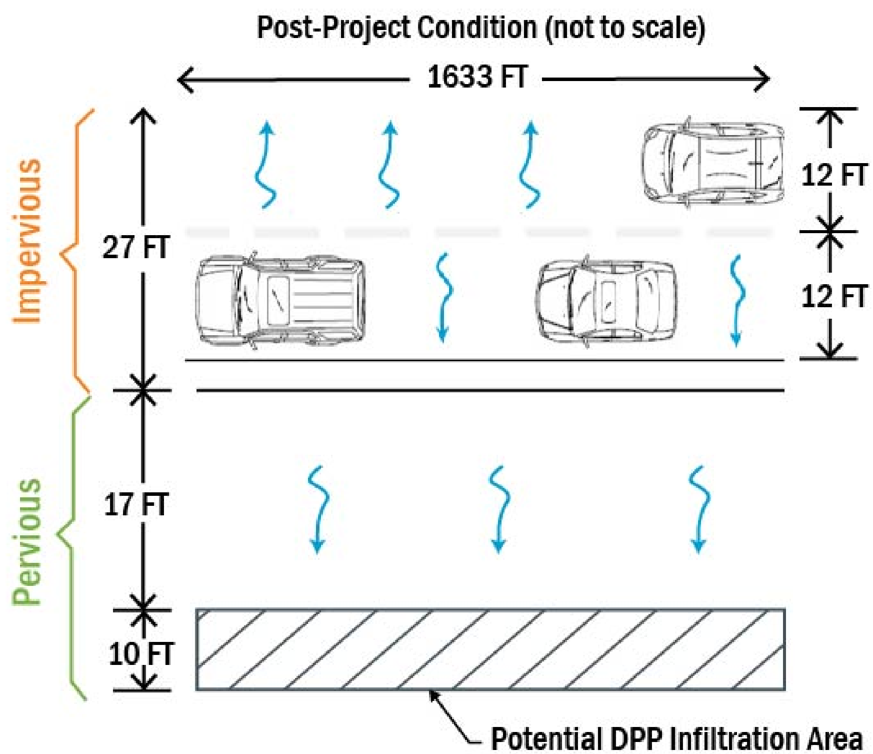

Figure 3-4. CDA with less than 50% Impervious

Step 1: Calculate the CDA upstream of the TBMP to determine percent impervious

The CDA consists of 1 travel lane, a shoulder, and the embankment.

CDA = (12 ft + 3 ft + 17 ft) x 1,633 ft = 52,256 ft^2

Calculate the percent impervious for the CDA:

$$\text{Percent Impervious} = (\text{Impervious Area} / \text{CDA}) \times 100$$

Percent Impervious = (15 ft x 1,633 ft) / 52,256 ft^2) x 100 = 47 percent

The CDA has less than 50% impervious surfaces and the CDA drains the impervious area to the pervious area therefore, a composite WQV calculation is required. Determine separate R_v values, calculate separate WQVs for impervious and pervious drainage areas, and then combine for a total WQV.

Step 2: Determine the volumetric runoff coefficients (R_v)

<u>Impervious Drainage Area:</u>

Using Table 5-2 of the PPDG as shown in Figure 3-3, R_v for 100% impervious is 0.89.

<u>Pervious Drainage Area:</u>

Using Table 5-2 of the PPDG as shown in Figure 3-3, R_v for clayey soils is 0.22.

Step 3: Calculate WQV

$WQV_{impervious} + WQV_{pervious} = WQV_{total}$

$WQV = R_v(P/12)A$

Where:

WQV = Runoff volume generated by the 85th percentile 24-hour storm event (CF)

R_v = From Step 2

P = 0.64 in – given in problem statement

A = From Step 1

$WQV_{impervious}$ = 0.89 x 0.64 in (1 ft /12 in) x (15 ft x 1,633 ft) = 1,163 CF

$WQV_{pervious}$ = 0.22 x 0.64 in (1 ft /12 in) x (17 ft x 1,633 ft) = 326 CF

WQV_{total} = 1,163 CF + 326 CF = 1,489 CF

The WQV (volume of runoff to be treated) calculated for the proposed CDA will be used to size the TBMP such that the WQV can be infiltrated by the facility.

3.2.3 Design Storm Event

The Design Storm event peak flows will typically govern the DPPIA design regarding shear stress and erosion. Determine the peak flows generated by the CDA and TBMP footprint area in accordance with HDM Topic 831. Continue to use the Rational Method from HDM Chapter 810, the runoff coefficients in HDM Topic 819.2, and the total CDA in acres (including the TBMP footprint) for drainage design and flood flows. The average rainfall intensity used in the Rational Method is for the Design Storm frequency and for a duration equal to the time of concentration. See the National Oceanic and Atmospheric Administration (NOAA) website for precipitation frequency data at https://hdsc.nws.noaa.gov/hdsc/pfds/.

The following example calculates the design flow at the Design Storm event and it builds on Example 3-1 above, refer to Figure 3-2.

Example 3-3

Given:

- Sacramento County, Clarksburg Station
- Time of concentration (TOC) is 5 minutes
- The project Design Storm event has a 25-year return frequency
- CDA (Figure 3-2) is 0.3-mile (1,633 ft) long with 2 new lanes, a shoulder, and an embankment
- The TBMP footprint is 0.3-mile (1.633 ft) long and 12 ft wide
- The potential DPPIA shown on Figure 3-2 is sufficient to infiltrate 100% of the WQV
- Calculate the flow at design storm event:

Q_{25} = C x i X A

Where all units are English as follows:

Q_{25} = flow at Design Storm event (cfs)

C = runoff coefficient

i = intensity (in/hr)

A = area (CDA + TBMP Footprint), (acres)

Step 1: Calculate the area

From Example 3-1, Step 1

CDA = 68,586 ft^2 (1 ac / 43,560 SQFT) = 1.6 acre

The TBMP Footprint area is

= (12 ft x 1,633 ft) (1 ac / 43,560 SQFT) = 0.4 acre

Step 2: Calculate a composite runoff coefficient

From Example 3-1, Step 1 and Step 1 above the project areas are:

Impervious area (asphaltic), 1.0 acre

Pervious area (unimproved), 0.6 acre + 0.4 acre

From HDM Table 819.2B, the runoff coefficients are:

Impervious area (asphaltic), 0.95

Pervious area (unimproved), 0.30

Because HDM Table 819.2B lists coefficients appropriate for storms of up to 5 or 10-year frequencies, the resulting coefficient must be adjusted using a frequency factor to account for major storms. For a 25-year frequency, the frequency factor is 1.1. See HDM Topic 819.2 for additional details.

Impervious area: 0.95 * 1.1 = 1.05, which is greater than 1.00 → use 1.00

Pervious area: 0.30 * 1.1 = 0.33

Composite C:

[(Impervious Area * Impervious Coefficient) + (Pervious Area * Pervious Coefficient)] / Total Area

[(1.0 acre * 1.00) + (1.0 acre * 0.33)] / 2.0 acres = 0.67

Step 3: Calculate intensity

Using the NOAA Atlas 14, Volume 6, Version 2, find the precipitation frequency estimate (in/hr) for Clarksburg Station for the 25-year storm (given) with a duration equal to the TOC (given). http://hdsc.nws.noaa.gov/hdsc/pfds/

From the table, the precipitation frequency estimate is 2.78 in/hr

Step 4: Calculate flow

Q_{25} = C x i x A

Q_{25} = 0.67*2.78 in/hr * 2.0 acres = 3.73 cfs

3.3 Hydraulic Calculations

The hydraulic calculations include the following:

1. Size the TBMP to infiltrate as much of the WQV possible

Determine the design velocity generated during the Design Storm by the CDA and TBMP footprint to evaluate surface lining material

Consider drainage lining material

The following subsections include details and examples of these calculations.

3.3.1 WQV Infiltrated

Size the TBMP to infiltrate as much of the WQV as possible without causing negative impacts. Use the Caltrans Infiltration Tool or other appropriate modeling program to determine the volume of runoff infiltrated by the TBMP. Refer to the Caltrans Infiltration Tool and Caltrans Infiltration Tool Guidance document to see how the WQV (planned volume of runoff to be treated) is used to determine both how much infiltration can be achieved and how much of the WQV bypasses the DPPIA. The Caltrans Infiltration Tool Guidance document has example calculations. The Caltrans Infiltration Tool and Tool Guidance are available at the OHSD website. Consider soil amendments to improve site infiltration rates and WQV capture.

Designing DPPIAs is an iterative process. If the WQV infiltrated is either less than 100 percent or more than 100 percent, additional iterations may be required. The TBMP location, size, and CDA should be adjusted, as feasible, to achieve 100 percent WQV infiltration. Once the volume of runoff infiltrated by the TBMP has been determined, clearly document the TBMP design assumptions, sizing calculations, and volume of runoff treated in the SWDR for use by future projects. The location and extent of the TBMP should be shown in the project plans for subsequent depiction on project as-built plans.

3.3.2 Erosion Potential

To evaluate erosion potential, the velocity of the runoff generated during the Design Storm event is used. The DPPIA must convey the flow calculated for the Design Storm (± 5 percent). See example 3-4 in Section 3.3.2.1. The Caltrans Infiltration Tool may be used to assist in the design of DPPIAs.

Alternatively, the following sections can be used for design. The sections describe and provide examples for estimating velocity of flow over a DPPIA configured as a vegetated embankment slope that receives sheet flow. Concentrated flows are not present. When concentrated flows are present, refer to the HDM Chapter 860 and Federal Highway Administration (FHWA) Hydraulic Engineering Circular (HEC) No. 15 (FHWA 2005) for flexible channels.

3.3.2.1 Design Flow and Design Flow Depth

Calculate the design flow and the design flow depth conveyed by the TBMP. Use Manning's equation (a simplified and rearranged version of Manning's equation is shown below) to calculate the design flow and design flow depth. For this example, it is assumed that there are no concentrated flows present and that 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" = 0.05

A = Cross-sectional area of the flow in the channel (SQFT)

R = Hydraulic Radius = "A" / Wetted Perimeter[1] ("P")

S = longitudinal slope (ft/ft)

If the flow contribution of the side slopes is neglected, then the area, A, equals the depth times the 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 following example calculates the TBMP sizing required to convey the design flow. This example builds on Examples 3-1 and 3-3 above, refer to Figure 3-2.

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

Example 3-4

Given:

- Sacramento County, Clarksburg Station
- Manning's coefficient, n = 0.05 (earth with growth)
- Embankment slope is 10% and the maximum TBMP width is the width of the CDA
- CDA (Figure 3-2) is 0.3-mile (1,633 ft) long with 2 new lanes, a shoulder, an embankment, and TBMP footprint
- From Example 3-3, Q_{25} = 3.73 cfs
- Calculate the design flow and design flow depth

<u>Calculate design flow and design flow depth:</u>

Start by assuming a design flow depth and solving for design flow using the following equation:

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

Trial 1: d = 0.02 ft. w = 1,633 ft.

$$Q = ({}^{1.49}/{}_{0.05}) \times (0.02 \text{ ft} \times 1{,}633 \text{ ft}) \times ((0.02 \text{ ft} \times 1{,}633 \text{ ft})/(2{*}0.02 \text{ ft} + 1{,}633 \text{ ft}))^{2/3} \times 0.10^{1/2}$$

$$Q = 22.7 \text{ cfs}$$

The design flow of 22.7 cfs is not within ±5% of Q_{25}. Therefore, another iteration is required. For Trial 2, a smaller design flow depth is assumed.

Trial 2: d = 0.0065 ft. w = 1,633 ft.

$$Q = ({}^{1.49}/{}_{0.05}) \times (0.0065 \text{ ft} \times 1{,}633 \text{ ft}) \times ((0.0065 \text{ ft} \times 1{,}633 \text{ ft})/(2{*}0.0065 \text{ ft} + 1{,}633 \text{ ft}))^{2/3} \times 0.10^{1/2}$$

$$Q = 3.48 \text{ cfs}$$

Trial 2 Q is within ±5% of Q_{25} .

3.3.2.2 Design Velocity

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

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

where

V = Design velocity (ft/s)

d = Design flow depth (ft)

w = Design flow width (ft)

The following example calculates the design velocity. This example builds on Examples 3-1, 3-3, and 3-4 above, refer to Figure 3-2.

Example 3-5

Given:

- Sacramento County, Clarksburg Station
- Manning's coefficient, n = 0.05 (earth with growth)
- Embankment slope is 10% and the maximum TBMP width is the width of the CDA
- From Example 3-4, design flow = 3.48 cfs and design flow depth = 0.0065 ft
- From HDM Table 865.2, use a permissible velocity for vegetation lining of 3.5 ft/s
- Calculate the velocity

Calculate velocity:

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

$$V = 3.48 \text{ cfs} /(0.0065 \text{ ft} \times 1{,}633 \text{ ft}) = 0.33 \text{ ft/s}$$

$V_{25} < 3.5$ ft/s, vegetated lining okay

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. Lining designs should follow methods in HDM Chapter 860 and Federal Highway Administration (FHWA) Hydraulic Engineering Circular (HEC) No. 15 (FHWA 2005) for flexible channels.

3.3.3 Lining Considerations

Highway drainage channels and embankments should be kept in a stable condition and lining materials must be used if deemed necessary. If the estimated design storm velocity is greater than the permissible velocity and permissible shear stress of the DPPIA (vegetated or non-vegetated), consider using a scour resistant strategy. Channel lining materials may be flexible or rigid, flexible linings are able to conform to the channel shape as outlined in HDM Section 860. Other strategies for both channels and embankments include aggregate/soil mixtures, cellular confinement, turf reinforcement mat and rock slope protection.

HDM Table 865.2 categorizes lining materials along with the permissible shear stress and permissible velocity based on boundary category and types. Work with Geotechnical Design to determine soil boundary category and type for the DPPIA. If the DPPIA is newly constructed, the boundary category and type will be based on the proposed bare ground embankment material. If the DPPIA is in an existing area preserved during construction, these values will be based on the existing condition of the area.

The boundary category and type will impact the Manning's coefficient assumption made when calculating the Design Storm flow depth in Section 3.2.3. If the boundary category and type determined with Geotechnical Design do not correspond with the coefficient assumption of a vegetated surface (n=0.05), recalculate Design Storm flow depth and velocity using the appropriate Manning's coefficient for other drainage scour protection options.

Using the boundary category and type of the DPPIA obtained in consultation with Geotechnical Design, verify that the permissible velocity (HDM Table 865.2) is greater than the velocity calculated from Section 3.3.2.2. As mentioned above, the Manning's coefficient used to calculate the design flow depth in Section 3.3.2.2 is dependent on the lining material. Recalculate design flow depth and velocity anytime a new lining material is considered using the appropriate Manning's coefficient.

To verify that the permissible velocity and permissible shear stress is greater than the Design Storm velocity and shear stress, use the calculation methods in HEC No.15, which is the primary reference for stable channel design, and HDM Topic 864 to calculate the velocity and shear stress on the TBMP surface during the Design Storm. This calculation is an iterative process as shown in Figure 3-5 which is a flow chart from HEC No. 15 Chapter 3, where safety factor (SF) is greater than or equal to one. Lining materials, when used, must be designed by a licensed Civil Engineer. Calculations included and are not limited to those mentioned in this design guidance.

3.3.3.1 Vegetation

If vegetation is chosen as the lining material, the permissible velocity and permissible shear stress values in HDM Table 865.2 are valid only after vegetation is established. Temporary erosion control protection should be used to protect the soil from concentrated flows that occur before vegetation is established.

3.3.3.2 Rock Slope Protection

DPPIAs may utilize rock slope protection (RSP) to provide protection against erosion. Design of lining materials, including rock size and Manning's coefficient, is specific to the project. Refer to HDM Section 860 and FHWAs (HEC) No. 15 (FHWA 2005) to design roadside channels to remain stable for estimated flows. It is expected that the majority of DPPIA channel and swale flows will be less than 50 cubic feet per second. Also, designers should consult with Geotechnical Design, Hydraulics, and Traffic Safety if within the CRZ.

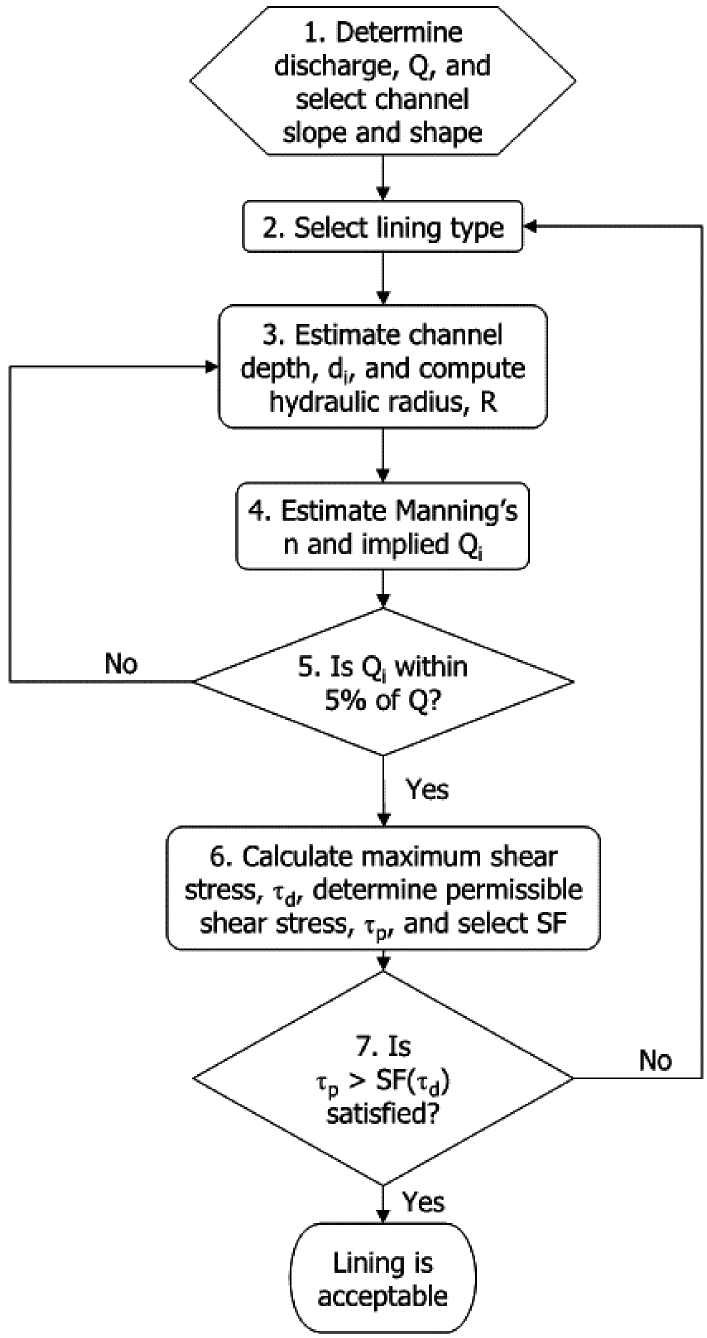

Figure 3-5. Flexible Channel Lining Design Flow Chart

Section 4

BMP Layout and Design

This section includes considerations for layout and specific design elements of a DPPIA.

4.1 Layout

4.1.1 Location

A DPPIA can be used as a stand-alone device or can be placed upstream of other TBMPs as pretreatment. They should be considered upstream of other TBMPs that benefit from pretreatment to reduce sediment loading such as Infiltration Devices, Detention Devices, and Media Filters. DPPIA used as pretreatment is an example of a treatment train.

4.1.2 Maintenance

DPPIAs are generally part of our existing embankments and drainage systems. The purpose is to take credit for the existing areas that infiltrate. Maintenance is expected to be minimal and based on what we are already currently doing. The maintenance should be typical for drainage systems and road side embankments including: mowing, erosion repairs, scour repairs, and part of roadside inspections. Maintenance may be required to repair surface erosion or shearing and to reevaluate functional performance as needed. District Maintenance should concur with the proposed DPPIA location and configuration, as part of the SWDR review. The DPPIAs should be designed for least amount of maintenance possible.

4.2 Site Specific Design Elements

4.2.1 Soil Modification

When project soils are modified to improve infiltration, organic or non-organic amendments may be used based on the site design for slope stability, safety, CRZ, drainage design, distance to structures, compaction requirements, suitable materials and overall site design parameters in accordance with the HDM. The project engineer must determine the amendments and if vegetation is appropriate for the site design.

4.2.1.1 Soil Modification Non-Vegetated

Soil modification for non-vegetated applications may include organic or non-organic materials. Design of soil amendments should be coordinated with other functional experts such as the District Hydraulics, District Traffic Operations, Geotechnical Design, Traffic Safety, and OHSD. When needed, a geotextile or geogrid 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.

4.2.1.2 Soil Modification Vegetated

If a vegetated DPPIA design is selected, organic and non-organic soil amendments should be coordinated with other functional experts such as the District Hydraulics, District Traffic Operations, District Landscape Architecture, Geotechnical Design, Traffic Safety, and OHSD. When needed, a geotextile or geogrid can be used to enhance the subgrade stability of vegetated areas. Coordinate with Geotechnical Design when considering geotextiles or geogrids including for use in embankments to help with slope stability

4.2.2 Use of Dikes Within the Roadway Cross Section

When existing dike is to be removed to allow sheet flow to DPPIAs or other 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 DPPIAs. 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.

4.3 Alternative Paving Surfaces

Alternative paving surfaces may allow stormwater to filter through voids in the materials and infiltrate in a manner consistent with pervious surfaces thus mimicking DPPIAs. While pervious pavement designs may vary, they all have a similar structure consisting of a surface pavement layer with an optional underlying reservoir layer. Other terms such as permeable pavement or porous pavement are used in literature to describe what Caltrans has termed pervious pavement.

Prior to implementing pervious pavement into a contract within Caltrans right of way, concurrence is needed from the Office of Hydraulics and Stormwater Design and the Division of Maintenance. Caltrans currently only allows for non-highway applications. If alternative paving surfaces are being considered, see the Pervious Pavement Design Guidance (Caltrans 2020d).

Section 5

PS&E Preparation

This section provides guidance for incorporating DPPIAs into the PS&E package, discusses 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 DPPIAs into the PS&E in accordance with the requirements of Section 2 of the Construction Contract Development Guide (Caltrans 2019b).

5.1 PS&E Drawings

DPPIAs 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 DPPIAs may include:

- Layout(s): Show location(s) of the DPPIAs. This will aid in recognizing, both within and outside Caltrans, that DPPIAs were placed within the project limits.
- Drainage Plan(s), Profiles, Details, and Quantities:
    - Drainage Plan sheets should show each DPPIA in plan view, along with other existing (or proposed) drainage conveyance devices that direct runoff into the device. DPPIAs need to be 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 DPPIA 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 DPPIA not provided elsewhere in the contract plans, (i.e., Planting Plans).
- Planting Plans/Erosion Control Plans: These sheets are used to show incorporated materials and vegetative portion of the TBMP, as needed. Planting quantities (e.g., hydroseed) for each vegetated DPPIA should be provided.
- Temporary Water Pollution Control Plans: These sheets are used to show the temporary BMPs used to establish the DPPIA TBMPs and compliance with the Construction General Permit.

5.2 Specifications

Contract specifications for DPPIA projects will include Standard Specifications and may include Standard Special Provisions (SSPs) and nSSPs.[2]

The various items of work to construct the DPP Infiltration Areas can be addressed as full compensation nonstandard special provision, so that the costs of TBMPs and location can be tracked. The PE and the District Office Engineer may consider other methods if appropriate.

5.2.1 Standard Specifications

Standard Specifications may be used for a DPPIA in conjunction with DPPIA NSSP from OHSD. Consider the construction of the DPPIA in the context of the entire project to determine what Standard Specifications are applicable. Within the Standard Specifications, these are the sections that may be applicable:

13 Water Pollution Control

17 General (Earthwork and Landscape)

19 Earthwork

20 Landscape

21 Erosion Control

26 Aggregate Base

68 Subsurface Drains

70 Miscellaneous Drainage Facilities

71 Existing Drainage Facilities

72 Slope Protection

96 Geosynthetics

5.2.2 Standard Special Provisions

SSPs can be used for a project that constructs a DPPIA. Consider the construction of DPPIAs 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

DPPIAs can consist of a variety of infills, blends, and/or surface treatments. Most will require a nSSP to provide details for a site-specific soil amendment design to assure that the design assumptions are constructed properly. The PE and PDT should decide the most appropriate specifications for the site-specific site conditions to

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

infiltrate water and meet other goals in the HDM (e.g., safety, slope stability). If the PE and PDT deem nSSPs necessary, coordinate with OHSD. OHSD can provide nSSPs to support the design. An nSSP can provide details for a site-specific soil amendment design that infiltrates runoff and provide specifications for constructing embankments to meet CRZ (AASHTO Clear Zone) traversable requirements.

DPPIA NSSPs are recommended, so the costs and location of DPPIA can be captured and tracked for compliance with the NPDES permit. OHSD has developed NSSPs to cover the many variables that a DPPIA may contain and they are available upon request.

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, Office of Project Support has developed the following website to assist in the development of cost estimates:

http://www.dot.ca.gov/design/pjs/index.html

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 the PID phase of the project. A refined version of the PPCE is developed in the 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. 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 TBMPs 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 DPPIA location and determine limits of excavation and backfill. Sample quantity sheet can be provided by OHSD.

5.4 Developing DPPIA Cost Estimates

Develop a quantity-based cost estimate. 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 DPPIA and include them in the DPPIA nSSP. There are two strategies that can be employed to promote infiltration, either used together or apart:

1. A complete replacement of the existing soils with rock or other blends as an "infill"
2. To "blend" in either compost, rock or sand into the existing soils

Costs associated with embankment enhancement (aggregate topsoil) would be included in the DPPIA cost estimate as an infill.

Include Cellular Confinement systems or Turf Reinforcement Mat (TRM) to protect the DPPIA TBMP against erosive velocities, or to enhance load bearing capacity.

The nSSP for DPPIA describes the material, measurement, construction, and payment, the PE will select the appropriate items for the site design and include in quantities. DPPIA will typically be shown as a volumetric measurement but may also include element that are measured as square feet.

It may not be necessary to include costs for items that support the TBMP in the unit cost of the TBMP to be reported as EACH in the SWDR. For example, utility relocation, traffic safety items, drainage systems, or site design elements that are required for the project. Some of these items may be included if they are standalone TBMPs for water quality projects and are due solely to the TBMP construction.

- Table 5-1 includes typical contract items that may be included in the unit cost (CY & SQFT) estimate if they are required for DPPIAs. 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 DPPIA Estimate					
Contract Item	Type	Unit	Quantity	Price	Amount
Excavation, as Roadway Ex or Structure Ex.		CY			
Rock Infill, Soil Infill or Blend (type and depth of incorporation)		CY			
Compost		CY			
Topsoil		CY			
Rock		CY			
Rock Mulch		CY			
Cellular Confinement		SQFT			
Turf Reinforcement Mat		SQFT			
Slope Protection		SQFT			
Erosion Control (e.g. Dry Seed – Hydroseed, Hydromulch)		SQFT			

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

http://sv08web/contractcost/

The DPPIA should be labelled as a DPP Infiltration Area - Infill or Blend in a table format on the Drainage Detail Sheet. The table should include length, width and depth for each specific DPPIA location, as these items of work will be combined to estimate the CY cost for this TBMP. The location should be shown with, station and offset and unit quantity of each DPPIA by location.

Estimate the total cost of each DPPIA used on the project for tracking TBMP costs at PS&E. Document all TBMP costs in the project SWDR at PS&E. Some DPPIA features may be required for drainage or other project features, therefore, cost items will vary by project.

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Section 6

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