Flow Splitters

Design Guidance

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California Department of Transportation
HQ Division of Design

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Caltrans Division of Design

Office of Hydraulics and Stormwater Design

P.O. Box 942874, Sacramento, CA 94274-0001

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List of Abbreviations

AASHTO	American Association of State Highway and Transportation Officials
BCE	Bypass Control Elevation
BEES	Basic Engineering Estimate System
BMP	Best Management Practice
BP	Bypass
CRZ	Clear Recovery Zone, (AASHTO Clear Zone)
CF	cubic feet/foot, curb face
DPPIA	Design Pollution Prevention Infiltration Area
Elev. (EL.)	Elevation
fps	feet per second
ft	foot/feet
FHWA	Federal Highway Administration
GSRD	Gross Solid Removal Device
HEC	Hydraulic Engineering Circular
H	Hydraulic head above the weir crest elevation (BCE)
HDM	Highway Design Manual
HGL	Hydraulic Grade Line
in	inch/inches
IN	inflow
LRFD	Load and Resistance Factor Design
NPDES	National Pollutant Discharge Elimination System
nSSP	non-Standard Special Provision
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
RCP	Reinforced Concrete Pipe
SQFT	square feet
SQYD	square yard
SFS	Surface Flow Splitter
SSHM	Small Storm Hydrology Method
SSP	Standard Special Provision
SUR	Surcharge(d)
SWDR	Stormwater Data Report
TBMP	Treatment Best Management Practice
TOG	Top of Grate
UFS	Underground Flow Splitter
WQ	Water Quality
WQF	Water Quality Flow
WQV	Water Quality Volume

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Section 1

Introduction

This document provides guidance to Caltrans Designers for incorporating Flow Splitter Standard Detail Drawings into projects during the planning and design phases of projects.

Flow Splitters are drainage bifurcation structures designed to direct flows to stormwater Treatment Best Management Practices (TBMPs) and to provide a bypass during peak flow conditions. They are installed upstream of the TBMP and direct the Water Quality Flow (WQF) or the Water Quality Volume (WQV) to the TBMP. The condition in which stormwater in excess of the WQF or WQV is conveyed to the TBMP is known as surcharge. The bypass function provided by a flow splitter is intended to minimize the magnitude and adverse impacts of the surcharge and to allow offline placement of TBMPs. Flow Splitters may be used in conjunction with approved TBMPs. Providing bypass of the surcharge flows can prevent resuspension of pollutants captured in the TBMP.

The Project Planning and Design Guide (PPDG) requires consideration of Dry Weather Flow Diversion structures at sites where Caltrans activities or facilities generate non-stormwater flows. The Dry Weather Flow Diversion structure is simply a Flow Splitter installed to divert non-stormwater flows to a municipal sanitary sewer system during the dry season.

1.1 Design Responsibility

The Project Engineer (PE) is responsible for the design of flow splitter 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 treatment may have on the roadway especially in consideration of the Clear Recovery Zone (CRZ). Coordinate with other functional experts to implement successful and functioning Flow Splitters.

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.

1.2 Types of Flow Splitters

The two major types of flow splitter are: (1) the Underground Flow Splitter (UFS); and (2) the Surface Flow Splitter (SFS). This document provides design guidance for the UFS configuration only.

The UFS is an underground structure which directs the WQF or WQV conveyed by a storm drain system to the downstream TBMP through a water quality (WQ) diversion pipe. As much as possible, stormwater in excess of the WQF or WQV is directed to a bypass (BP) pipe, rather than to the WQ diversion pipe and the downstream TBMP.

The SFS directly intercepts the WQF or WQV conveyed on the surface in the shoulder/gutter of a roadway before it is collected in a storm drain. The WQF or WQV is intercepted by an opening (curb cut) in an otherwise continuous curb or dike and directed to the TBMP. Flows exceeding the interception capacity of the curb opening continue flowing in the gutter and bypass the TBMP. The SFS curb opening functions like the curb opening drainage inlet, however the opening is typically smaller to intercept only the WQF or WQV and bypass as much of the peak design storm as possible. The bypassed flow would then be picked up in a conventional drainage inlet at some point downstream along the shoulder/gutter.

1.3 Underground Flow Splitter (UFS)

There are five standard types of UFS, each with an alternative configuration. Table 1-1 describes the configuration, principal characteristics, and benefits of each type of UFS. Since more than one of the types of flow splitter will provide the necessary hydraulic capacity, the information in Table 1-1 is useful in the initial selection of the UFS that will minimize the size and the depth of the structure. Consult with Geotechnical Design, Hydraulics, and Traffic Safety if within the CRZ.

Table 1-1. UFS Types

UFS Type	Structure Configuration	Weir Length (Ft)	Description/Benefits
1	Rectangular vault. (See Figure 1-1) Length(1): 10.0 ft – 16.0 ft Width: 9.0 ft – 10.0 ft Height: 7.0 ft – 8.0 ft	10 - 16	Provides longer weir length than the circular configurations which will reduce the hydraulic head over the weir and lessen adverse hydraulic impacts. The cost is likely more than Types 2 and 3 since pre-cast components are not an option.
2	Circular manhole. (See Figure 1-2) Diameter(2): 4.0 ft – 5.0 ft Depth to Invert: 20.0 ft maximum	4 - 5	Provides the shortest weir length which will require the largest hydraulic head over the weir for higher flows. Precast components are acceptable which can reduce cost.
2	Circular vault. (See Figure 1-3) Diameter(2): 6.0 ft – 10.0 ft Height: 6.0 ft – 8.0 ft	6 – 10	Provides the shortest weir length which will require the largest hydraulic head over the weir for higher flows. Precast components are acceptable which can reduce cost.

Table 1-1. UFS Types			
UFS Type	Structure Configuration	Weir Length (Ft)	Description/Benefits
3	Circular manhole. (See Figure 1-4) Diameter(2): 5.0 ft Depth to Invert: 20.0 ft maximum	5	Configuration is similar to Type 2, but the pipes are close in elevation and a weir wall provides the separation. This structure can be used where the drop from the IN to the BP pipe in the Type 2 is not possible. However, the height of the weir wall may increase the impact to upstream systems. An optional orifice plate can be constructed on the WQ diversion pipe to control the flow to the TBMP during the bypass flow stage due to the height of the weir wall.
3	Circular vault. (See Figure 1-5) Diameter(2): 6.0 ft – 10.0 ft Height: 6.0 ft – 15.0 ft	6 - 10	Configuration is similar to Type 2, but the pipes are close in elevation and a weir wall provides the separation. This structure can be used where the drop from the IN to the BP pipe in the Type 2 is not possible. However, the height of the weir wall may increase the impact to upstream systems. An optional orifice plate can be constructed on the WQ diversion pipe to control the flow to the TBMP during the bypass flow stage due to the height of the weir wall.
4	Circular manhole. (See Figure 1-6) Diameter(2): 4.0 ft - 5.0 ft Depth to Invert: 20.0 ft maximum	NONE	This structure has no weir. Bypass is accomplished by setting the BP pipe above the invert elevation of the WQ diversion pipe. This is the least expensive structure, but hydraulic analysis is more complex and requires site-specific rating curves. This structure has the highest surcharge to the WQ diversion pipe.
5	Rectangular vault. (See Figure 1-7) Length(1): 10.0 ft – 16.0 ft Width: 9.0 ft – 10.0 ft Height: 7.0 ft – 8.0 ft	20 - 32	Configuration is similar to Type 1 with a double-sided weir. Provides the longest weir length and lowest surcharge to the WQ diversion pipe. High cost and difficult maintenance.

1. *The length of Types 1 and 5 may be specified at any value between the minimum and maximum values listed.*
2. *The diameter of circular structures must be specified in increments of whole feet between the minimum and maximum values listed.*

The UFS consists of an underground chamber with the following four basic elements: (1) an inflow (IN) pipe (typically a storm drain); (2) a WQ diversion pipe; (3) a bypass (BP) pipe; and (4) a bypass weir or in a Type 4 structure, simply a difference in pipe invert elevations, which separates the flow to the BP pipe from the other pipes.

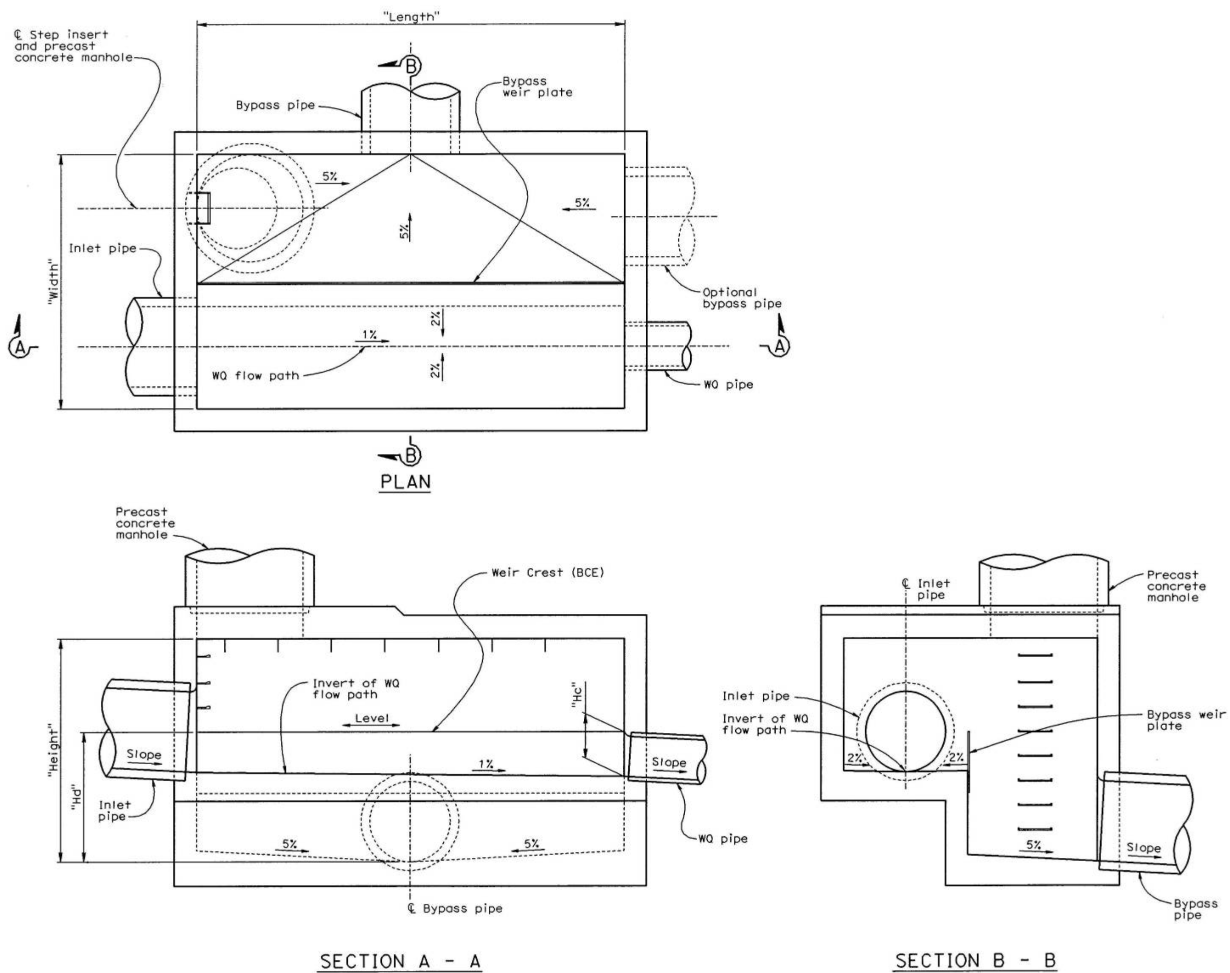


Figure 1-1. Type 1 Underground Flow Splitter

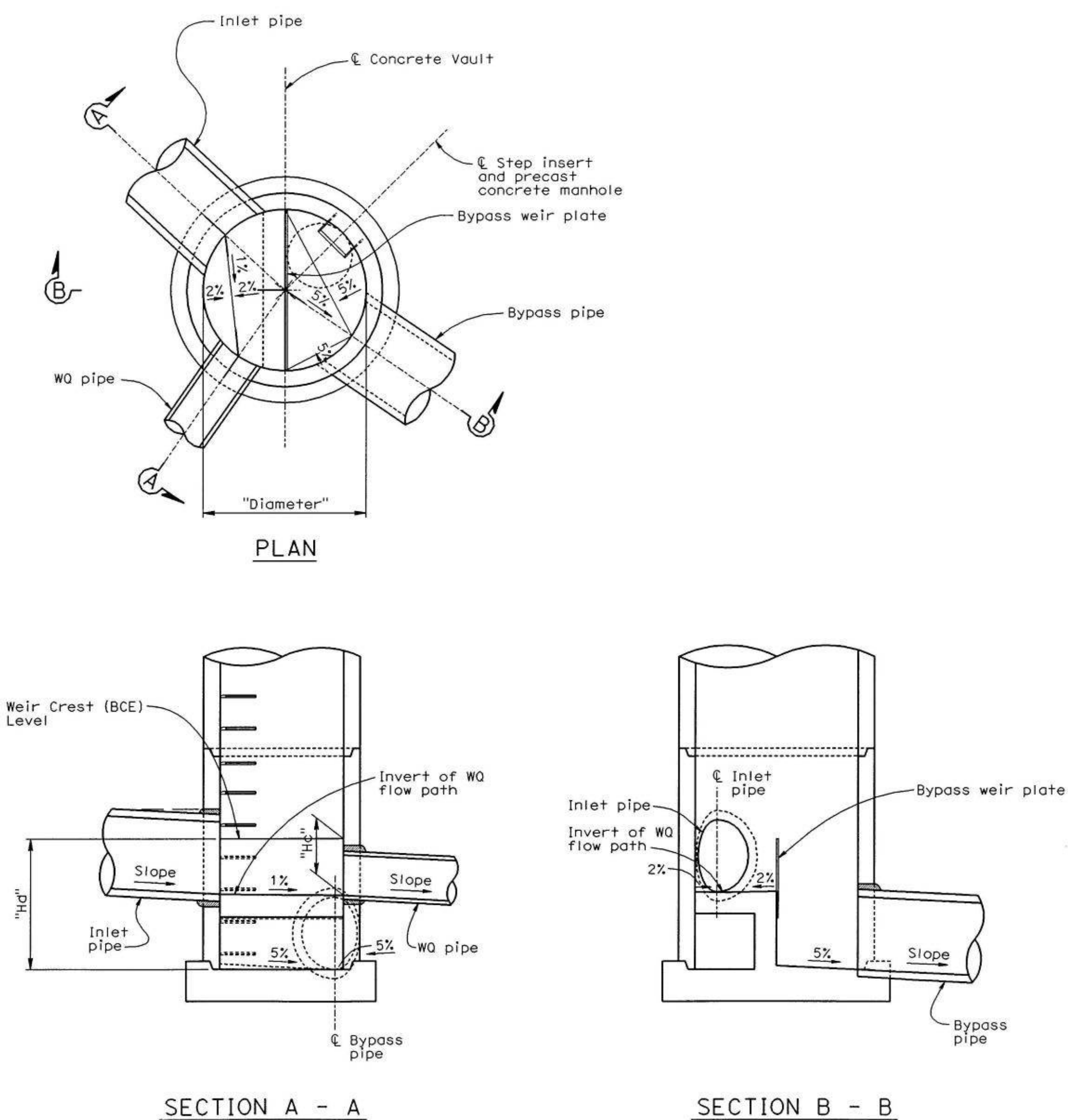


Figure 1-2. Type 2 (Manhole Configuration) Underground Flow Splitter

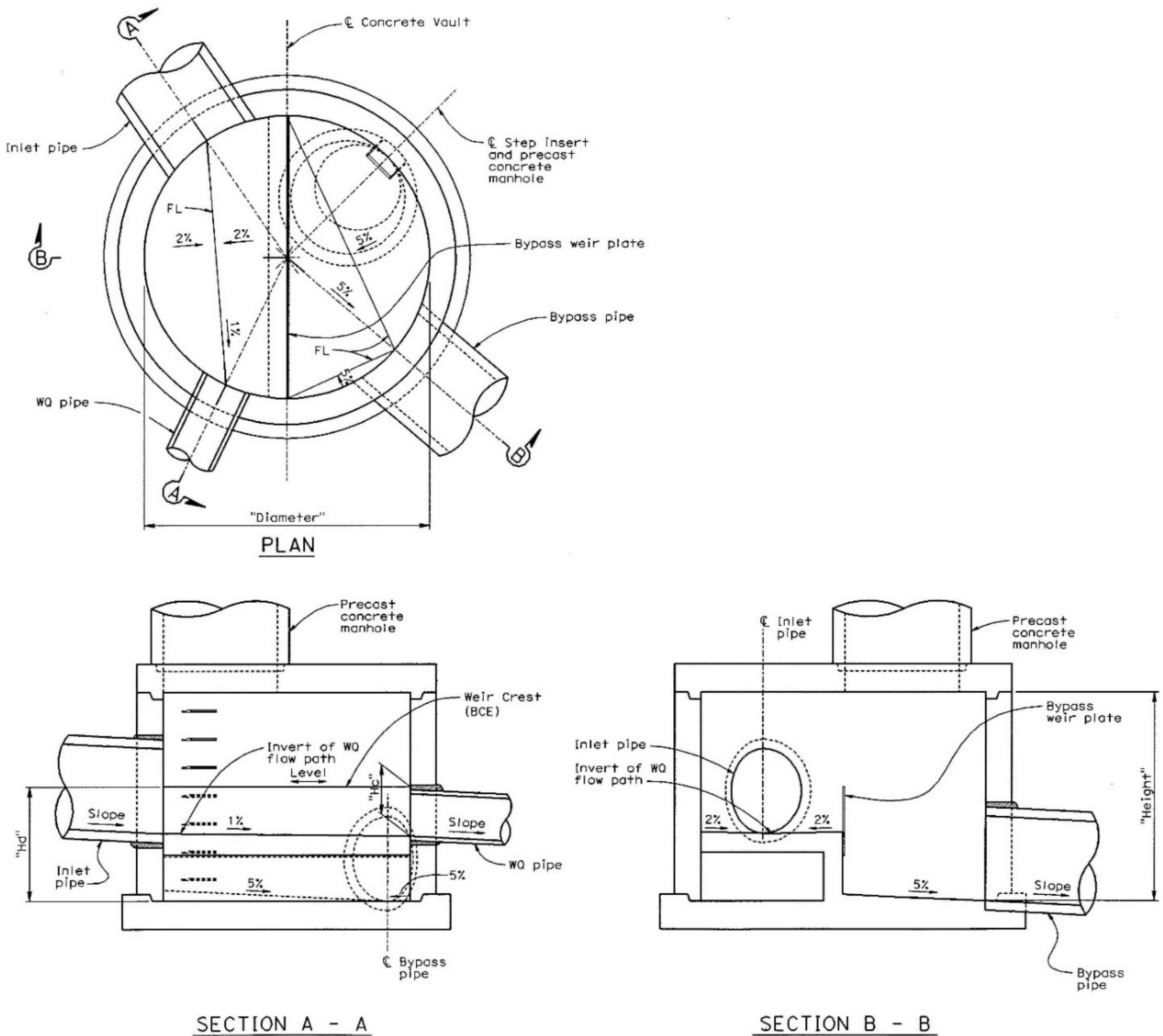


Figure 1-3. Type 2 (Vault Configuration) Underground Flow Splitter

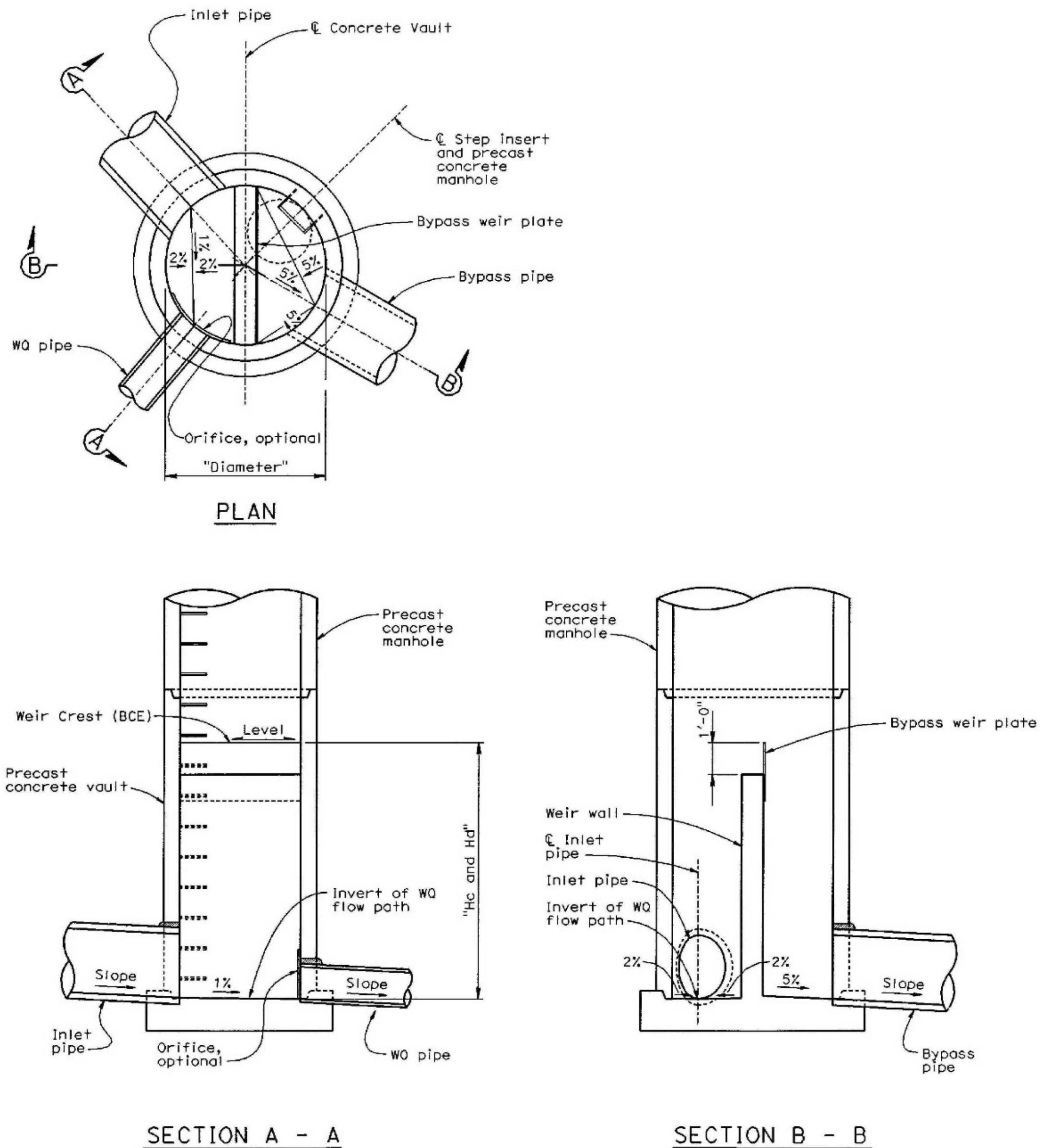


Figure 1-4. Type 3 (Manhole Configuration) Underground Flow Splitter

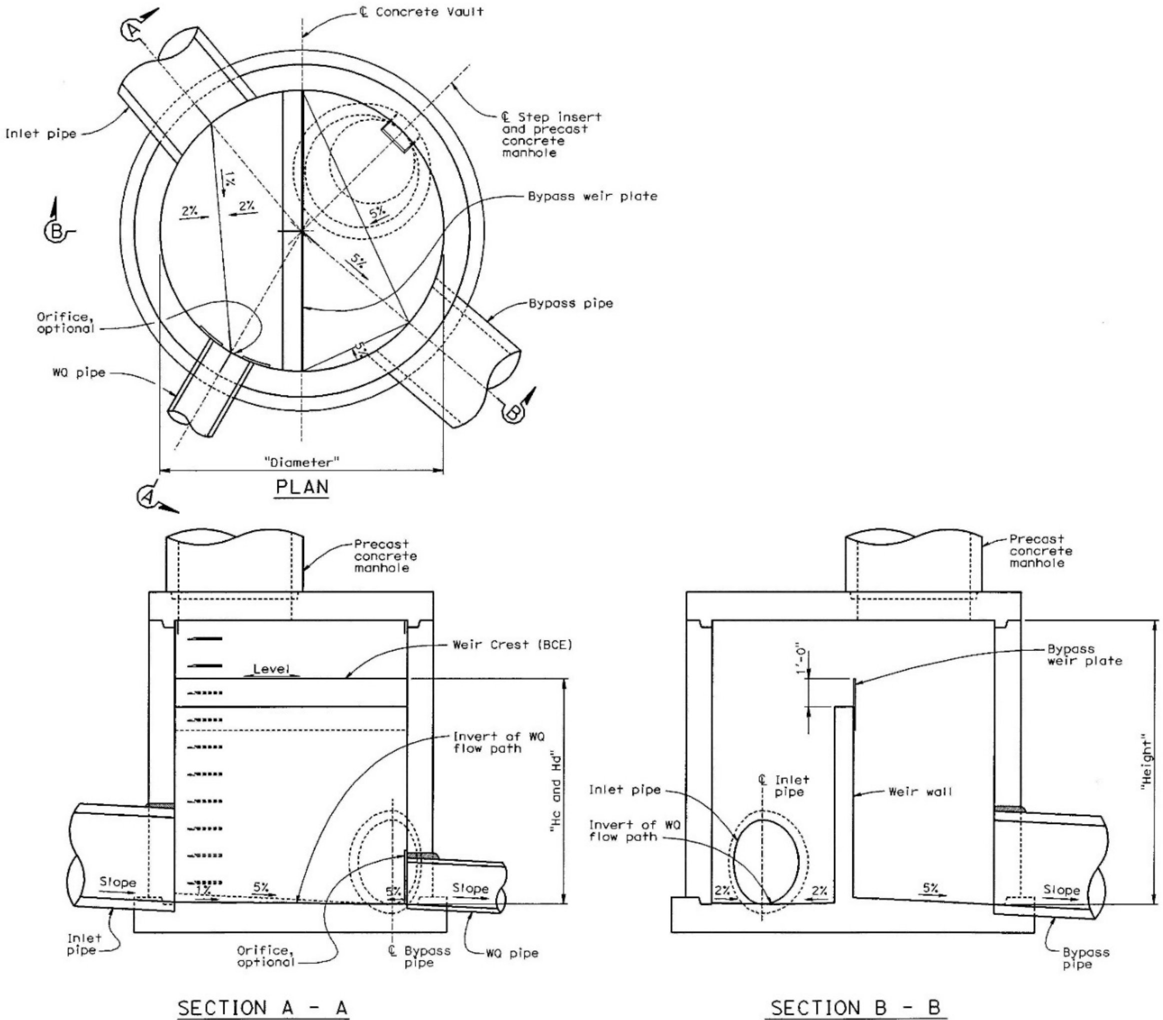


Figure 1-5. Type 3 (Vault Configuration) Underground Flow Splitter

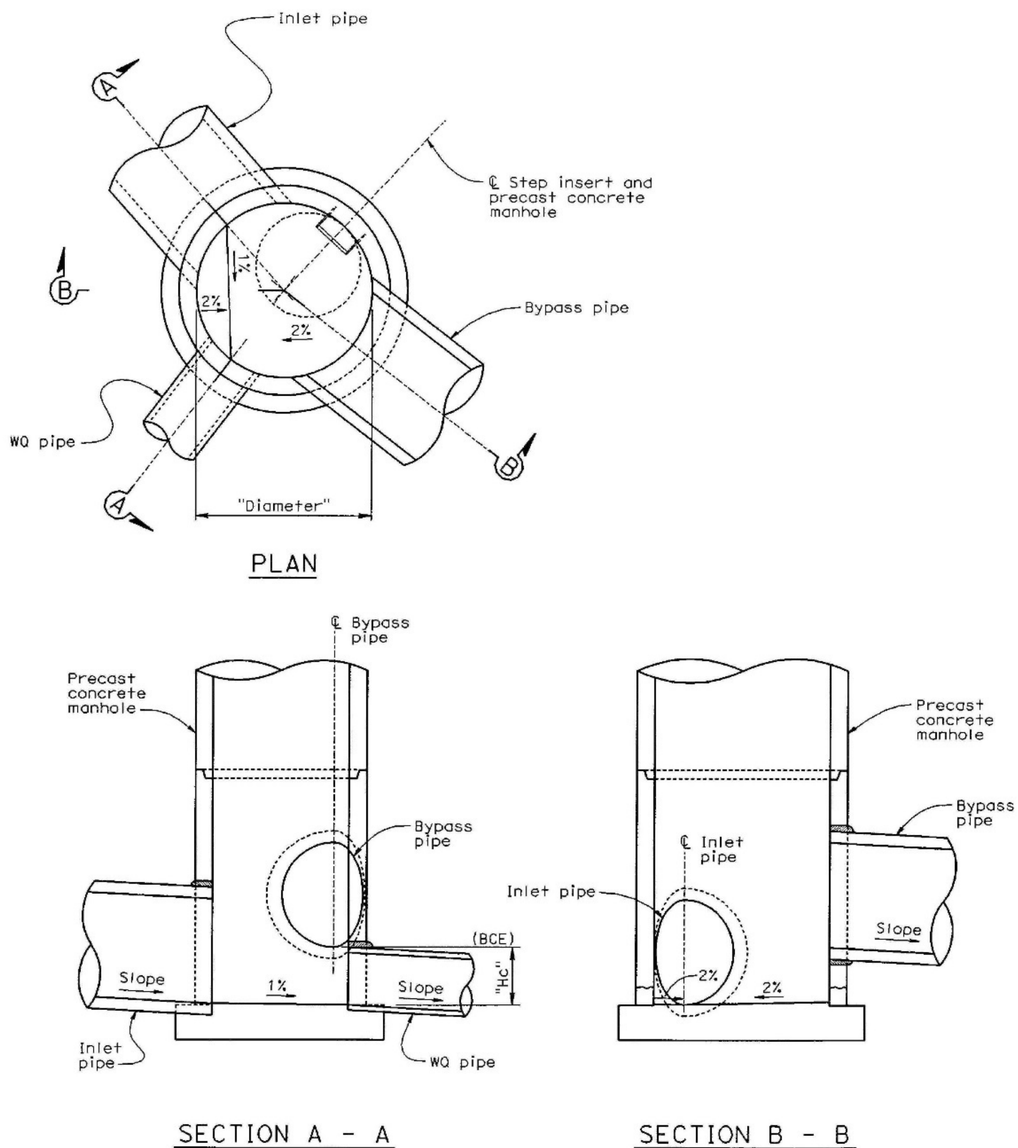


Figure 1-6. Type 4 Underground Flow Splitter

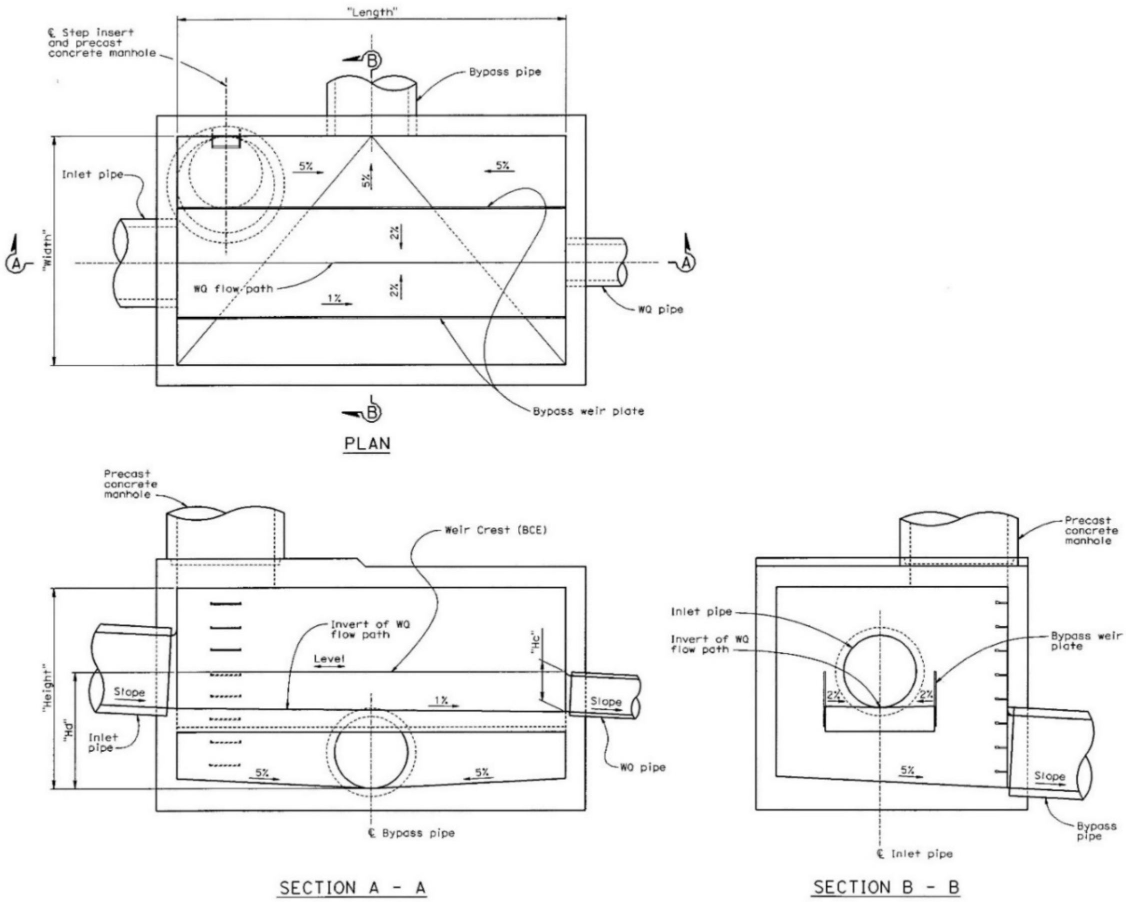


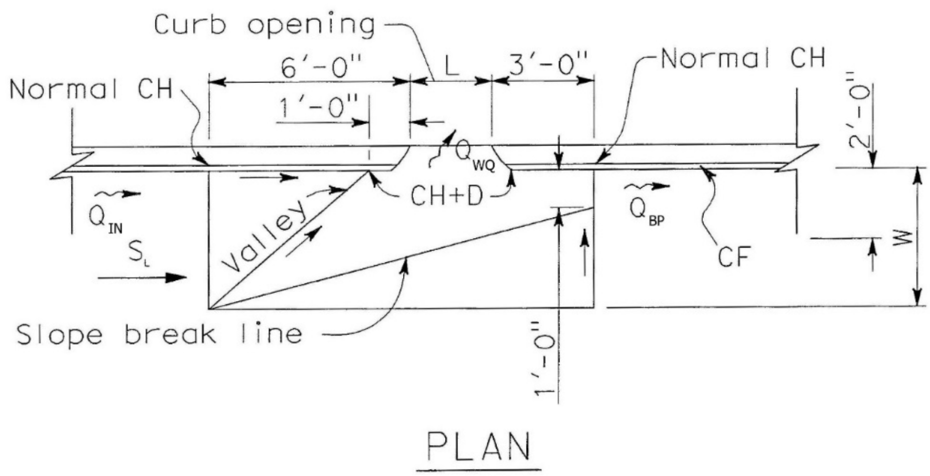
Figure 1-7. Type 5 Underground Flow Splitter

1.4 Surface Flow Splitter

Surface Flow Splitters (SFS) capture and divert the WQF and/or WQV flowing on the paved surface along the curb or dike of roadways, parking lots or similar paved areas. They can be used in most of the same situations requiring a flow split described elsewhere in this document for UFSs, assuming the flow split can be accomplished along the roadway flow line as opposed to an intercepted conduit. The hydraulic performance of SFSs is similar to curb opening drainage inlets. Therefore, the hydraulic capacity of this type of split is dependent on various site conditions defined by the roadway geometry. These include longitudinal slope (S_L), cross slope, depth of the local depression, type of curb or dike, and the type of street surface. All of these factors determine the depth, spread and velocity of flow in the shoulder or gutter, which determine the interception capacity of the curb opening.

Like UFSs, SFSs can be designed based on volume and/or flow depending on the downstream TBMP. Flow-based designs are controlled by the depth of flow approaching the curb opening and the required curb opening length to capture 100% of the WQF. Larger flows in the gutter at greater depths may result in a significant increase in flow conveyed to the TBMP. Volume-based designs are controlled by the depth of the water that is ponded downstream of the curb opening. If the hydraulic grade line immediately downstream of the curb opening submerges the opening, the interception capacity of the curb opening will be significantly reduced and the surcharge flow to the TBMP can be reduced, similar to the curb opening of a flooded curb opening drainage inlet.

The design of a surface flow splitter can be accomplished using the standard design procedures established for curb opening inlets as described in Chapter 800 of the HDM and Federal Highway Administration (FHWA) Hydraulic Engineering Circular (HEC) No. 22 (FHWA 2009). There are several commercially available hydraulic engineering software packages that are useful tools for calculating street flow and interception capacities of curb openings. A schematic plan of a typical surface flow splitter is shown in Figure 1-8. It is shown with a standard local depression for a 2-foot wide gutter that may be required and/or allowed depending on the site conditions. Determine the length of curb opening (L) required to intercept the WQF for the roadway configuration at each specific site, similar to the calculations required for a standard curb opening drainage inlet. The surcharge is determined by the interception capacity of the curb opening at the street flow conditions occurring at the peak design flow rate. As described above, the surcharge could be reduced if the tailwater is set at an elevation that submerges the curb opening. However, be careful not to exceed the maximum allowable water spread in a submerged condition as prescribed in Chapter 800 of the HDM.



S_L = Longitudinal Slope

CH = Curb Height

D = Depth of the Local Depression

CF = Curb Face

L = Length of the Curb Opening

W = Width of the Local Depression

Figure 1-8. Surface Flow Splitter Schematic

The type of structure behind the curb opening may vary depending on the type of TBMP proposed and its location with respect to the curb opening. Options include a downdrain, overside drain, concrete ditch, rock slope protection, or a connection directly to the TBMP.

Caltrans Standard Plans have several details for gutter and inlet depressions, and overside drains that can be used as a surface flow splitter. If used, these details will require modifications.

The design of SFSs can be accomplished using standard design procedures for curb opening inlets, and the reader is directed to standard references, such as HEC No. 22. The remainder of this document is devoted to providing design guidance for UFS.

Section 2

Design Basis for Underground Flow Splitters

The main design parameters for selecting the type and size of UFS are the discharge capacity of the bypass element and the capacity of the UFS to convey the WQF or WQV to the TBMP. For Type 4, the bypass capacity is determined by the rating curve for the BP pipe. This calculation procedure is described in Section 4.

For Types 1, 2, 3, and 5 the bypass capacity is determined by the design of the bypass weir, Figure 2-1. The discharge capacity of the weir is calculated using the discharge equation for an unsubmerged sharp-crested rectangular weir with end contractions (FHWA 2009), shown below.

$$Q_w = C_{SCW} (L_w - 0.2\ H)\ H^{1.5}$$

Where:

Q_w = weir discharge, cfs

L_w = horizontal weir length, ft

H = head above weir crest excluding velocity head, ft

C_{SCW} = weir discharge coefficient [3.27 + 0.4(H/H_c)]

H_c = height of the weir crest on the upstream side of the weir, ft

H_d = height of the weir crest above the flow line of the BP Pipe, ft

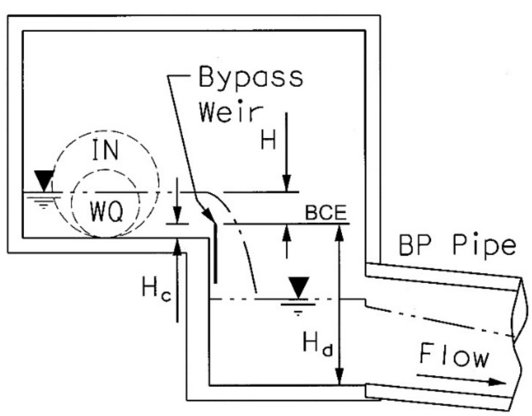


Figure 2-1. Bypass Weir

The height of the weir crest (H_C), or the Bypass Control Elevation (BCE), is calculated to ensure that the WQF or WQV is conveyed to the TBMP without overtopping the bypass weir. This calculation procedure is described in more detail in Section 4. Subsequently, the elevations of the components of the UFS are set and checked with hydraulic analyses of the various portions of the drainage system. The hydraulic analyses verify that the hydraulic grade line of the system, including the effect of the UFS during the WQF and peak design discharge, demonstrates that the system performs adequately. UFSs are intended to operate automatically without any personnel required to control the flow split.

2.1 Design Criteria

A set of UFS Detail Drawings has been developed for use in designing UFSs and can be obtained from OHSD (Caltrans 2020d). The Standard Detail Drawings can be renamed and/or revised as necessary by the PE in responsible charge of the project. The drawings are intended for standard configuration designs under normal conditions and typical external loading requirements as described in the drawings. They do not cover use in corrosive environments, abrasive flow conditions, or areas where there are substantial freeze-thaw conditions. The UFS Detail Drawings account for specific design load cases and a Special Design will be required for sites or conditions that do not meet the standard design criteria, such as:

- High ground water table (above the bottom elevation of the UFS)
- Surcharge loads that exceed the AASHTO LRFD load rating
- Inadequate foundation bearing capacity
- Seismically induced differential settlement or loss of foundation support during liquefaction

Table 2-1 presents general design criteria utilized for the development of the UFS Detail Drawings.

Table 2-1. UFS General Design Criteria

Parameter	Value
Bypass Flow Rate, Qweir	70 cfs maximum
Head over the Bypass Weir, H	2.0 ft maximum
Soil Cover on Top Slab (Does not apply to Manhole Configurations or Type 4)	12.0 ft maximum
Depth to the UFS invert, (Manhole Configurations and Type 4)	20.0 ft maximum
Unsupported Height of Weir Plate, “Hc”, (Types 1,2, and 5)	2.0 ft maximum
Unsupported Height of Weir Plate, (Type 3)	1.0 ft

2.2 Safety Considerations

UFSs 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 UFS 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, Structure Design, and Traffic Safety, as applicable.

2.3 Restrictions/Coordination

Successful implementation and utilization of the UFS Detail Drawings may require coordination with District Hydraulics and will depend on properly positioning the UFS horizontally and vertically within a site. Therefore, it is important to take note of location restrictions when designing the UFS, particularly for retrofit applications. The use of the UFS Detail Drawings in any conditions outside the range of values presented in Table 2-1 (for exceptions, see Section 7) or in conflict with the UFS Detail Drawings is considered a Special Design and should be evaluated by the PE, in coordination with District Hydraulics, District Maintenance, District Traffic Operations, District Landscape Architecture, Geotechnical Design, and Traffic Safety, as applicable per site design. UFS design decisions and coordination must be documented in the SWDR and project file.

UFSs should generally be constructed in an unobstructed location that can be easily accessed by maintenance vehicles. The footprints of the approved UFSs and space considerations are discussed in Sections 3 and 5, respectively; however, the following major restriction should be considered during the process of selecting the type, size, and location of a UFS.

2.3.1 Pipeline Diameter Restrictions

Table 2-2 presents the maximum pipe diameters allowed to connect to each UFS type. A maximum of one pipe connection is allowed for the IN, WQ, and BP pipes. Connection of multiple pipes for either of the IN, WQ, or BP pipes or use of pipe diameters exceeding the values in Table 2-2 is considered a Special Design. Evaluate the effect of multiple connections to the structural and hydraulic performance of the UFS structure. The minimum pipe diameters connected to the UFS shall be in compliance with the requirements in Chapter 800 of the HDM.

Table 2-2. Maximum Pipe Diameter			
UFS Type	Maximum IN Pipe Diameter (in)	Maximum WQ Pipe Diameter (in)	Maximum BP Pipe Diameter (in)
1	36	18	36
2 (Manhole)	27	15	27
2 (Circular Vault)	36	18	36
3 (Manhole)	24	12	24
3 (Circular Vault)	36	18	36
4	36	18	36
5	36	18	36

Section 3

Getting Started

This section presents the prerequisite design parameters required to determine if a UFS can and should be implemented in the design of a drainage system and to initiate the design and selection of the UFS. It also includes general guidance for selecting the appropriate type of UFS and the vertical position[1] of the UFS relative to the TBMP and IN pipe. Existing site conditions must also be considered in selecting, sizing, and laying out the appropriate UFS.

A UFS is generally used where the downstream TBMP is sensitive to surcharge and a significant surcharge flow cannot be conveyed solely through the overflow facilities of the TBMP. The overflow facilities in the TBMP may be limited and incapable of conveying the peak design flow (Q_{HDM}) of the drainage system due to space constraints or an inadequately sized downstream existing drainage system. A UFS may also be utilized in drainage systems with proposed TBMPs in which the size of the TBMP is sensitive to and a function of the maximum flow rate that is anticipated to flow through the TBMP. The size of these types of TBMPs can be minimized by sizing them for the WQF, which is typically a fraction of Q_{HDM}, and constructing a UFS to provide a safe bypass for the larger flows.

3.1 Preliminary Design Parameters

The following design parameters are required in order to verify the need for a UFS and to select the appropriate UFS:

- Peak Design Storm Flow Rate (Q_{HDM}). The peak design storm flow rate for the inflow drainage system is calculated using the methodology described in HDM Chapter 830, or as directed by the District Hydraulics Branch. The storm frequency for the peak design storm is dependent upon the type of drainage facility in which the UFS will be installed. A peak design storm flow rate for assessing impacts to upstream roadway drainage may be different than the peak design storm flow rate used to calculate surcharge on a TBMP. For example, it may be desirable to use a 25-year peak design storm flow rate to determine freeboard in the upstream roadside DIs and a 100-year peak design storm flow rate to assure no structural damage to the downstream TBMP during larger storm events. The PE should be familiar with HDM Topic 811.3 Peak Discharges, and Topic 861.3 Selection of Design Flood. The PE must also be

[1] Vertical Position. A term that describes the general vertical placement or location of a UFS within the overall drainage system profile relative to the elevation of the other components of the drainage system, including TBMPs.

familiar with any permit regulations applicable to the project location while determining a Peak Design Storm Flow Rate. As an example, the RWQCB Lahontan Region (1999 NPDES Permit) required that flows generated through a facility can only be discharged to a stabilized drainage adequate to convey the 100-year, 24-hour flow.

- WQF or WQV. The WQF is calculated using the methodology in Section 3 of the Biofiltration Swale Design Guidance (Caltrans 2020b). The WQV is calculated using the methodology in Section 3 of the DPPIA Design Guidance (Caltrans 2019a). The WQF or WQV used in the design of the UFS must be coordinated with the values used in the design of the TBMP.
- TBMP Parameters. The PE should consult with the design(er) of the TBMP to determine the design parameters for the TBMP that will be critical in the selection and design of the UFS. The parameters may include:
  - The type of TBMP.
  - Volume-Based vs. Flow-Based Design. The preferred vertical position of the UFS is dependent on whether the TBMP is designed based on the WQV (Volume-based) or the WQF (Flow-based). This issue is discussed in more detail in Section 3.3.
  - The WQF or WQV used to size the TBMP and its components (inlets, basin invert, outlets, spillways, etc.).
  - The elevations of the physical components of the TBMP.
  - Volume-based TBMP:
    - The pool elevation (WS_{WQ}) in the TBMP at the design WQV and the maximum allowable pool elevation (WS_{SUR}) in the surcharged condition.
    - The volume (V_X) of runoff modeled by a simulated hydrograph in the form of a triangle of height equal to Q_{HDM} [CFS] and base-width equal to the Time of Concentration (T_C) [minutes] associated with the Q_{HDM}. V_X is defined as the lesser of:

$$V_X = 0.5 \times Q_{HDM} \times T_C \times (60 \text{ sec / min}), \text{ or}$$

$$V_X = 0.5(WQV)$$

    - Water surface elevation (WS_X) of the pool in the TBMP corresponding to a volume of water in the TBMP equal to the WQV minus V_X.
  - Flow-based TBMP: The maximum flow rate through the TBMP (Q_{SUR}) and corresponding HGL at the TBMP in the surcharged condition for the specified Q_{HDM}.
- Allowable Surcharge of TBMP. The maximum surcharge which can be allowed in the TBMP is a critical factor in the selection and design of a UFS. The surcharge is the flow rate or volume of water in excess of the WQF or WQV conveyed to the TBMP during the bypass of the peak design storm in the UFS. Since there are no mechanical closure devices used in the standard UFSs, it is important to note that

the stormwater directed to the TBMP through the UFS will always exceed the WQF or WQV during the peak design storm. Therefore, there is an unavoidable degree of surcharge during the bypass flow condition that is site-specific. This surcharge is due to the difference in head that must build up above the BCE (elevation of the weir crest or BP pipe invert) in order to affect the full bypass flow. This additional head on the WQ diversion pipe will result in flow conveyed to and/or through the TBMP that exceeds the WQF or WQV. The PE, in consultation with the designer or design guidance documentation for the TBMP, must determine the site-specific maximum for the degree of surcharge allowed on the TBMP in order to determine if the installation of a UFS is warranted and to properly select and size the UFS.

The UFS is a means for minimizing the adverse effects of the surcharged condition on the TBMP during the peak design storm. As a general rule, the allowable surcharge of the TBMP and the length of the bypass weir are inversely proportional since the surcharge is caused by the additional head exerted on the TBMP as the head builds up on the bypass weir within the UFS. As the sensitivity to surcharge increases, the allowable head over the bypass weir decreases and the weir length must increase to achieve the full bypass flow over the weir.

- Upstream Drainage System Parameters. The UFS is the outlet for the upstream drainage system. The invert elevation at the connection with the UFS must be determined. The water surface elevation required to bypass the peak design flow (less the surcharge flow to the TBMP) will act as the downstream control for this drainage system at this location during the peak design storm. Therefore, the configuration and placement of the UFS must be developed so that the capacity of the upstream drainage system is not adversely impacted. As described in Section 4, a hydraulic analysis of the upstream drainage system is an important and the final step in the design of the UFS in order to ensure that the UFS does not cause a rise in the HGL that encroaches on the minimum freeboard of any drainage inlet structures or violates any other hydraulic design criteria. In a retrofit situation, the pre-UFS HGL for the drainage system can be compared to the post-UFS HGL in order to assess the hydraulic impact of the installation of the UFS.

3.2 General Type Selection Guidelines

After determining that a flow split is desired to reduce the surcharge on the TBMP during the peak design storm, select a type of UFS as part of the design process. General guidelines for the selection of the type of UFS are described in this section. The type and size of the selected UFS will be finalized and confirmed using the design procedure for the UFS as described in Section 4.

Five types of UFS structures are provided in the UFS Detail Drawings. The Type 4 has no weir, but Types 1, 2, 3 and 5 provide different ranges of weir length which enable the designer to tailor the selection of the UFS to the specific project. This decision depends on the amount of vertical clearance available in the system profile and its ability to accommodate increasing values of hydraulic head over the weir (H). Although all five types of UFS have the flow capacity to be used within the design flow range (peak design flow rate of less than 70 cfs), select the smallest UFS that provides the required bypass flow rate at the maximum allowable H in order to provide the most economical structure. The rating curves in Appendix A show the range of weir capacity for UFS Types 1, 2, 3, and 5 for various combinations of design parameters to assist the designer in the initial selection of the smallest applicable structure.

Types 3 and 4 provide unique performance and layout features that may be useful in some projects as described below. The following descriptions should be considered in selecting the type of UFS during the design process:

- TYPE 4. The Type 4 UFS is the smallest, simplest, and probably the most economical structure if it can meet the site specific hydraulic criteria. This structure does not have a bypass weir and the split is accomplished with pipes set at different invert elevations. The large difference in head between the WQ and design flows associated with this type of structure makes the Type 4 UFS less efficient in limiting surcharge than the weir structures. This is due to the steeper slope of the headwater versus discharge rating curve for the BP pipe relative to a weir. Consequently, the head builds up quicker for the pipes than for a weir for a given rate of increase in flow. This increased head on the WQ diversion pipe during bypass will generally result in a higher ratio of the flow rate diverted through the WQ diversion pipe to the bypass flow rate and a higher surcharge of the TBMP relative to the weir structures. If the TBMP can accommodate a significant surcharge consider a Type 4 UFS. The design of a Type 4 UFS involves setting the invert elevation of the BP pipe relative to the invert elevation of the WQ diversion pipe. This requires a hydraulic analysis and development of headwater versus discharge rating curves for the pipe outlets as described in Section 4.
- TYPES 1, 2, and 5. These structures provide a bypass weir. The weir length and size of the structure increases from a Type 2 to a Type 1 and is largest for a Type 5. This is also the order of increasing construction cost and order of decreasing weir head for a given bypass flow rate. Types 1 and 5 are similar rectangular structures and can be specified at any length between 10 feet and 16 feet. However, Type 5 offers a double weir length which can lower the required weir head with a nominal increase in construction cost relative to Type 1.

  The Type 2 is a circular vault and is specified in incremental diameters of 1 foot, from 4 feet to 10 feet. Therefore, the calculated weir length should be rounded up to the nearest foot in selecting the diameter of the structure. This will result in a smaller weir head than required for the design bypass flow and a decreased surcharge on the TBMP, satisfying the project requirements.

- TYPE 3. The Type 3 is a circular vault similar to the Type 2 and is specified in incremental diameters of 1 foot, from 5 feet to 10 feet. Similar to the Type 2, the calculated weir length should be rounded up the nearest foot in selecting the diameter of the structure. The difference from the Type 2 UFS is that the pipes are constructed in close vertical proximity to each other and a concrete wall supports the weir which separates the WQ and bypass flow paths. This structure can be used for drainage systems in which the system profile cannot accommodate the drop between the IN pipe and BP pipe that is included in Types 1, 2, and 5. However, the high weir wall submerges the outlet of the IN pipe and a hydraulic analysis of the IN pipe must be completed to ensure that the increased tailwater has no adverse hydraulic impacts on the upstream drainage system. Between the WQF and bypass flow stages there are potentially large surcharges on the TBMP. An optional orifice plate can be added to the WQ diversion pipe to reduce the surcharge of the TBMP. The use of the orifice plate is discussed in Section 7.

3.3 General Vertical Position Guidelines

The preferred vertical position of the UFS depends on the design basis for the TBMP, whether it is based on water volume (WQV) or flow rate (WQF). General guidelines for setting the vertical position of the UFS for each design case are described below. The precise elevations for the components of the UFS are calculated as described in Section 4.

- Volume-based Design. Volume-based TBMPs are designed to capture and treat the WQV. They include approved TBMPs such as Infiltration Basins, Detention Basins, Wet Basins, Multi-Chambered Treatment Trains, and Media Filters. Because these TBMPs capture and store the WQV for treatment over an extended period of time, they have a pool of water associated with the storage component of the TBMP. The water surface of the pool in the TBMP at the design WQV is denoted by the term WS_{WQ}. Any volume of water captured by the TBMP above WS_{WQ} is a surcharge of the TBMP. In order to minimize this surcharge, the BCE (elevation of the weir crest or BP pipe invert) within the UFS must be set relative to WS_{WQ}. Therefore, the UFS structure is placed relatively close in elevation to the TBMP for volume-based designs and the tailwater in the TBMP is likely to have a significant backwater effect on the hydraulic performance of the UFS. The IN pipe to the UFS is adjusted to connect to the UFS at an elevation in close proximity to the TBMP.
- Flow-based Design. Flow-based TBMPs are designed to convey and treat the WQF and do not include any appreciable runoff storage capacity. They include approved TBMPs such as Biofiltration Strips, Biofiltration Swales, and Gross Solid Removal Devices (GSRDs). These TBMPs do not have a stored pool of water that

can be used to help control the water surface elevation in the UFS. Therefore, the UFS does not necessarily need to be placed in close vertical proximity to the TBMP and the flow capacity of the WQ diversion pipe from the UFS becomes the critical element in controlling the surcharge of flow to the TBMP. Because the UFS may be located significantly higher than the TBMP, the WQ diversion pipe can operate under inlet or outlet control similar to a conventional culvert. The TBMP is less likely to have a significant backwater effect on the UFS than in the volume-based design.

Gross Solid Removal Devices (GSRDs) and Traction Sand Traps are designed to convey peak flows. If Flow Splitter devices are desired for these TBMPs, WQFs may be calculated and used as a flow-based design.

Section 4

UFS Design Procedure

This section presents the design procedures for selecting a UFS and the steps in calculating the elevations and dimensions of the selected UFS. This section does not apply to SFSs. The general guidelines presented in Section 3 should be considered in the selection of the type and design of the UFS and will aide in minimizing the number of iterations required to select the most appropriate and economical UFS. This section presents the general steps in the design process for completing the calculations for the various components of the UFS and the significance of the calculations in the design of the components and overall performance of the UFS. Separate procedures are included for the design of a UFS for a Volume-based and a Flow-based TBMP since the basis for the design differs in each case. The Type 4 UFS does not use a weir to control bypass flow and, therefore, some of the design steps for a Type 4 UFS differ from the other types of UFS. When applicable, a separate discussion unique to the Type 4 UFS is included.

4.1 Hydraulic Analysis

The hydraulic performance of the individual pipe conduits in and out of the UFS is an integral part of the overall hydraulic performance of the UFS. Although the general design steps in the design of a UFS are described herein, detailed discussions about the various methods of hydraulic analysis[2] that may be required for the conduits are not within the scope of this document. The method which is appropriate for a specific pipe conduit configuration depends on parameters specific for that particular conduit. The PE will need to exercise engineering judgment to determine the appropriate method of hydraulic analysis and computer software to use in the calculations. Consult Chapter 800 of the HDM for a more comprehensive reference on hydraulic calculations, the various methods of hydraulic analyses available, and guidance on selecting the appropriate method and software. Some of the parameters that should be considered in determining the appropriate hydraulic analysis method for a particular pipe conduit configuration include:

- The elevation of the tailwater relative to the elevation of the inlet and outlet of the pipe conduit and any backwater effects of the tailwater on the performance of the conduit;

[2] The term "hydraulic analysis" is used generically in this procedure and may refer to a variety of methods of hydraulic analyses.

- The complexity of the drainage system to which the pipe conduit is connected (junctions, grade changes, etc.);
- The slope of the pipe conduit; and
- Whether the pipe conduit is operating in an inlet-controlled or outlet-controlled condition.

The design examples included in Section 8 demonstrate the decision process in selecting the appropriate hydraulic analysis methods for specific design examples.

4.2 Design Procedure (Volume-Based TBMP)

The design procedure described in this section presumes that the designer has obtained the applicable prerequisite design parameters discussed in Section 3.

Step 1: Select the Diameter Of The WQ Diversion Pipe And Set The Bypass Control Elevation (BCE).

The BCE is generally the elevation of the weir crest or, in the case of a Type 4 UFS which has no weir; the BCE is the invert elevation of the BP pipe. The BCE is set equal to WS_{WQ} in the TBMP. To ensure that the WQV is fully captured in the TBMP before flow bypass is initiated, the diameter of the WQ diversion pipe is selected so that the Q_{HDM} can be conveyed to the TBMP without bypass when the pool in the TBMP is at elevation WS_X (See Section 3.1 for an explanation of WS_X).

Perform a hydraulic analysis of the WQ diversion pipe using the Q_{HDM} and including the following parameters: 1) pipe diameter and length of the WQ diversion pipe; 2) downstream invert elevation set at the invert of the TBMP; 3) tailwater conditions with elevation at WS_X; 4) headwater flow conditions; and any other necessary hydraulic parameters. The WQ diversion pipe size and vertical alignment are selected such that the HGL in the UFS calculated in this step is equal to or less than the BCE.

A Special Design may be required if the Q_{HDM} is large enough to produce excessive head loss in the WQ diversion pipe. In this situation the designer may choose a Special Design to reduce the head loss to a more manageable value by increasing the diameter of the WQ diversion pipe beyond the maximum allowed in the UFS Detail Drawings.

The diameter and slope of the WQ diversion pipe should also be selected in compliance with the standards for a trunk lateral described in Chapter 800 of the HDM. Where practicable, the slope of the WQ diversion pipe should be set to maintain a minimum self-cleansing velocity of 3 fps when the pipe flows half full. This velocity may only be achieved when the TBMP is empty.

Step 2: Calculate Dimension "H_C".

Dimension "H_C" is equal to the difference between the BCE and the upstream invert elevation of the WQ diversion pipe calculated in the hydraulic analysis in Step 1.

The invert elevation of the IN pipe will be set relative to the WQ diversion pipe once the length of the structure is determined and the change in elevation due to the slope of the UFS floor is calculated. In a retrofit situation, a portion of the IN pipe may require modification to join the new proposed invert elevation at the proposed connection elevation with the UFS.

Step 3: Calculate the Maximum Allowable Water Surface in The UFS During Bypass And Calculate The Corresponding Hydraulic Head "H".

The water surface in the UFS during the bypass stage should be limited to an elevation that will not cause the pool elevation in the TBMP to rise above the prescribed maximum allowable water surface (WS_{SUR}) during the surcharged condition. Volume-based TBMPs are designed with overflow facilities set at elevation WS_{WQ} and discharge from the overflow facility will begin when the pool elevation exceeds WS_{WQ}. The flow through the overflow from the TBMP must be subtracted from the Q_{HDM} to determine the required bypass flow for the UFS as follows[3]:

$Q_{BP} = Q_{HDM} - Q_{SUR}$

Q_{HDM} = Peak design storm flow rate used in the design of the inflow drainage system

Q_{SUR} = Flow through the TBMP overflow at the maximum allowable water surface in the TBMP (WS_{SUR})

The head loss produced by Q_{SUR} in the WQ diversion pipe must be added to WS_{SUR} in order to calculate the maximum water surface that will be experienced in the UFS during the surcharged/bypass condition. This requires a hydraulic analysis of the WQ diversion pipe for Q_{SUR} and the following parameters: 1) the diameter, slope, and length selected in Step 1; 2) tailwater conditions with elevation at WS_{SUR}; 3) headwater flow conditions; and 4) any other necessary hydraulic parameters. The hydraulic head over the weir during bypass is calculated by subtracting the BCE calculated in Step 1 from the headwater elevation calculated for Q_{SUR} through the WQ diversion pipe in this step. This may be an iterative process since the flows and corresponding water surfaces for both the TBMP and the UFS must be balanced to add up to the total peak design flow rate.

H = (Elev. of Headwater on WQ pipe for Q_{SUR}) – (BCE determined in Step 1)

[3] Note that this design procedure assumes that a UFS has been considered due to a limitation in the discharge capacity of the overflow facilities of a volume-based TBMP. If the TBMP overflow has adequate capacity to discharge Q_{HDM}, a UFS is not likely necessary for added bypass capacity. However, the UFS may be considered for other benefits, such as reduced maintenance resulting from a reduction in the total flow through the TBMP.

Step 4: Determine the Size Of Bypass (Weir Length or Pipe Diameter) and Select the Type of UFS.

UFS Type 4 - The Type 4 UFS is usually the most economical UFS structure and easiest to maintain. It should be checked first to determine if it can provide the desired bypass flow (QBP) within the allowable bypass hydraulic head (H) calculated in Step 3.

This requires a hydraulic analysis of the BP pipe for Q_{BP} considering all relevant parameters such as diameter, length, slope, tailwater, etc. in order to calculate the maximum headwater elevation which produces the maximum water surface in the UFS during the peak design flow. The inlet elevation of the BP pipe should be set at the BCE. If a BP pipe diameter can be selected that fits within the Type 4 UFS structure and can pass the required bypass flow within the allowable bypass head, the Type 4 UFS should probably be used. If this requires a large diameter BP pipe of significant length, it may be more economical to utilize one of the other types of UFS to reduce the diameter and therefore cost of the BP pipe required for a Type 4 UFS.

In order to determine the maximum water surface in the UFS when the BP pipe and WQ diversion pipe are simultaneously flowing, it is necessary to develop a combined outflow rating curve for the outflow from the UFS. This is done by combining rating curves for the WQ diversion pipe and the BP pipe. A site-specific graph similar to Figure 4-1 shown below can be useful to the designer.

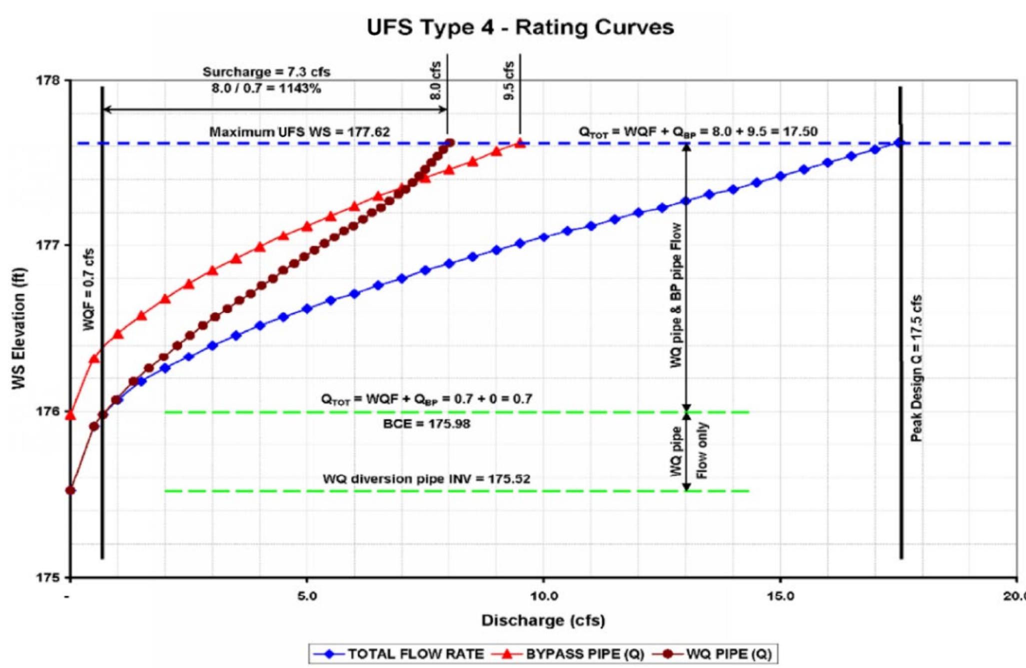


Figure 4-1. Site Specific Rating Curve, UFS Type 4

If a Type 4 is selected, skip to Step 6 after determining the size of the BP pipe that meets the maximum allowable water surface in the UFS. If the check for the Type 4 is unsuccessful, a Type 1, 2, 3, or 5 UFS must be checked.

UFS Types 1, 2, 3 and 5 - The weir length (L_w) is calculated for the bypass flow (Q_{BP}) calculated in Step 3, using the values of H_c and H calculated in Steps 2 and 3, respectively. The calculation is made using the equation for an unsubmerged sharp-crested rectangular weir with end contractions as described in Section 2.1. The equation is solved for L_w as follows:

$$L_w = (Q_w / C_{SCW} \times H^{1.5}) + 0.2H$$

Where:

L_w = horizontal weir length, ft

Q_w = weir discharge, cfs ($Q_w = Q_{BP}$)

H = head above weir crest excluding velocity head, ft

C_{SCW} = weir discharge coefficient $[3.27 + 0.4(H/H_c)]$

H_c = height of the weir crest on the upstream side of the weir, ft

Select the type of UFS based on the calculated weir length. Types 1 and 5 can be specified to any length between 10 feet and 16 feet. The diameter of Types 2 and 3 are specified in increments of one foot between 4 feet (5 feet for Type 3) and 10 feet. The diameter of Types 2 and 3 is selected by rounding the calculated weir length up to the nearest foot. This will result in a slight reduction in the actual head over the weir and the surcharge of the TBMP during the peak design flow rate and will fall below the maximum allowable values for these parameters.

Step 5: Set the Invert Elevation For The BP Pipe And Calculate (H_d) – (TYPES 1, 2, 3 AND 5).

Once the size of the weir is selected, the profile of the BP pipe can be set so that it does not affect the weir flow calculation. A hydraulic analysis must be completed for the BP pipe profile in order to ensure that the elevation of the headwater on the BP pipe produced by Q_{BP} provides a minimum of 10 inches of freeboard relative to the BCE to assure that the unsubmerged weir equation, above, used to establish the weir length is valid. The minimum height of the weir on the downstream side, H_d, is set equal to the headwater depth on the BP pipe at a discharge of Q_{BP} plus the required freeboard.

The hydraulic analysis should be performed for Q_{BP} including the following parameters: 1) the pipe diameter of the BP pipe (usually equivalent to the IN pipe); 2) the invert elevation for the BP pipe is set in accordance with the minimum clearances shown on the applicable UFS Detail Drawings; 3) the downstream invert elevation set at the invert of the outfall drainage facility; 4) tailwater set at the HGL of the outfall drainage facility at the point of connection; and any other necessary hydraulic parameters.

Step 6: Confirm that the UFS Fits within the Vertical Drop Available in the System.

The selected type and size of UFS and appurtenant pipes must fit within the vertical drop available in the system between the IN pipe and BMP. Sketch two profiles of the selected UFS: one through the WQ flow path; and the other through the BP flow path. These profiles will be used to determine if there is sufficient vertical drop in the system to accommodate the selected standard UFS and that the hydraulic grade lines provide the minimum freeboard at all components of the system. The profiles should be drawn to the calculated elevations and dimensions and the dimensions and clearances shown in the applicable standard UFS Detail Drawings. The pipe profiles must also meet the minimum design standards for slope per Chapter 820 or Chapter 830 of the HDM. The two flow paths and the finished grade over the UFS should be evaluated as follows:

- WQ Flow Path. A check of the WQ flow path must be completed to ensure that there is adequate vertical drop in the system to accommodate the sum of H, H_C, the drop within the UFS, and the vertical drop in the WQ diversion pipe at the minimum required slope. If the profile indicates the WQ flow path cannot be constructed within the drop available in the system for the selected UFS, the possible adjustments to the design of the UFS include:
  - Select a UFS with a longer weir length in order to reduce the required H;
  - Select a larger diameter for the WQ diversion pipe in order to reduce the head loss in the WQ diversion pipe and Hc;
  - Consult with the designer of the BMP to see if the invert of the BMP can be lowered or some other BMP design parameters adjusted; or
  - Investigate the option of raising the elevation of the IN pipe to allow the UFS to be raised. (This may result in a flow-based design)
- BP Flow Path. A check of the BP pipe must be completed to ensure that it can be constructed to the outfall drainage facility to which it will discharge at the minimum required slope. If the profile indicates the BP pipe cannot be constructed at the minimum required slope or the HGL does not provide the minimum freeboard from the BCE, the possible adjustments to the design of the UFS include:
  - Find an alternate outfall location or facility with a lower connection elevation and/or HGL for the BP pipe;
  - Select a larger diameter for the BP pipe in order to lower the headwater for the BP and reduce Dimension "H_d";
  - Consider switching from a Type 1, 2 or 5 UFS to a Type 3 UFS, which eliminates the drop between the IN pipe and BP pipe within the structure. However, the weir wall increases the height of the weir crest relative to the IN pipe. This could cause a rise in the maximum water depth over the weir and adverse hydraulic impacts to the upstream drainage system during bypass; or

  - Investigate the option of raising the elevation of the IN pipe to allow the UFS to be raised. (This may result in a flow-based design)
- Finished Grade Over the UFS. The selected UFS must be checked to ensure that the minimum height of the UFS and manhole shaft, as shown on the applicable standard UFS Detail Drawings, can be constructed below the finished grade elevation at the proposed site. It should also be checked to ensure that the maximum fill over the UFS, as shown on the UFS Detail Drawings, is not exceeded. The elevation of the UFS will require adjustment or Special Design if either of these checks yields unfavorable results.

If any of the checks performed in this step yield unfavorable results, some of the components of the UFS or the entire UFS must be adjusted in size and/or elevation. The PE will need to determine which calculations and hydraulic analyses are to be revised for the new configuration. This may be an iterative process until a design is developed that meets all of the space and hydraulic constraints for the project. The figures in Appendix A are rating curves for the various types of UFS, excluding Type 4 which are site-specific, for various values of "H_C" and may be useful in selecting an alternate configuration for subsequent iterations.

Step 7: Complete the Hydraulic Analysis for the Upstream Drainage System.

Once the type, size, and elevations for the UFS are finalized and the corresponding maximum water surface in the UFS during bypass is calculated, a hydraulic analysis must be completed for the upstream drainage system. The hydraulic analysis uses this maximum water surface in the UFS as a downstream control and must confirm that the upstream drainage system has adequate capacity for the peak design storm. The HGL produced by this hydraulic analysis must demonstrate that the minimum freeboard is maintained at all drainage inlets in accordance with Chapter 800 of the HDM. If this check yields unfavorable results, the maximum allowable water surface in the UFS may have to be reduced, thereby reducing the allowable bypass head above the BCE. The UFS structure must be resized by returning to Step 4. If resizing does not produce adequate results, the BMP may be lowered in order to eliminate the hydraulic deficiencies. This would require revisions to all of the calculations for the UFS for the new configuration. This may be an iterative process until a design is developed that meets all of the hydraulic constraints for the upstream drainage system.

4.3 Design Procedure (Flow-Based TBMP)

The design procedure described in this section presumes that the designer has obtained the applicable prerequisite design parameters discussed in Section 3.

Step 1: Set the Invert Elevation of the IN Pipe and Select the Diameter of the WQ Diversion Pipe.

Since a flow-based UFS is not necessarily controlled by the water surface elevation in the downstream TBMP, it generally can be placed further upstream than in a volume-based design, limited by the invert elevation of the IN pipe and the minimum depth of the proposed UFS structure.

New Construction. The invert elevation of the IN pipe should be set at the minimum depth from finished grade that satisfies the vertical clearances shown on the applicable UFS Detail Drawings and the vertical constraints of the upstream drainage system.

Retrofit. The invert elevation of the IN pipe should be set at the existing invert elevation of the existing conduit at the proposed location for the UFS. It should be checked to ensure that it meets the minimum depth from finished grade that satisfies the vertical clearances shown on the applicable UFS Detail Drawings.

The diameter of the WQ diversion pipe must be selected to provide a headwater depth for the WQF that is less than the maximum dimension for "H_C" shown on the UFS Detail Drawings. Setting "H_C" to this headwater depth will ensure that the WQF is fully conveyed to the BMP before flow bypass is initiated. Perform a hydraulic analysis of the WQ diversion pipe using the WQF and the following parameters: 1) select the smallest allowable pipe diameter that produces a headwater depth less than the maximum "H_C" (the minimum pipe diameter will minimize the flow surcharge to the WQ diversion pipe during bypass); 2) downstream invert elevation set at the invert of the BMP; 3) upstream invert elevation set 0.16 feet below the invert elevation of the IN pipe determined as described above; 4) tailwater conditions with elevation at the HGL produced in the BMP by the WQF; 5) headwater flow conditions; and any other necessary hydraulic parameters.

A Special Design will be required if the WQF is large enough to produce excessive headwater depths in the WQ diversion pipe. In this situation, the headwater depth produced by the WQ diversion pipe may require a Type 3 UFS or the PE may choose a Special Design to reduce the headwater depth to a more manageable value by increasing the diameter of the WQ diversion pipe beyond the maximum allowed in the UFS Detail Drawings.

The diameter and slope of the WQ diversion pipe should also be selected in compliance with the standards for a trunk lateral described in Chapter 800 of the HDM. Where practicable, the slope of the WQ diversion pipe should be set to maintain a minimum self-cleansing velocity of 3 fps when the pipe flows half full.

Step 2: Calculate Dimension "H_C" and Set the Bypass Control Elevation (BCE).

Dimension "H_C" is set equal to the headwater depth calculated for the WQ diversion pipe in Step 1.

The BCE is the elevation of the weir crest or invert elevation of the BP pipe for Type 4. The BCE is set at a height of "Hc" above the upstream invert elevation of the WQ diversion pipe, determined in Step 1, to ensure that the WQF is fully conveyed to the BMP before flow bypass is initiated.

Step 3: Calculate the Maximum Allowable Water Surface in the UFS During Bypass and Calculate the Corresponding Hydraulic Head "H".

The water surface in the UFS during the bypass stage determines the degree of flow surcharge to the BMP because it results in a headwater depth on the WQ diversion pipe in excess of the headwater depth produced by the WQF. The headwater depth on the WQ diversion pipe during bypass should be limited to a depth that will not produce a surcharged flow (Q_{SUR}) to the BMP in excess of the maximum Q_{SUR} prescribed by the designer for the BMP. Because a Type 4 UFS is not as efficient as the weir structures in splitting flow, the Type 4 will generally result in a high flow surcharge to the BMP and generally should not be used for flow-based BMPs. However, if the designer elects to check the performance of a Type 4, the procedure is described in Section 4.1.4. The graph shown in Section 4.1.4 demonstrates the high degree of flow surcharge that is typical of a Type 4 UFS.

The calculation of the maximum allowable water surface in the UFS requires a second hydraulic analysis of the WQ diversion pipe using Q_{SUR} and the following parameters: 1) the pipe diameter, slope and length for the WQ diversion pipe used in the hydraulic analysis completed in Step 1; 2) tailwater conditions with elevation at the HGL produced in the BMP by the Q_{SUR}; 3) headwater flow conditions; and any other necessary hydraulic parameters. The hydraulic head over the weir during bypass is calculated by subtracting this calculated headwater depth from the BCE determined in Step 2.

H = (Elev. of Headwater on WQ diversion pipe for Q_{SUR}) – (BCE determined in Step 2)

Step 4: Determine the Weir Length and Select the Type of UFS for the Calculated Weir Length – (Types 1, 2, 3 and 5)

The weir length (L_w) is calculated for the prescribed bypass flow (Q_{BP}) using the values of H_c and H calculated in Steps 2 and 3, respectively. The calculation is made using the equation for an unsubmerged sharp-crested rectangular weir with end contractions as described in Section 2.1. The equation is solved for L_w as follows:

$L_W = (Q_W / C_{SCW} \times H^{1.5}) + 0.2H$

Where:

L_W = horizontal weir length, ft

Q_w = weir discharge, cfs ($Q_w = Q_{BP}$)

H = head above weir crest excluding velocity head, ft

C_{SCW} = weir discharge coefficient [$3.27 + 0.4(H/H_c)$]

H_c = height of the weir crest on the upstream side of the weir, ft

Select the type of UFS based on the calculated weir length. Types 1 and 5 can be specified to any length from 10 feet to 16 feet, and 20 to 32 feet, respectively. The diameter of Types 2 and 3 are specified in increments of one foot between 4 feet (5 feet for Type 3) and 10 feet. The diameter of Types 2 and 3 is selected by rounding the calculated weir length up to the nearest foot. This will result in a slight reduction in the actual head over the weir and the surcharge of the BMP during the peak design flow rate and will fall below the maximum allowable values for these parameters.

Step 5: Set the Invert Elevation for the BP Pipe and Calculate (H_d) – (Types 1, 2, 3 AND 5)

Once the type and size of the UFS is selected, the profile of the BP pipe can be calculated. A hydraulic analysis must be completed for the BP pipe profile in order to ensure that the elevation of the headwater on the BP pipe produced by Q_{BP} provides a minimum of 10 inches of freeboard relative to the BCE to assure that the unsubmerged weir equation, above, used to establish the weir length is valid. The height of the weir on the downstream side H_d, is set equal to the headwater depth on the BP pipe at a discharge of Q_{BP} plus the required freeboard. The hydraulic analysis should be performed for Q_{BP} with the following parameters: 1) match the pipe diameter of the IN pipe; 2) the invert elevation for the BP pipe is set in accordance with the minimum clearances shown on the applicable UFS Detail Drawings; 3) the downstream invert elevation set at the invert of the outfall drainage facility; and 4) tailwater set at the HGL of the outfall drainage facility at the point of connection.

Step 6: Confirm That the UFS Fits within the Vertical Drop Available in the System

The selected type and size of UFS and appurtenant pipes must fit within the vertical drop available in the system between the IN pipe and BMP. Sketch two profiles of the selected UFS: one through the WQ flow path; and the other through the BP flow path. These profiles will be used to determine if there is sufficient vertical drop in the system to accommodate the selected standard UFS and that the hydraulic grade lines provide the minimum freeboard at all components of the system. The profiles should be drawn to the calculated dimensions and elevations and the dimensions and clearances shown in the applicable standard UFS Detail Drawings. The pipe profiles must also meet the minimum design standards for slope per Chapter 820 or Chapter 830 of the HDM. The two flow paths and the finished grade over the UFS should be evaluated as follows:

- WQ Flow Path. A check of the WQ flow path must be completed to ensure that there is adequate vertical drop in the system to accommodate the sum of H, H_c, the drop within the UFS, and the vertical drop in the WQ diversion pipe at the minimum required slope. If the profile indicates the WQ flow path cannot be constructed within the drop available in the system for the selected UFS, the possible adjustments to the design of the UFS include:
  - Select a UFS with a longer weir length in order to reduce the required H;
  - Select a larger diameter for the WQ diversion pipe in order to reduce the head loss in the WQ diversion pipe and H_c;
  - Consult with the designer of the BMP to see if the invert of the BMP can be lowered or some other BMP design parameters adjusted; or
  - Investigate the option of raising the elevation of the IN pipe to allow the UFS to be raised.
- BP Flow Path. A check of the BP pipe must be completed to ensure that it can be constructed to the outfall drainage facility to which it will discharge at the minimum required slope. If the profile indicates the BP pipe cannot be constructed at the minimum required slope or the HGL does not provide the minimum freeboard from the BCE, the possible adjustments to the design of the UFS include:
  - Find an alternate outfall location or facility with a lower connection elevation and/or HGL for the BP pipe;
  - Select a larger diameter for the BP pipe in order to lower the headwater for the BP and reduce Dimension "H_d";
  - Consider switching from a Type 1, 2 or 5 UFS to a Type 3 UFS, which eliminates the drop between the IN pipe and BP pipe within the structure. However, the weir wall increases the height of the weir crest relative to the IN pipe. This could cause a rise in the maximum water depth over the weir and adverse hydraulic impacts to the upstream drainage system during bypass; or
  - Investigate the option of raising the elevation of the IN pipe to allow the UFS to be raised.
- Finished Grade Over the UFS. The selected UFS must be checked to ensure that the minimum height of the UFS and manhole shaft, as shown on the applicable standard UFS Detail Drawings, can be constructed below the finished grade elevation at the proposed site. It should also be checked to ensure that the maximum fill over the UFS, as shown on the UFS Detail Drawings, is not exceeded. The elevation of the UFS will require adjustment or Special Design if either of these checks yields unfavorable results.

If any of the checks performed in this step yield unfavorable results, some of the components of the UFS or the entire UFS must be adjusted in size and/or elevation. The PE will need to determine which calculations and hydraulic analyses are to be revised for the new configuration. This may be an iterative process until a design is developed that meets all of the space and hydraulic constraints for the project. The figures in Appendix A are rating curves for the various types of UFS, excluding Type 4 which are site-specific, for various values of "H_C" and may be useful in selecting an alternate configuration for subsequent iterations.

Step 7: Complete the Hydraulic Analysis for the Upstream Drainage System

Once the type, size, and elevations for the UFS are finalized and the corresponding maximum water surface in the UFS during bypass is calculated, a hydraulic analysis must be completed for the upstream drainage system. The hydraulic analysis uses this maximum water surface in the UFS as a downstream control and must confirm that the upstream drainage system has adequate capacity for the peak design storm. The HGL produced by this hydraulic analysis must demonstrate that the minimum freeboard is maintained at all drainage inlets in accordance with Chapter 800 of the HDM. If this check yields unfavorable results, the UFS and possibly the BMP must be lowered in order to eliminate the hydraulic deficiencies. This would require revisions to all of the calculations for the UFS for the new configuration. This may be an iterative process until a design is developed that meets all of the hydraulic constraints for the upstream drainage system.

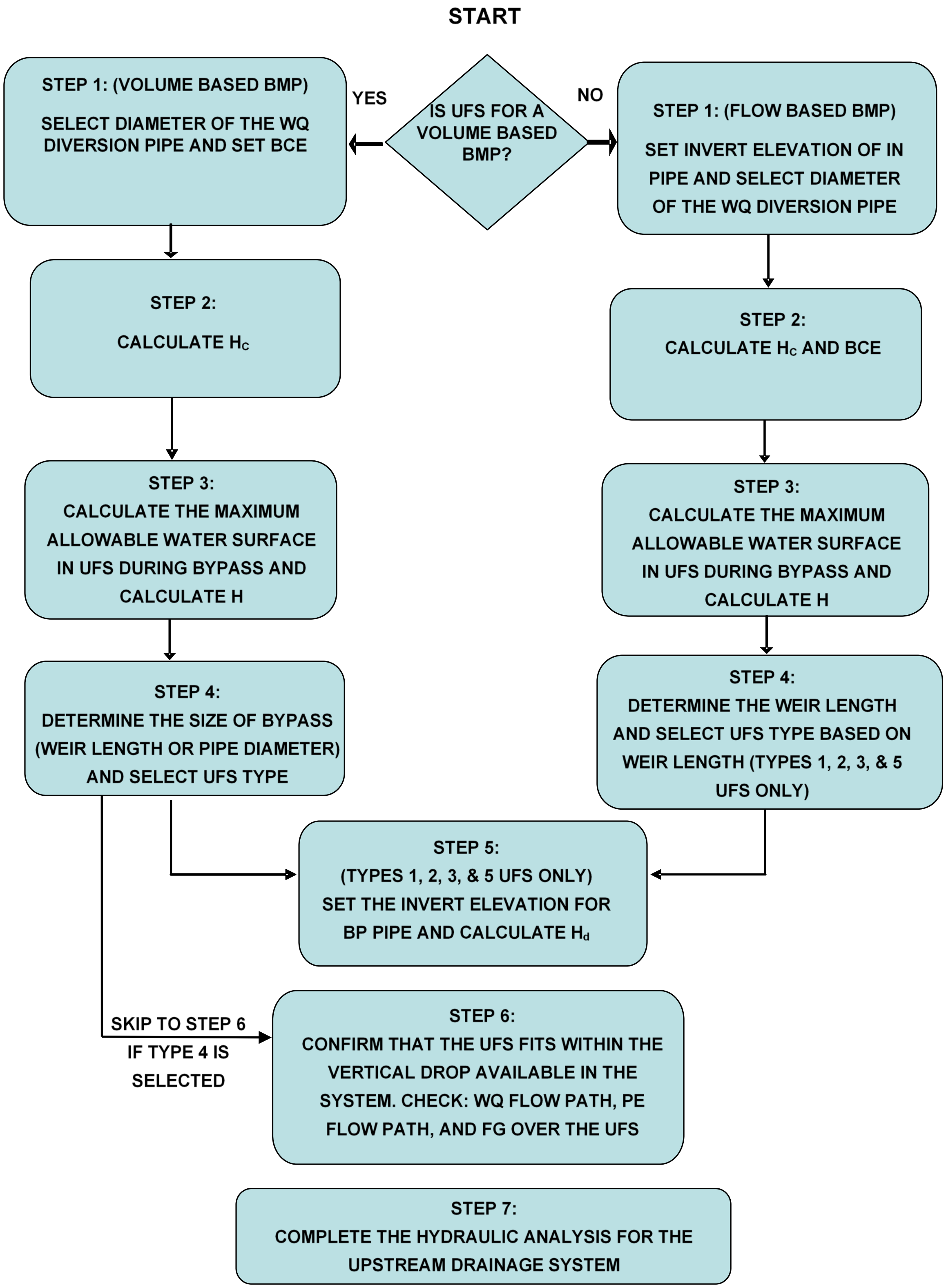


Figure 4-2. UFS Design Procedure Flow Chart

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Section 5

UFS Horizontal Layout

Because the UFS is an integral part of the system profile for the entire drainage system, its horizontal location is mostly determined by the vertical position of the UFS in the system profile relative to the upstream drainage system, bypass drainage system and the downstream BMP. However, once the vertical position is determined, the horizontal layout of the UFS must be developed to suit the site conditions and in relation to the adjacent drainage and BMP structures. The UFS should be oriented to minimize bends and angle points and skewed connections required for the IN and outflow pipes. This will require a review of the site conditions. The layout of the UFS must consider the structure's footprint "out-to-out" concrete dimensions compared to the available space at the site in coordination with the layout of the adjacent drainage, BMP, and highway facilities, including the pipes connected to the UFS.

Note that the dimensions calculated in Section 4 are only for the interior of the UFS, and do not take into account the dimensions of the concrete walls, top slabs or the footings. Thus, when siting the UFS, the designer should carefully consider construction access, final outside dimensions, and formwork around the outside of the structure.

5.1 Maintenance Access

Rather than collecting sediment, trash, and other debris or pollutants, UFSs are intended to convey these to the downstream BMP where treatment and/or removal as part of a more intensive maintenance program will be performed. Access for minor maintenance should however be provided for the UFS. Greater maintenance at a UFS would likely be required where an orifice plate is used on the WQ diversion pipe and where standing water may occur for short durations and associated sediment deposition may take place within the UFS.

UFSs require sufficient space and/or access for maintenance and inspection, including the use of vacuum trucks and other equipment for cleaning and replacement of the weir plates. Vehicle access should be provided around the UFS to adequately and safely allow access to the manhole lid and accommodate all sizes of vehicles to cover routine visits and occasional trash and debris removal using vacuum trucks, should it become necessary.

Vehicle access may be incorporated into the access road for the BMP when the UFS is located adjacent to the BMP. Otherwise, a separate road will be required and must be located within Caltrans right-of-way or within a maintenance easement. Adequate turn around areas must also be provided when necessary for vehicles to re-enter the highway safely. The proposed UFS location should be verified with District Maintenance to confirm the space and access availability for maintenance and inspection of the structure.

5.1.1 Weepholes

If standing water may occur in the UFS, weepholes can be considered. Design weepholes to drain standing water to avoid vector issues. Details and design parameters of weepholes can be found in Section 12 of the Supplemental Details Design Guidance (Caltrans 2018b).

5.2 Construction Requirements

All construction requirements for UFSs are specified in the drawings and accompanying Special Provisions (see Sections 6.1 and 6.2).

The entire UFS structure must be above seasonally high groundwater. In cold regions, the bottom of the UFS structure must be below the frost line to prevent damage from frost heave.

Section 6

PS&E Preparation

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

6.1 Plans

The PE is responsible for incorporating the UFS design into the PS&E in accordance with the procedures typically followed when developing a PS&E package. For example, the applicable drainage sheets should be updated to reflect the required design features of the UFS with the appropriate references to incorporate the UFS Detail Drawings into the PS&E package.

The PS&E drawings for most projects having UFSs may include:

- Drainage Plan(s): Show the UFS plan with the existing and proposed conveyance systems, including pipes and inlets/outlets. Call out specific UFS pipe inlet and outlet flow line elevations and weir elevation.
- Drainage Profile(s): Show the UFS in profile with the existing and proposed drainage conveyance system. These sheets should also call out the specific UFS inlet and outlet flow line elevations, weir elevations, and invert elevation.
- Drainage Detail(s): Show the details as needed to construct or clarify interface points. Most of the required information is included on UFS Detail Drawings. These drawings should be included with the Drainage Details section of the PS&E. Other details may be necessary to adequately reflect the required improvements.
- Drainage Quantity Sheet(s): Show the UFS in the summary of quantities table when used.

6.2 Specifications

Contract specifications for UFS projects will include a combination of Standard Specifications, Standard Special Provisions (SSPs), and may include non-Standard Special Provisions (nSSPs). In some cases, specific nSSPs have been developed by OHSD.

Special provisions for the various items of work needed to construct the UFS could be organized under an umbrella 'UFS' nSSP with the required items listed as subheadings. Payment would be made for by 'each' UFS. 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.

6.2.1 Standard Specifications

Listed below are Standard Specifications that would typically be used for a project that constructs a UFS. Consider the construction of the UFS in the context of the entire project to determine if other Standard Specifications may be required.

51 Concrete Structures

52 Reinforcement

61 Drainage Facilities- General

64 Plastic Pipe

65 Concrete Pipe

66 Corrugated Metal Pipe

70 Miscellaneous Drainage Facilities

71 Existing Drainage Facilities

6.2.2 Standard Special Provisions

SSPs may be included for a project that constructs a UFS. Additional SSPs may be required depending on the types of appurtenant facilities and materials proposed for the project. The listed SSP section numbers are presented to assist in preparing the Contract Special Provisions. Consult the current index of SSPs available on the Office of Construction Contract Standards section of the Caltrans website. Each SSP topic should be examined in the context of the entire project to determine if other SSPs may be required.

6.2.3 Non-Standard Special Provisions

A project that constructs a UFS may require nSSPs so the PE can assure the design assumptions are constructed properly in the drainage system. The PE and PDT should decide the most appropriate specifications for the site-specific conditions to meet other goals in the HDM for safety. If the PE and PDT deem nSSPs necessary, coordinate with OHSD. OHSD can provide nSSPs to support the design.

6.3 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.

6.3.1 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. 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 6.3.2. A cost escalation should be added for projects that are anticipated to advertise more than a year after the date of the estimate.

6.3.2 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 permanent BMPs and are inputs to the Basic Engineering Estimating System (BEES). Verify the quantities for inclusion in the project cost estimate to identify which should be considered Final Pay items, and to determine appropriate unit prices for each.

6.4 Developing UFS 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 UFS. Table 6-1 includes typical contract items that may be included in the cost estimate if they are required for the UFS. Table 6-1 is not a complete list and must be modified on a project specific basis to accommodate all aspects of design.

Table 6-1. Example UFS Estimate

Contract Item	Type	Unit	Quantity	Price	Amount
Clearing and Grubbing		LS			
Structural Concrete		CY			
Bar Reinforcing Steel		LB			
Structure Excavation		CY			
Structure Backfill		CY			
Miscellaneous Metal		LB			
Joint Seal (Type AL)		LF			
Lean Concrete Backfill		CY			

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.

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

Estimate the total cost of each UFS used on the project for tracking TBMP costs at PS&E. Document all BMP costs in the project SWDR at PS&E.

If the UFS is a Special Design, as defined elsewhere in this document, then quantities for cost estimating and construction pay items will need to be calculated by the PE and incorporated into the modified UFS Detail Drawings and estimates.

Section 7

Special Designs

This section provides guidance for situations where the specific project requirements do not meet the design parameters specified in the standard UFS Detail Drawings. The following recommendations are provided as alternatives to expand the applicability of the UFSs beyond the design elements and constraints shown in the UFS Detail Drawings.

Note that any of the following design approaches may require additional engineering, such as a structural and hydraulic analysis.

7.1 BMP Design Parameters

This section presents a discussion of the design parameters included in the UFS Detail Drawings, and how the design of UFSs may be revised for values outside the ranges presented in Section 2.

7.1.1 Excessive Flow

In cases where the bypass flow rate over the weir would require a UFS footprint larger than what is available, a special structure must be designed to provide a longer weir length, greater depths of hydraulic head over the weir, and/or larger diameter pipe connections. Detailed hydraulic and structural analyses would be required to properly size and design the flow splitter structure and its components.

7.1.2 UFS Orientation

The orientation of the UFS and the connecting pipes may be rotated within the limits shown on the UFS Detail Drawings. The IN and WQ diversion pipes may be switched in flow direction. However, the flow paths must be constructed within the separate chambers (WQ vs. Bypass) as shown in the Detail Drawings.

7.2 Customizing the BMP Detail Drawings

When using a Special Design, the UFS Detail Drawings must be modified as required to show any changes relative to the following:

- Sheet 1 – "General Notes" Section: Any notes should be changed as required to fit the Special Design.
- Reinforcing Steel Details: The Reinforcing Steel Details of the UFS Detail Drawings should be updated for new dimensions as appropriate.
- Non Payment Estimated Quantity Tables: The tables should be updated for new values as appropriate.

- Dimensions: In general, changing the design of the UFS structures may result in changes to various dimensions; these should be updated on all sheets, views, sections, and details as required.

In addition to these changes, other changes may be required to facilitate use of the UFS Detail Drawings. In the event that the drawings are changed, the PE must also remove the seal, signature, and firm name on the UFS Detail Drawings. A structural review will be required whenever there are changes in geometry not covered on the drawings. The changed drawings must go through the standard PS&E review process and then be signed and sealed by the PE.

Section 8

Design Examples

This section presents two examples on how to implement the procedure presented in Section 4 for a particular site. Example 1 is for the design of a UFS proposed for a Volume-based BMP and Example 2 is for a Flow-based BMP. In both examples it is presumed that the designer has collected the necessary prerequisite design parameters as described in Section 3 and determined that a flow split is necessary for the BMP.

8.1 UFS Design Example (Volume-Based BMP)

The following design example is for the installation of a UFS upstream of a BMP Infiltration Basin for a site in Orange County. The bottom of the Infiltration Basin has been set at an elevation of 172.00 feet to maintain a 10-foot clearance above the seasonally high ground water elevation of 162.00 feet. The infiltration rate of the sandy loam soil is 1-inch per hour and, assuming a safety factor of 2, the depth of the WQV in the basin is limited to 2 feet to provide a 48-hour drawdown time. The water surface elevation associated with the WQV (WS_{WQ}) was, therefore, set to 174.00 feet. The basin is designed "offline" by utilizing a UFS upstream of the basin to limit the inflow volume so that the maximum 25-year water surface elevation in the surcharged condition, WS_{SUR}, will be at least 0.7-feet below the roadway subgrade. The allowable WS_{SUR} elevation has been set at 174.17 feet. The control of the UFS will be the volume stored in the downstream BMP.

Figure 8-3 is a schematic drawing of the plan and Figures 8-4 and 8-2 show the profile of the proposed storm drain, UFS, and BMP Infiltration Basin. The BP pipe will discharge into Orange County Creek, which flows adjacent to the project site.

Given Data:

The following hydrologic data and design parameters have been provided by the designer of the BMP Infiltration Basin and will be the basis for the design of the UFS:

Q_{25} = <u>5.25 cfs</u>

(Peak design flow rate for the design of the storm drain system, Q_{IN}, Q_{HDM})

T_C = <u>15 minutes</u>

WQV = <u>0.390 acre-ft</u>

(Water quality volume required to be treated in the Infiltration Basin)

WS_{WQ} = <u>174.00 ft</u>

(Water surface elevation in the Infiltration Basin for the full WQV)

WS_{SUR} = 174.17 ft

(Maximum allowable water surface elevation in the Infiltration Basin at the 25-year peak flow rate)

Q_{SUR} = 2.0 cfs

(Maximum allowable discharge from the overflow structure in the Infiltration Basin at the 25-year peak flow rate)

V_X = 0.5(5.25 cfs) (15 minutes)(60 s/min) = 2,362.50 CF

= 0.054 ac-ft (Less than 0.39 WQV)

WS_X = 172.50 ft

(Pool elevation in the Infiltration Basin produced by Volume V_X)

In addition, a number of design parameters for the proposed system are given:

Elevation of the BP pipe invert at Orange Creek (INV_1) = 166.70 feet

Elevation at the bottom of the BMP Infiltration Basin (INV_2) = 172.00 feet

TOG elevation on drainage inlet upstream of the UFS = 178.70 feet

IN pipe diameter (D_1) = 24 inches

Step 1: Select the Diameter of the WQ Diversion Pipe and Set the Bypass Control Elevation (BCE).

The proposed site of the UFS is selected and the length of the WQ diversion pipe will be approximately 30 feet. The BCE is set at Elevation 174.00, equal to WSWQ.

BCE = WS_{WQ} = Elevation B (Figure 8-6) 174.00 feet

The invert elevation of the WQ diversion pipe (Elevation A in Figure 8-6) is initially assumed as follows and will be verified by hydraulic analysis:

Elevation A = 172.50 feet

In order to minimize the depth of the headwater on the WQ diversion pipe at Q_{25}, the largest standard pipe diameter (D_2) of 18 inches is selected. A hydraulic analysis is performed for the initial selection of an 18 inch pipe diameter to check that the pipe produces a headwater depth below the BCE for the Q_{25}. The analysis is completed using HY-8, FHWA's culvert analysis computer program (FHWA 2016). The hydraulic analysis is based on the following parameters:

- Flow rate (Q_{25}) = 5.25 cfs
- Diameter = 18 inches
- Length of pipe = 30 feet
- Upstream invert elevation (Assumed) = 172.50 feet
- Downstream invert elevation = 172.00 feet
- Slope = 0.0167 ft/ft

- Manning's "n" = 0.012, for precast RCP

The results of the hydraulic analysis are presented in the rating table in Table 8-1. The peak flow rate of 5.25 cfs is low relative to the cross sectional area of the UFS and the flow velocity within the structure is less than 1 fps. Therefore, the velocity head in the UFS at the headwater of the WQ diversion pipe is not considered in the calculation of the headwater depth.

Table 8-1. Rating Table for the WQ Diversion Pipe	
Flow Rate (cfs)	WQ Diversion Pipe Headwater Depth (feet)
0.00	0.00
0.05	0.06
1.05	0.52
1.58	0.64
2.10	0.75
3.15	0.97
3.68	1.06
4.20	1.16
4.73	1.24
5.25	1.33 (El. 173.83)[1]

1. *Less than BCE = El. 174.00*

The velocity for half-full flow and an empty basin is also checked to ensure a minimum self-cleansing velocity of 3 fps during smaller storm events. The minimum slopes on the pipe for a minimum velocity of 3 fps are shown in Table 8-2. This minimum slope should be provided to meet the requirements of the HDM Topic 838.4(3).

Manning's "n" = 0.012 for precast RCP per HDM Table 851.2

Minimum Velocity, v, when half full = 3.00 fps

Table 8-2. Half Full Flow Hydraulic Analysis of WQ Diversion Pipe						
Pipe Diameter, D (ft)	Pipe Area, A=πD2/4 (sf)	Half Full Area, a=A/2 (sf)	Half Full Discharge Q = va = 3a (cfs)	Wetted Perimeter, p=πD/2 (ft)	Hydraulic Radius, R = a/p (ft)	Minimum Allowable Slope, S(1)
1.50	1.767	0.884	2.65	2.356	0.375	0.00217

$S = S_0 = [Qn/(K_U a R^{0.67})]^2$, K_U = 1.486 in English units, (FHWA 2009).

The slope of the WQ diversion pipe (0.0167 ft/ft) exceeds the minimum required for half-full flow. Therefore, the pipe will be self-cleansing and the proposed pipe profile is acceptable.

Step 2: Calculate Dimension "H_C".

Dimension H_C is calculated as shown below:

$$H_C = \text{Elevation B} - \text{Elevation A} = 174.00 - 172.50 = \underline{1.50\text{ feet}}$$

The hydraulic profile for the QHDM and a tailwater at WSX is shown in Figure 8-4.

Step 3: Calculate the Maximum Allowable Water Surface in the UFS During Bypass and Calculate the Corresponding Hydraulic Head "H".

The prescribed maximum water surface elevation in the Infiltration Basin during the surcharged condition, WS_{SUR}, is 174.17 feet. The flow rate to the Infiltration Basin during surcharge, Q_{SUR}, is 2.0 cfs. The headloss through the WQ diversion pipe for Q_{SUR} is added to WS_{SUR} to calculate the maximum allowable water surface in the UFS and the corresponding hydraulic head, H, on the bypass component (Table 8-3) as follows:

Table 8-3. Full Flow Hydraulic Analysis of WQ Diversion Pipe (Q_{SUR})

Pipe Diameter, D (ft)	Pipe Area, A = πD2/4 (sf)	Velocity, V = Q/A (fps)	Velocity Head, Vh=V2/2g (ft)	Entrance Loss, 0.2Vh (1)	Exit Loss, 1.0Vh (2)	Friction Slope, Sf (3) (ft/ft)	Friction Head Loss, Hf = SfL (ft)	Total Head Loss, HT (ft)
1.50	1.767	1.13	0.0198	0.0040	0.0198	0.00031	0.0094	0.0332

Entrance loss coefficient (K_e) = 0.2, for rounded headwall entrance (FHWA 2009).

Exit loss coefficient (K_e) = 1.0, for exit with D_2/D_1 > 10 and V < 2.0 fps (FHWA 2009).

$S_f = [Qn/(K_Q D^{2.67})]^2$, K_Q = 0.46 in English units (FHWA 2009).

$$\text{Elevation D} = WS_{SUR} + H_T = 174.17 + 0.0332 = \underline{174.20\text{ feet}}$$

$$H = \text{Elevation D} - \text{Elevation B} = 174.20 - 174.00 = \underline{0.20\text{ feet}}$$

The hydraulic profile for the bypass/surcharge condition is shown in Figure 8-2.

Step 4: Determine the Size of Bypass (Weir Length or Pipe Diameter) and Select the Type of UFS.

The bypass flow rate for the design of the UFS is calculated by subtracting the surcharge flow through the Infiltration Basin, which flows over the overflow structure of the basin, from the peak flow rate as follows:

$$Q_{BP} = Q_{HDM} - Q_{SUR} = 5.25 - 2.0 = \underline{3.25\text{ cfs}}$$

If a Type 4 UFS is used, the BP pipe would have to convey 3.25 cfs with only 0.20-feet of headwater. Rating curves for various BP pipe diameters are developed as shown in Figure 8-1 below.

UFS Type 4 – Rating Curves

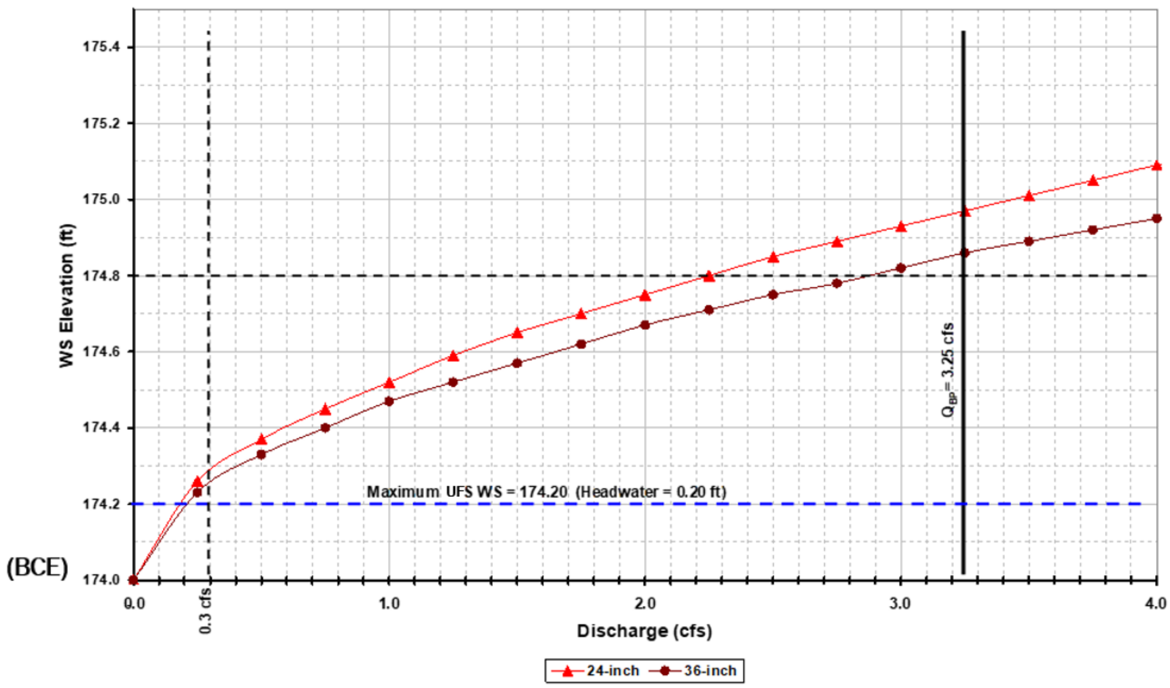

Figure 8-1. UFS Type 4 – Rating Curves

It can be seen that a headwater depth of 0.20 feet on a Type 4 BP pipe for diameters of 24 or 36 inches produces a bypass capacity of less than 0.3 cfs, well short of the 3.25 cfs bypass requirement. A headwater elevation in the UFS greater than 174.80 feet would be required to bypass 3.25 cfs using this type of UFS. This would exceed the maximum Q_{SUR} and WS_{SUR} in the Infiltration Basin. Reviewing the BMP design criteria for the site, this is not acceptable so the Type 4 UFS does not work and a weir type UFS is proposed.

The weir equation is used to determine the weir length. The unsubmerged sharp-crested weir coefficient, C_{SCW}, may be computed as:

$$C_{SCW} = 3.27 + 0.4(H / H_c) = 3.27 + 0.4(0.20 / 1.50) = \underline{3.32}$$

The required weir length for a sharp-crested weir with end contractions, L_w, is computed for $Q_w = Q_{BP}$:

$$L_w = [Q_w/(C_{SCW} \times H^{1.5})] + 0.2H = \underline{10.98 \text{ feet}}$$

$$= [3.25/(3.32 \times 0.20^{1.5})] + 0.2(0.20)$$

In order to accommodate this weir length, a Type 1 UFS is selected for the site.

Step 5: Set the Invert Elevation for the BP Pipe and Calculate (H_d).

Since the flow rate over the weir was determined above to be 3.25 cfs, a hydraulic analysis of the BP pipe for this flow rate is performed with the given tailwater elevation in Orange County Creek of 168.90 feet. The invert of the BP pipe at the connection to Orange County Creek is set at 166.70 feet. The invert elevation of the BP pipe (Elevation C in Figure 8-6) is set at 171.50 feet for the initial analysis. The hydraulic analysis must verify that the proposed pipe profile will provide a minimum of 10 inches of freeboard to the weir crest (BCE).

The analysis is completed using HY-8. The hydraulic analysis is based on the following parameters:

- Flow rate (Q_{BP}) = 3.25 cfs
- Diameter = 24 inches (Equal to IN pipe diameter)
- Length of pipe = 85 feet
- Upstream invert elevation (Assumed) = 171.50 feet
- Downstream invert elevation = 166.70 feet
- Slope = 0.0565 ft/ft
- Manning's "n" = 0.012, for precast RCP

The results of the hydraulic analysis are presented in the rating table in Table 8-4.

Table 8-4. Rating Table for the BP Pipe

Flow Rate (cfs)	WQ Diversion Pipe Headwater Depth (feet)
0.00	0.00
0.05	0.05
0.65	0.35
0.98	0.44
1.30	0.51
1.63	0.58
1.95	0.63
2.27	0.68
2.60	0.74
2.93	0.79
3.25	0.83 (El. 172.33)[1]

1. Provides 1.67 ft freeboard from BCE

Elevation C = <u>171.50 feet</u>

H_d = Elevation B – Elevation C = 174.00 – 171.50 = <u>2.50 feet</u>

The hydraulic profile for this analysis is shown in Figure 8-2.

Step 6: Confirm that the UFS Fits within the Vertical Drop Available in the System.

The system profiles for the WQ flow path and bypass flow path are shown in Figures 8-4 and 8-2. The designer confirmed that there is sufficient drop within the system to accommodate these profiles and that the UFS fits below the proposed finished grade at the site.

Step 7: Complete the Hydraulic Analysis for the Upstream Drainage System.

A hydraulic analysis for the peak design flow rate (Q_{25}) was completed for the upstream drainage system using a downstream water surface control equal to the maximum water surface in the UFS calculated in Step 3. The elevation of this water surface is 174.20 feet. The resultant HGL for the upstream drainage system provided sufficient freeboard at all the drainage inlets. Therefore, the proposed UFS is determined to be acceptable.

Conclusion: The UFS designed in this example is adequate to direct the required WQV to the proposed BMP Infiltration Basin. The WQ diversion pipe satisfies the required conveyance capacity for the peak design storm, Q_{HDM}, and the maximum water surface in the UFS during bypass will not cause the maximum water surface and flow rate in the BMP to be exceeded during the surcharged condition. The hydraulic impacts of the UFS have been evaluated and it has been determined that the UFS does not reduce the hydraulic capacity of the upstream drainage system during the peak 25-year design storm. The Project Drawings will be prepared in accordance with the following design data and Figures 8-2 through 8-6.

Design Summary:

WQ diversion pipe diameter =	18 inches
UFS Type =	Type 1
Length of bypass weir (L_W) =	10.98 feet
H_C =	1.50 feet
H_d =	2.50 feet
Elevation A =	172.50 feet
Elevation B (BCE) =	174.00 feet
Elevation C =	171.50 feet

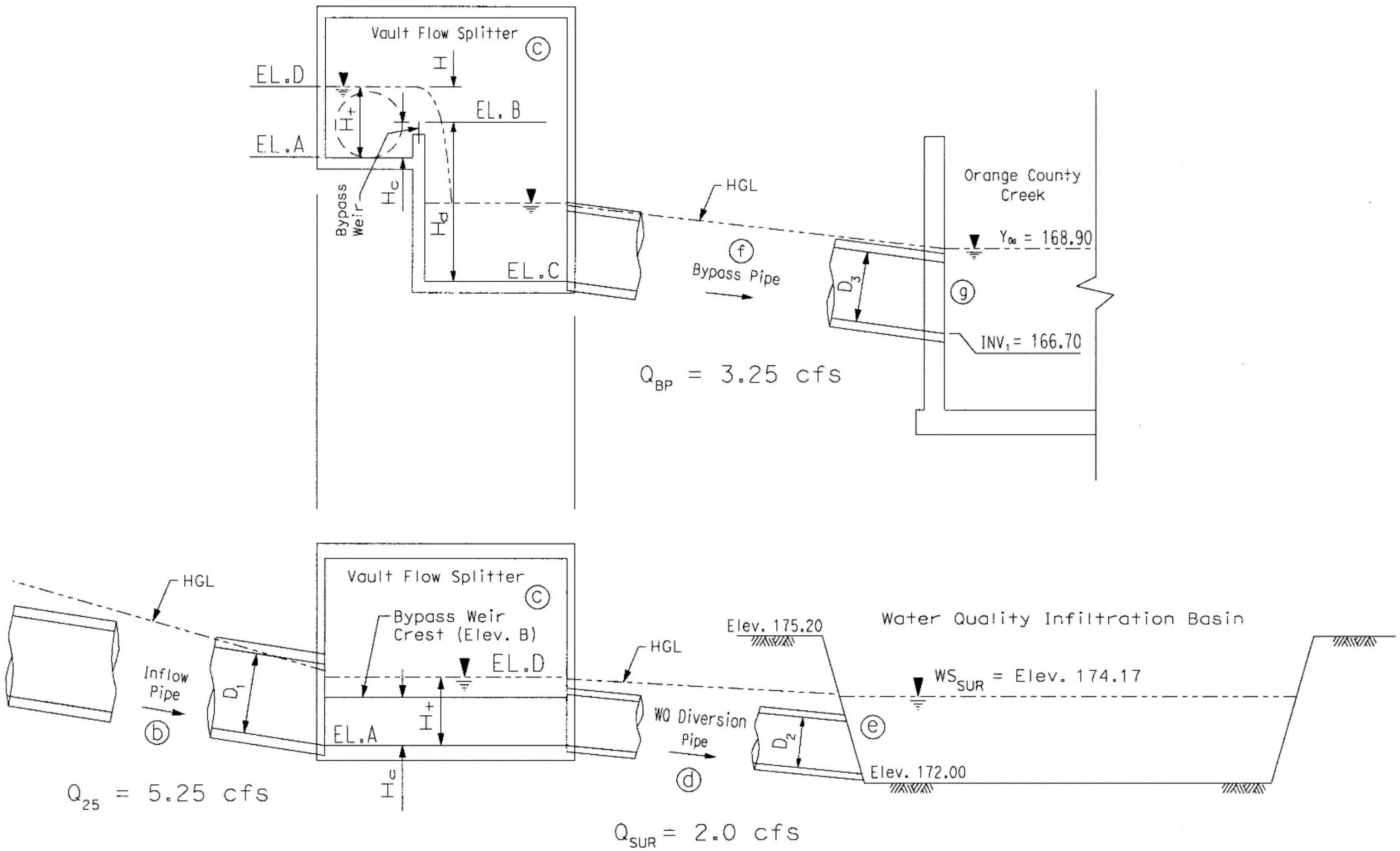

Figure 8-2. System Profile Showing Flow in the Surcharged Condition

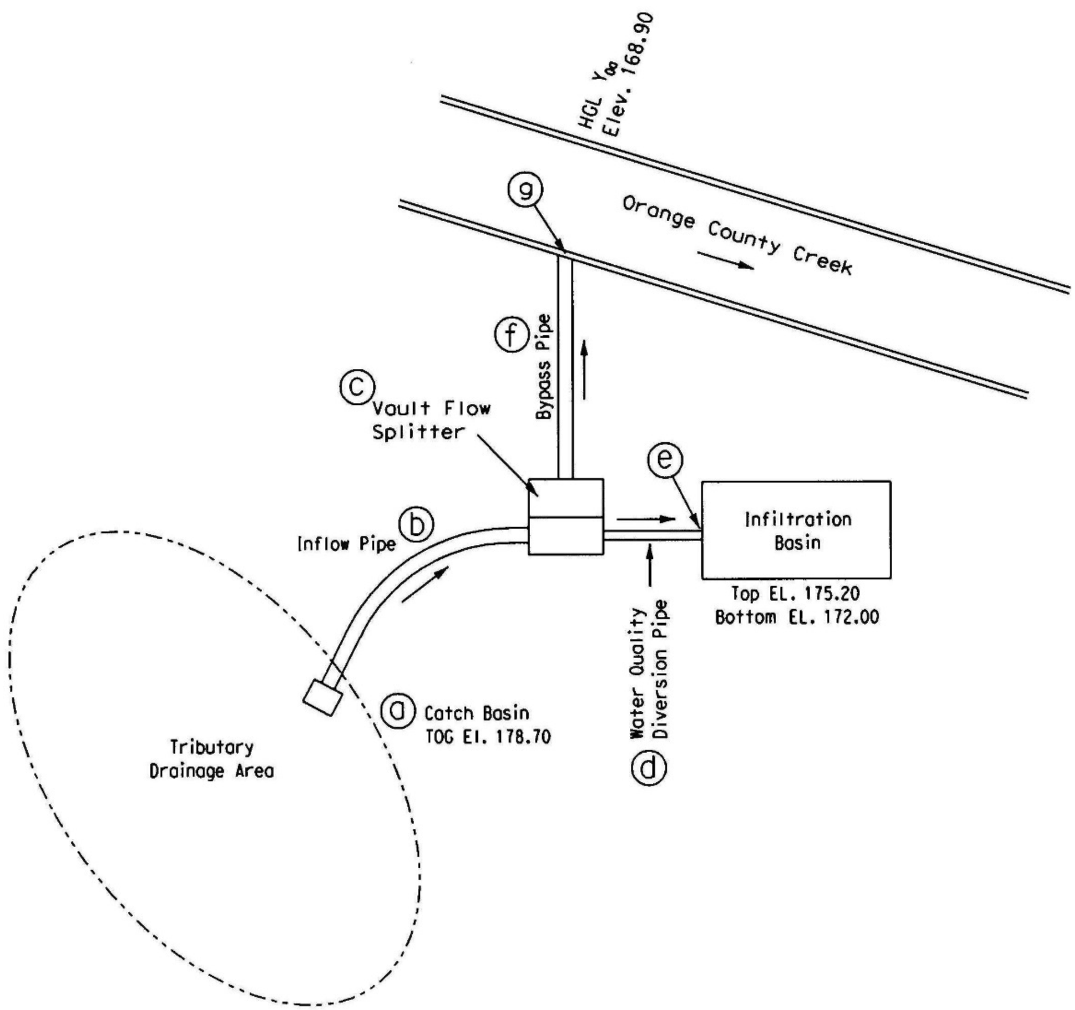

Figure 8-3. Plan of Project Site

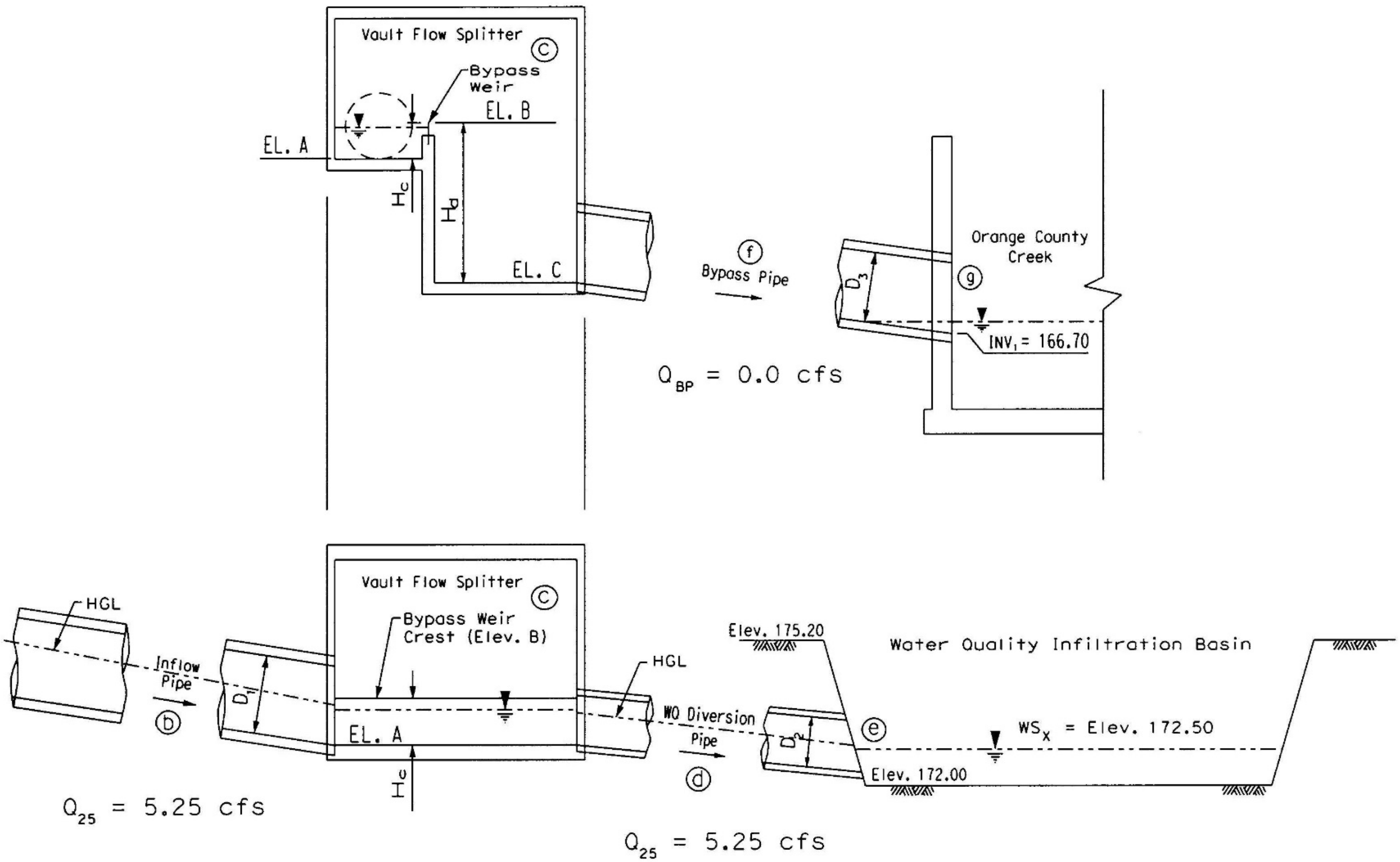

Figure 8-4. System Profile Showing Flow at Q25 Before Bypass.

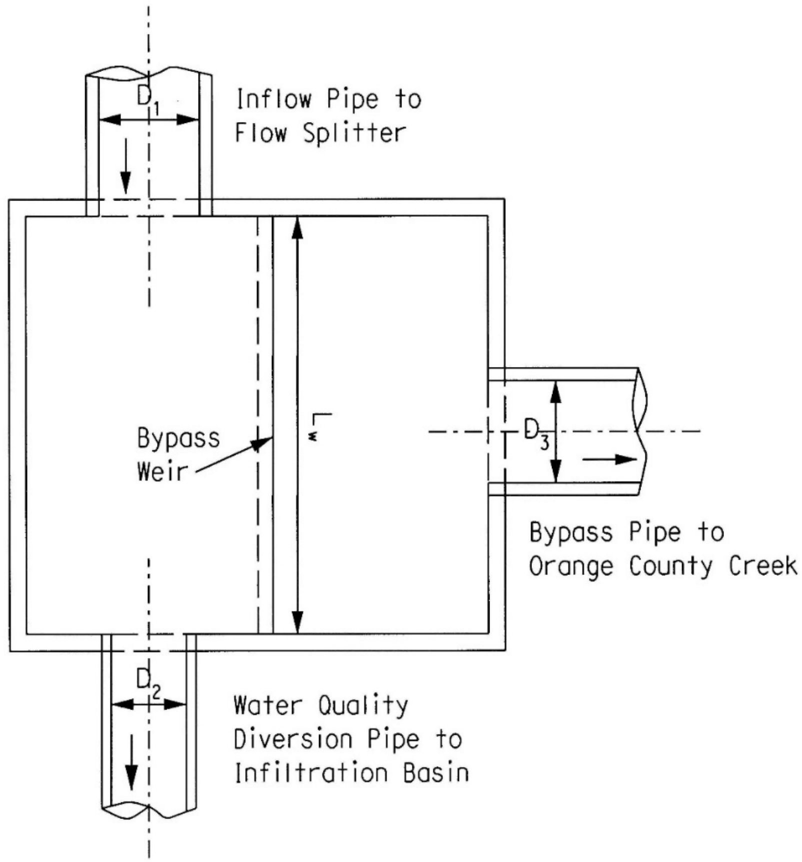

Figure 8-5. Type 1 UFS Plan

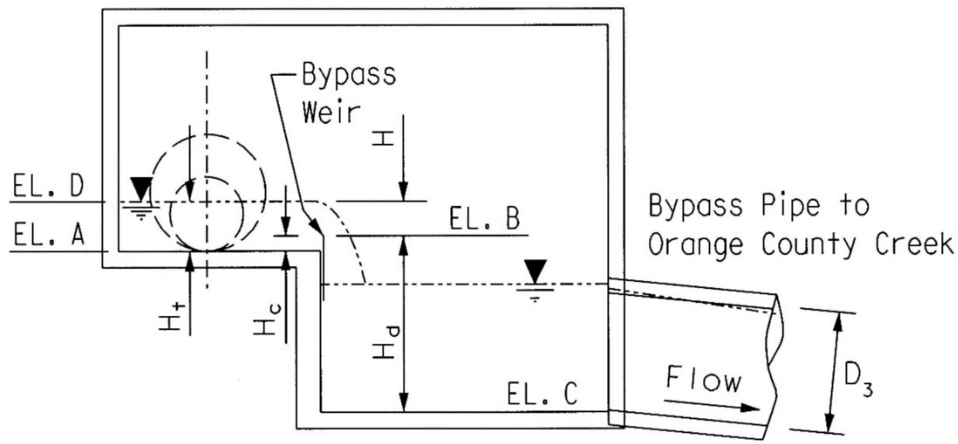

Figure 8-6. Type 1 UFS Section.

8.2 UFS Design Example (Flow-Based BMP)

The following design example is for the installation of a UFS upstream of a flow-based pilot TBMP (BMP) for a site in Orange County on an existing storm drain. The designer of the BMP has indicated that the maximum flow rate that can be conveyed through the BMP in a surcharged condition is 4.20 cfs. Due to this limitation, a UFS will be needed in order to divert excess flows into a BP Pipe. Thus, this structure will not only direct the WQF from the existing mainline storm drain pipe to the BMP but will also ensure that the maximum allowable surcharge flow rate for the BMP is not exceeded and provide an outlet for the excess flow.

Figure 8-7 is a schematic drawing of the plan of the proposed storm drain, UFS, and BMP. Both the BMP and the BP pipe will discharge into Orange County Creek, which flows adjacent to the project site. Because the slope to the creek is very steep, the UFS will be placed at an elevation several feet above the BMP. Figures 8-8 and 8-9 show the profile of the proposed storm drain, UFS, and BMP.

Given Data:

The following hydrologic data and design parameters have been provided by the designer of the BMP and will be the basis for the design of the UFS:

Q_{25} = 17.53 cfs

(Peak design flow rate for the design of the storm drain system, Q_{IN})

WQF = 2.19 cfs

(Water quality flow rate required to be treated by the BMP)

Q_{SUR} = 4.20 cfs

(Maximum flow rate allowed through the BMP for the 25-year peak flow rate)

In this case, surcharge is defined as (Q_{SUR} / WQF) = 192%

In addition, a number of design parameters for the proposed system are given:

Elevation of the BP pipe invert at Orange Creek (INV_1) =	170.00 feet
Elevation at invert of the BMP (INV_2) =	172.00 feet
Finished grade elevation at the UFS site =	183.8 feet
IN pipe diameter (D_1) =	24 inches
IN pipe invert elevation =	179.21 feet

Step 1: Set the Invert Elevation of the IN Pipe and Select the Diameter of the WQ Diversion Pipe.

The invert elevation of the WQ diversion pipe (Elevation A in Figure 8-11) is set 0.16 feet below the existing invert elevation given for the IN pipe.

Elevation A = 179.21 – 0.16 179.05 feet

Since the WQF for this example is relatively small, a pipe diameter (D_2) of 15 inches is selected because this is the minimum size allowed for trunk lateral pipes (HDM Topic 838.4). A hydraulic analysis is performed for the initial selection of a 15 inch pipe diameter to ensure that the pipe produces a reasonable headwater depth for the WQF. The analysis is completed using HY-8. The hydraulic analysis is based on the following parameters:

- Flow rate (WQF) = 2.19 cfs
- Diameter = 15 inches
- Length of pipe = 30 feet
- Upstream invert elevation = 179.05 feet
- Downstream invert elevation = 172.00 feet
- Slope = 0.235 ft/ft
- Manning's "n" = 0.012, for precast RCP

The results of the hydraulic analysis are presented in the rating table in Table 8-5. The peak flow rate of 4.20 cfs is low relative to the cross sectional area of the UFS and the flow velocity within the structure is less than 1 fps. Therefore, the velocity head in the UFS at the headwater of the WQ diversion pipe is not considered in the calculation of the headwater depth.

Table 8-5. Rating Table for the WQ Diversion Pipe

Flow Rate (cfs)	WQ Diversion Pipe Headwater Depth (feet)
0.00	0.00
0.60	0.35
1.20	0.50
1.80	0.62
2.19	0.72
3.00	0.90
3.60	1.03
4.20	1.16
4.80	1.31
5.40	1.46

The hydraulic analysis results in a headwater depth of 0.72 feet for the WQF of 2.19 cfs. This is a reasonable headwater depth. The proposed WQ diversion pipe is also checked for the flow velocity flowing half full (Table 8-6) as follows:

Manning's "n" = 0.012

Slope, S_o = 0.235 ft/ft

Table 8-6. Half Full Flow Hydraulic Analysis of WQ Diversion Pipe					
Pipe Diameter, D (in)	Pipe Area, A (sf)	Half Full Area, a=A/2 (sf)	Wetted Perimeter, p (ft)	Hydraulic Radius, R = a/p (ft)	Half Full Flow Velocity, V (1) (fps)
15	1.227	0.614	1.963	0.313	27.7

$V = Q/a = (K_U R^{0.67} S_0^{0.5})/n$, K_U = 1.486 in English units (FHWA 2009).

The flow velocity at the WQF was also calculated at 15.37 fps so the selected pipe is determined to be self-cleansing.

Step 2: Calculate Dimension "H_C" and Set the Bypass Control Elevation (BCE).

The headwater depth for the WQ diversion pipe for the WQF is 0.72 feet. Therefore, dimension "H_C" and the BCE (Elevation B in Figure 8-11) are set as follows:

H_C = (Headwater depth from hydraulic analysis in Step 1) = <u>0.72 feet</u>

BCE = Elevation B = Elevation A + H_C = 179.05 + 0.72 = <u>179.77 feet</u>

The hydraulic profile for the WQF condition is shown in Figure 8-9.

Step 3: Calculate the Maximum Allowable Water Surface in the UFS During Bypass and Calculate the Corresponding Hydraulic Head "H".

When the flow rate in the UFS exceeds the WQF, the headwater depth at the inlet of the WQ diversion pipe will be greater than the height of the bypass weir, allowing water to begin flowing over the weir. At the 25-year peak design flow rate of 17.53 cfs, the flow rate into the WQ diversion pipe, Q_{SUR}, can be no more than 4.20 cfs. By examination of the rating table (Table 8-5) provided in Step 1, it is determined that a headwater depth of 1.16 feet corresponds to this 4.20 cfs flow rate in the WQ diversion pipe. Thus, the depth of water in the structure at the peak 25-year flow rate, H_t, is set at this depth.

Based on this analysis, Elevation D and dimension "H", as shown in Figure 8-11, are computed as follows:

Elevation D = Elevation A + H_t = 179.05 + 1.16 = <u>180.21 feet</u>

H = H_t – H_C = 1.16 – 0.72 = <u>0.44 feet</u>

The hydraulic profile for the surcharged flow condition is shown in Figure 8-8.

Step 4: Determine the Weir Length and Select the Type of UFS for the Calculated Weir Length.

Since the flow rate in the WQ diversion pipe at the peak 25-year flow rate is 4.20 cfs, the required flow rate over the weir may be calculated as:

$Q_W = Q_{25} - Q_{SUR}$ = 17.53 – 4.20 = <u>13.33 cfs</u>

The weir equation is used to determine the weir length. The unsubmerged sharp-crested weir coefficient, C_{SCW}, may be computed as:

$$C_{SCW} = 3.27 + 0.4(H / H_c) = 3.27 + 0.4(0.44 / 0.72) = \underline{3.51}$$

The required weir length for a sharp-crested weir with end contractions, L_w, is then:

$$L_w = [Q_w/(C_{SCW} \times H^{1.5})] + 0.2H = \underline{13.10 \text{ feet}}$$

$$= [13.33/(3.51 \times 0.44^{1.5})] + 0.2(0.44)$$

In order to accommodate this weir length, a Type 1 UFS is selected for the site.

Step 5: Set the Invert Elevation for the BP Pipe and Calculate (H_d).

The headwater depth on the BP pipe is determined by using HY-8. The hydraulic analysis is based on the following parameters:

- Flow rate (Q_w) = 17.53 – 4.20 = 13.33 cfs
- Diameter = 24 inches
- Length of pipe = 103 feet
- Upstream Invert Elevation (Elevation C) =176.44 feet
  - (Set at the minimum depth from BCE = El. B – 0.833 ft of freeboard – 0.5 ft initial guess at headwater depth above soffit – 2.0 ft diameter)
- Downstream invert elevation = 170.00 feet
- Slope = 0.0625 ft/ft

From Table 8-7, the headwater depth for the BP pipe at the bypass flow rate of 13.33 cfs is equal to 1.64 feet. With an inlet invert elevation of 176.44 feet and headwater depth of 1.64 feet, the BP pipe is provided with 1.69 feet of freeboard which exceeds the 0.833 feet minimum. Therefore, Elevation C is set at 176.44 feet and H_d is calculated as follows:

$$H_d = \text{Elevation B} - \text{Elevation C} = 179.77 - 176.44 = \underline{3.33 \text{ feet}}$$

Table 8-7. Rating Table for the BP Pipe

Flow Rate (cfs)	BP Pipe Headwater Depth (feet)
0.00	0.00
1.50	0.55
3.00	0.79
4.50	0.98
6.00	1.18
7.50	1.37
9.00	1.54
10.50	1.59
12.00	1.62
13.33	1.64
15.00	1.66

The hydraulic profile for this analysis is shown in Figure 8-8.

Step 6: Confirm that the UFS Fits within the Vertical Drop Available in the System.

The system profiles for the WQ flow path and bypass flow path are shown in Figures 8-9 and 8-7. The designer confirmed that there is sufficient drop within the system to accommodate these profiles. Since the invert elevation of the IN pipe was calculated using the proposed finished grade at the site, the UFS will fit below the proposed finished grade at the site.

Step 7: Complete the Hydraulic Analysis for the Upstream Drainage System.

A hydraulic analysis for the peak design flow rate (Q_{25}) was completed for the upstream drainage system using a downstream water surface control equal to the maximum water surface in the UFS calculated in Step 3. The elevation of this water surface is 180.21 feet. The resultant HGL for the upstream drainage system provided sufficient freeboard at all the drainage inlets. Therefore, the proposed UFS is determined to be acceptable.

Conclusion: The UFS designed in this example is adequate to direct the required WQF to the proposed BMP and to prevent an excessive flow surcharge of the BMP in the peak 25-year design storm event. The hydraulic impacts of the UFS have been evaluated and it has been determined that the UFS does not reduce the hydraulic capacity of the upstream drainage system during the peak 25-year design storm. The Project Drawings will be prepared in accordance with the following design data and Figures 8-7 through 8-11.

Design Summary:

WQ diversion pipe diameter =	15 inches
UFS Type =	Type 1
Calculated Length of bypass weir (L_w) =	13.10 feet
H_c =	0.72 feet
H_d =	3.33 feet
Elevation A =	179.05 feet
Elevation B (BCE) =	179.77 feet
Elevation C =	176.44 feet

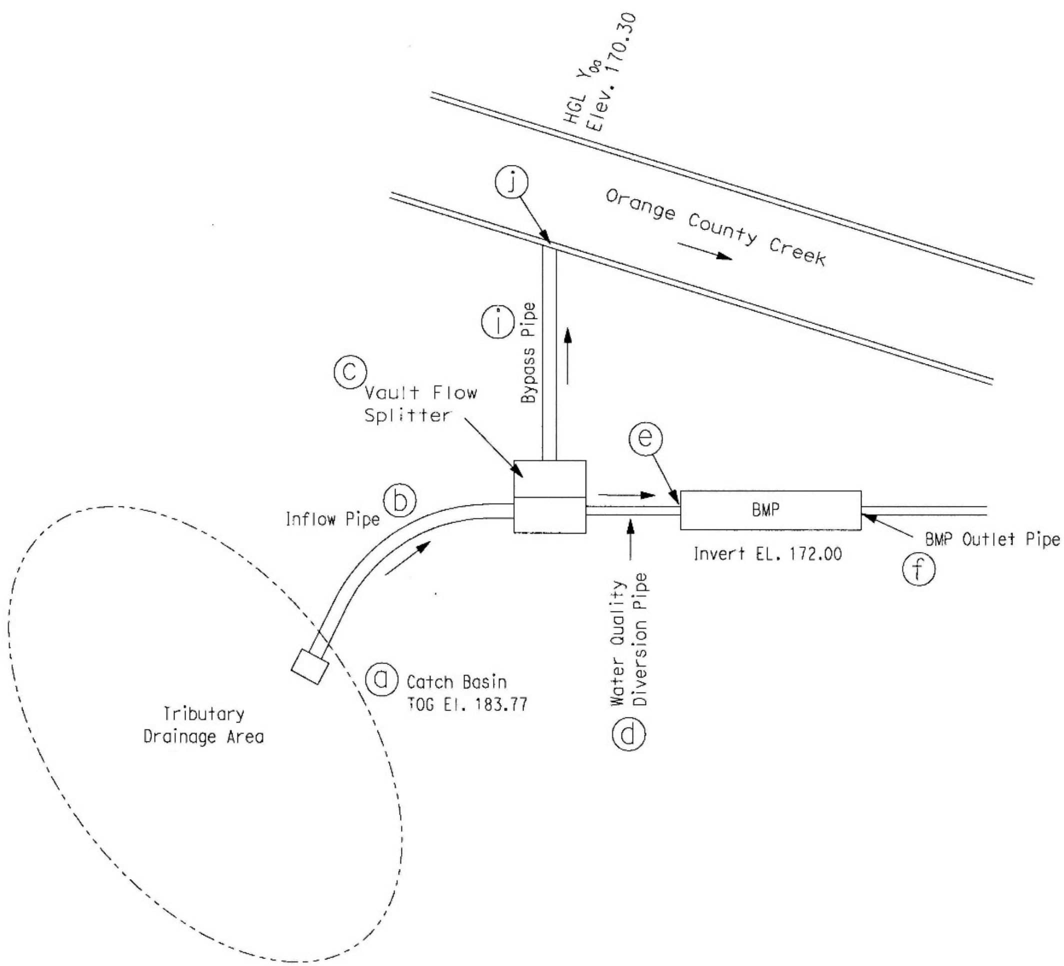

Figure 8-7. Plan of Project Site

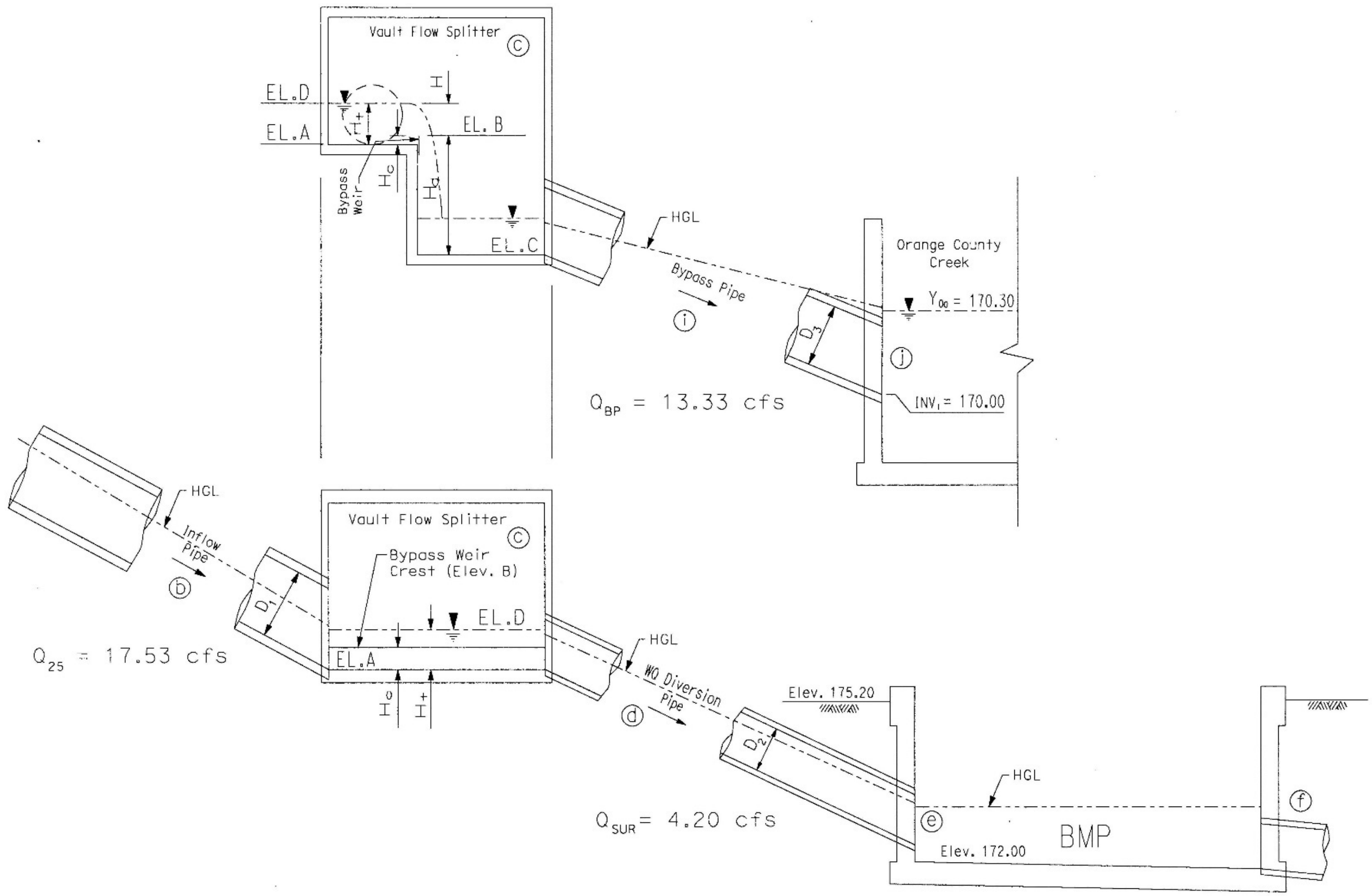

Figure 8-8: System Profile Showing Flow in the Surcharged Condition

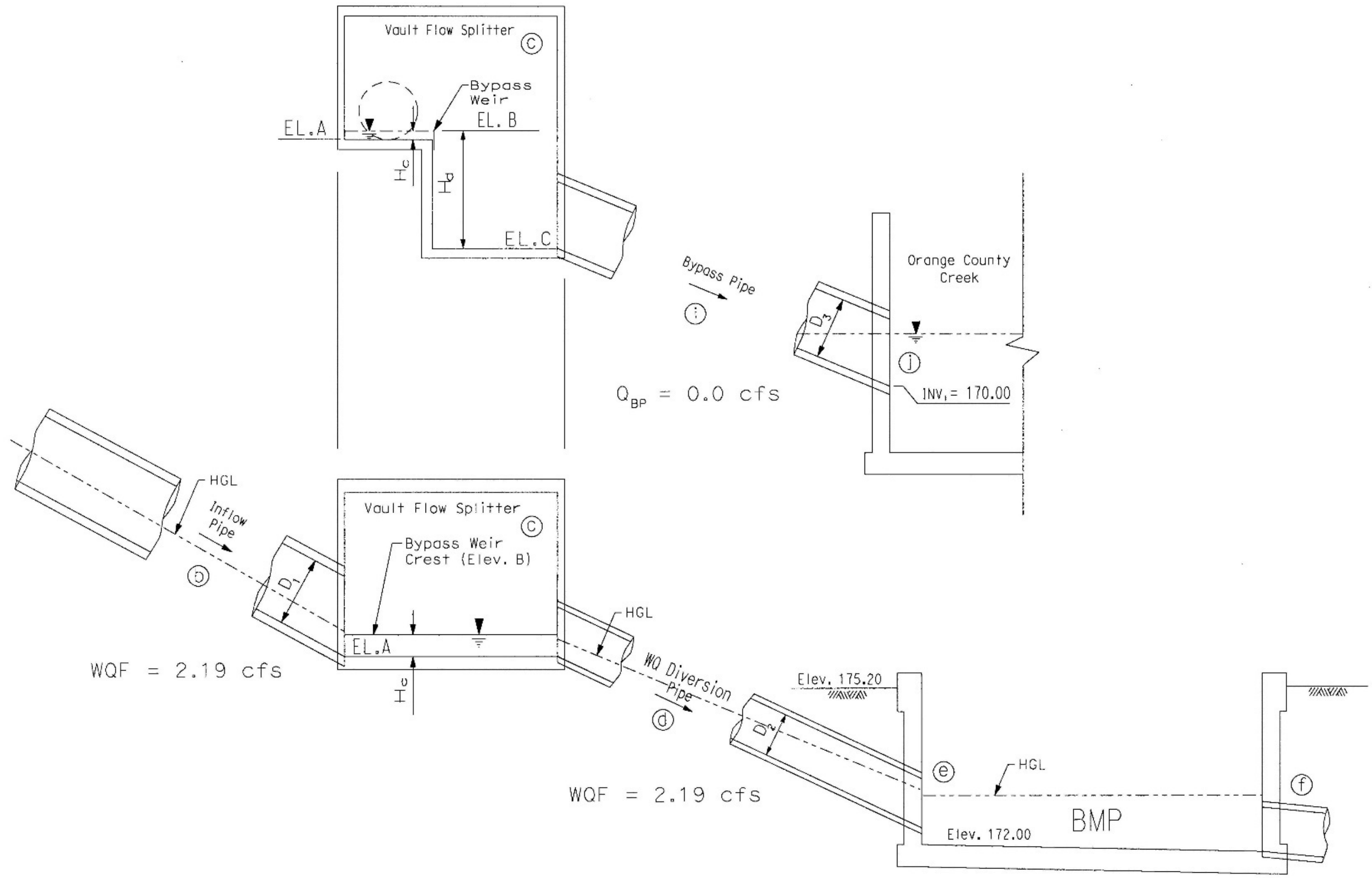

Figure 8-9. System Profile Showing Flow at WQV

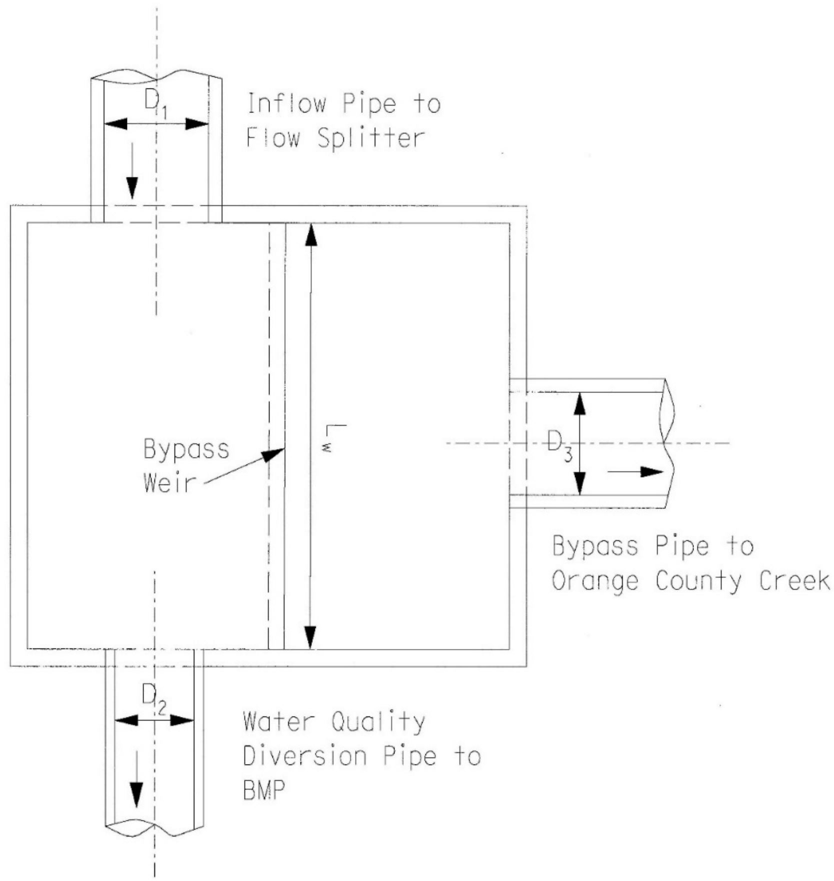

Figure 8-10. Type 1 UFS Plan

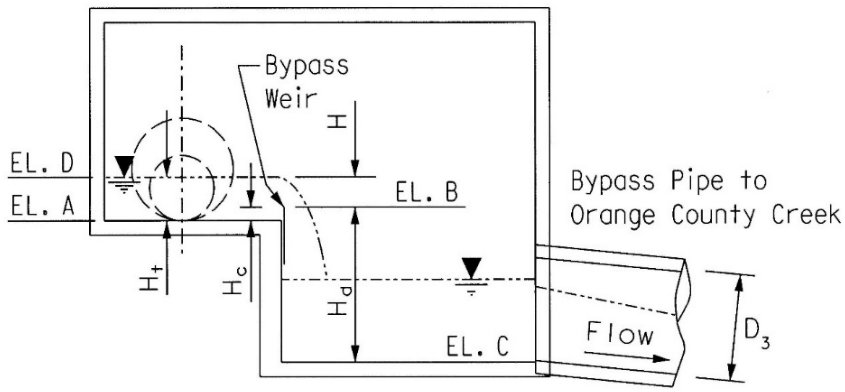

Figure 8-11. Type 1 UFS Section

8.3 PS&E Preparation

The PE is to incorporate the UFS design into the PS&E package, including revising the required drawings and adding the necessary UFS Detail Drawings. In a typical example, the following drawings are revised as shown in Figures 8-12 through 8-18:

- Layout: Show the location of the selected UFS; refer to Drainage Plans for detailed information (Sample not included).
- Drainage Plans: Show the selected UFS in plan; refer to appropriate Drainage Detail sheets, as required (Figure 8-12).
- Drainage Profiles: Show the selected UFS profile with the existing and proposed drainage conveyance systems, including pipes and inlets; refer to appropriate Drainage Detail sheets, as required (System No. 6 in Figure 8-13 and System No. 6A in Figure 8-14).
- Drainage Details: In order to show the required details to construct or clarify interfaces, show the location of the UFS in plan at a larger scale than in the Drainage Plans (Figure 8-15).
- UFS Detail Drawings: Most of the required structure information is included in the UFS Detail Drawings. These drawings are included with the Drainage Details section of the PS&E (Figures 8-16 to 8-17).

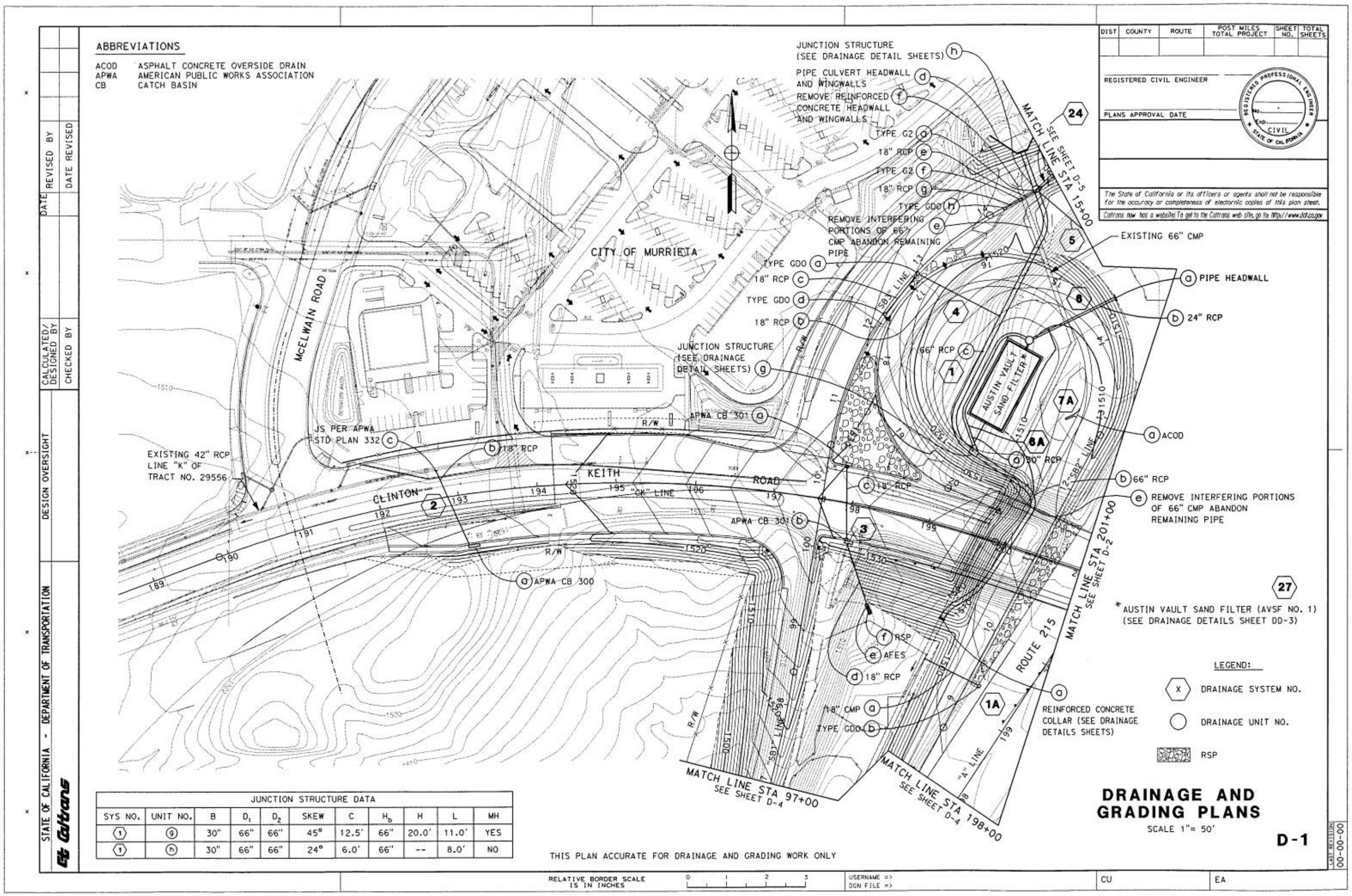

Figure 8-12. Sample Drainage Plan Sheet

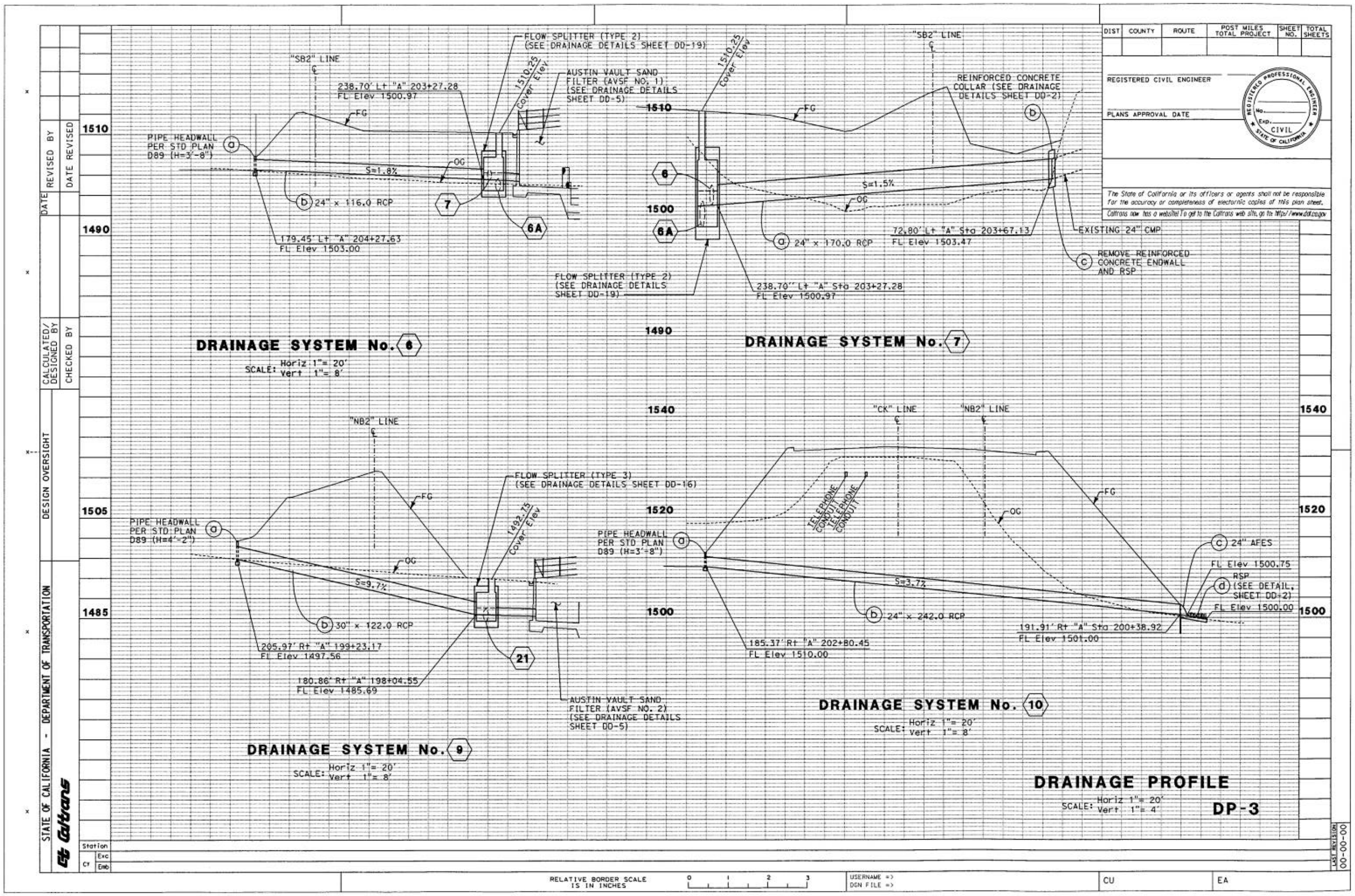

Figure 8-13. Sample Drainage Profile Sheet (1 of 2)

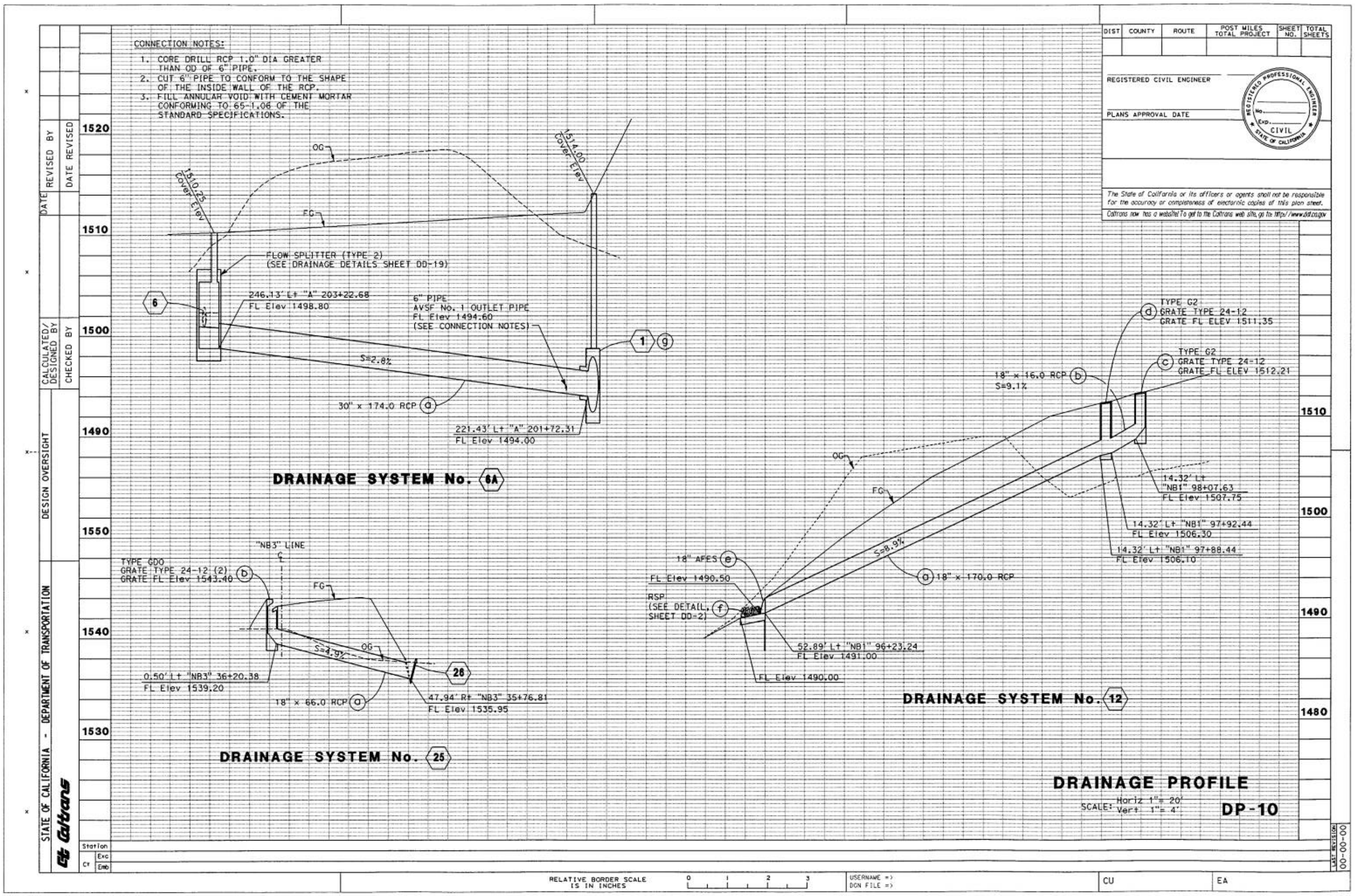

Figure 8-14. Sample Drainage Profile Sheet (2 of 2)

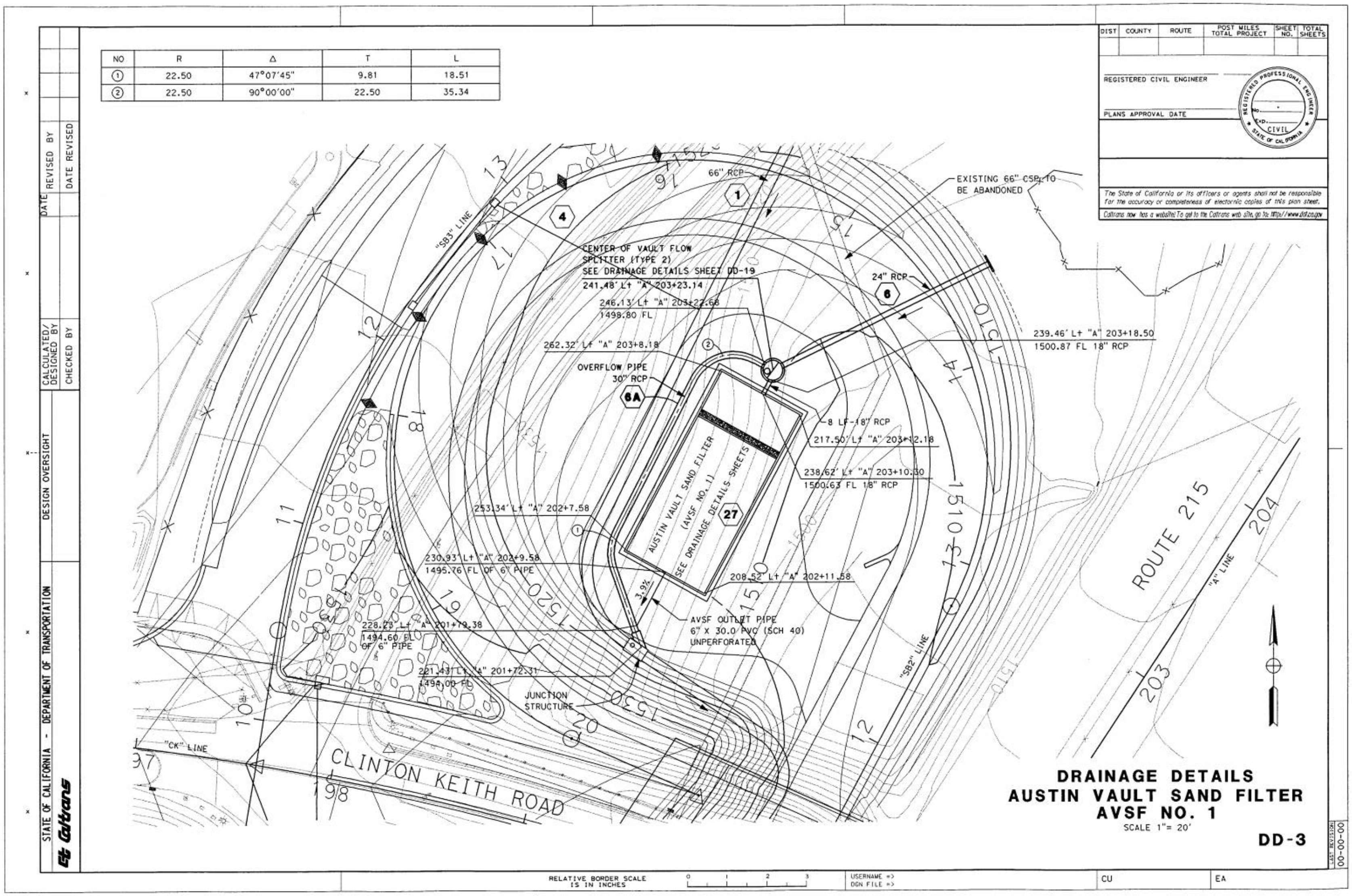

Figure 8-15. Sample Drainage Detail Sheet

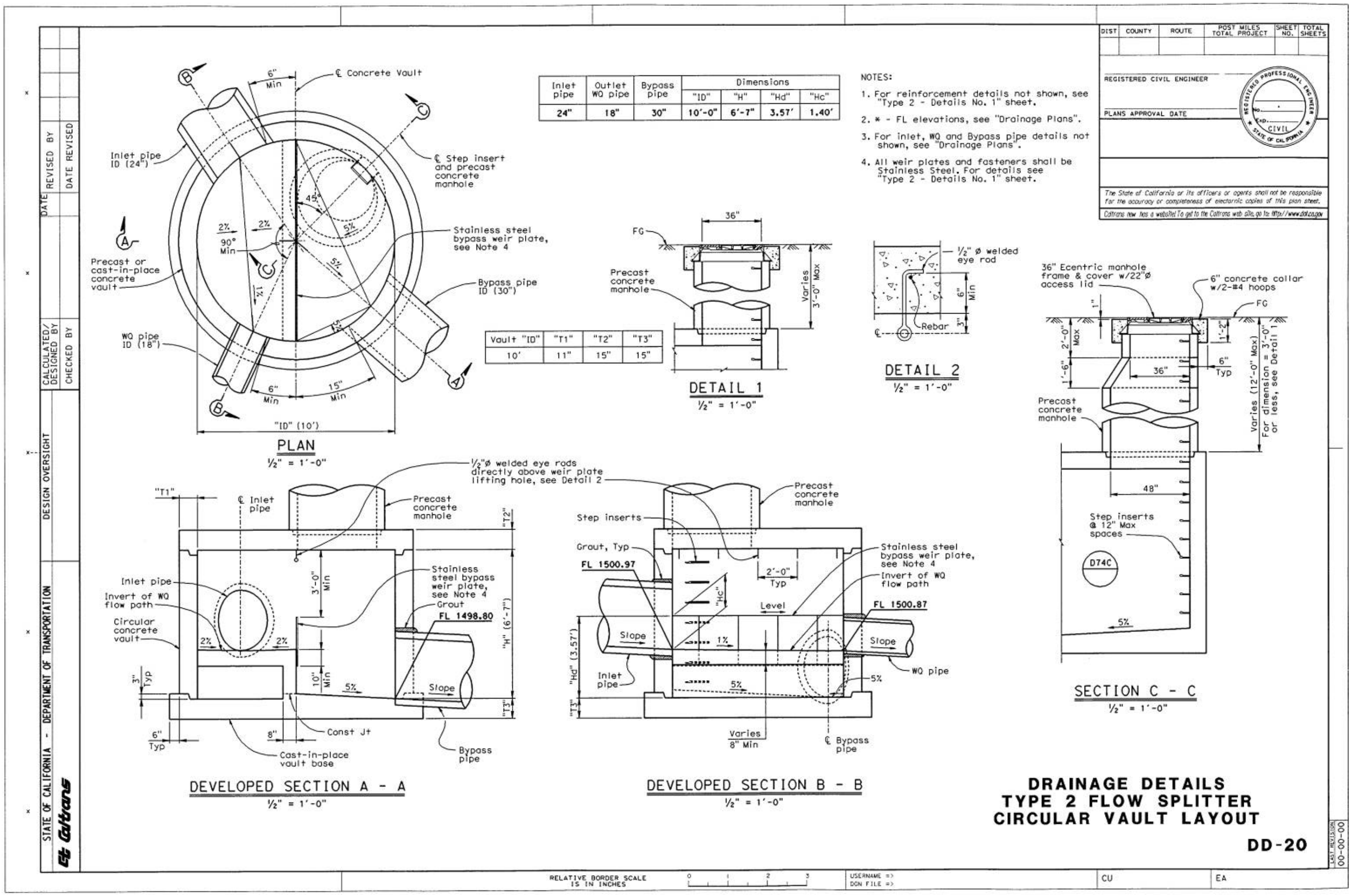

Figure 8-16. Sample UFS Detail Drawing (1 of 2)

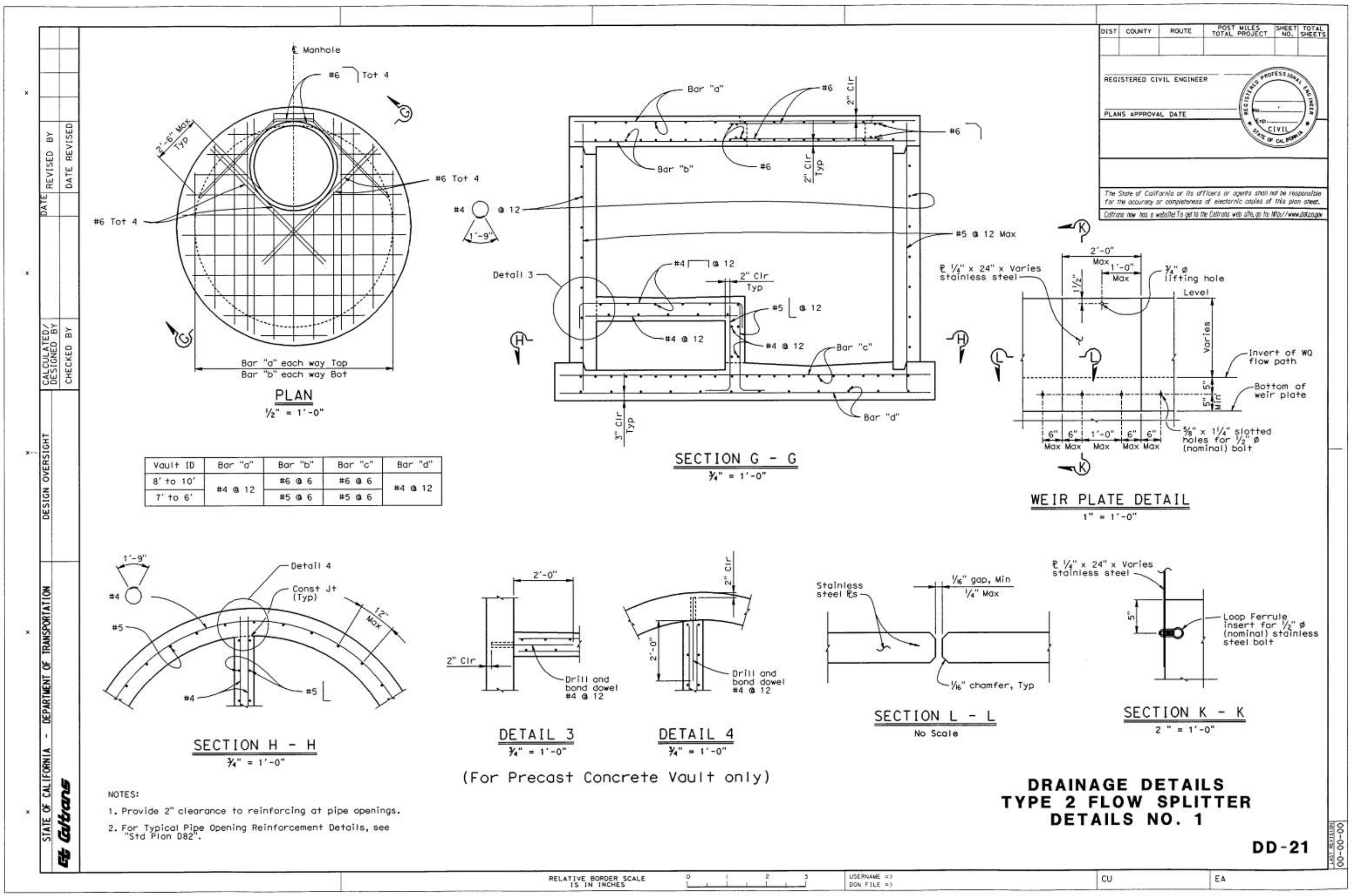

Figure 8-17. Sample UFS Detail Drawing (2 of 2)

Section 9

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Appendix A: UFS Weir Rating Curves

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INTRODUCTION

The weir rating curves included in this appendix are intended to aide in the initial selection of the type and size of UFS that may be appropriate for a particular project site and for the peak design flow rate prescribed for the project site. Use the curves to compare the weir discharge capacity of the various types of UFS based on the range of weir lengths each type provides in order to decide which UFS type and size is likely to provide a tolerable hydraulic head above the weir crest. The curves should be used for the initial selection and the actual bypass capacity for the weir and the associated hydraulic head (H) over the weir must be precisely calculated as described in Section 4.

These rating curves are based on the discharge equation for an unsubmerged sharp-crested rectangular weir with end contractions, as described in Section 2.1. The weir discharge coefficient (C_{SCW}) in this equation is a function of the height of the weir crest (H_C) on the upstream side of the weir. Since the UFS Standard Details offer a range of possible values for the Dimension "H_C", rating curves are included in this appendix at various values of H_C, as indicated on each chart, in order to represent the range of weir flow capacity as a function of H_C. Use the curve with the value of H_C closest to the project specific value of H_C.

The curves for the Type 3 UFS in Charts A.1 and A.2 are repeated at a value of 1.833 ft for H_C because this is the minimum dimension specified in the Standard Details for a Type 3. Chart A.6 is based on the maximum value of 11.0 ft for H_C for a Type 3 UFS per the Standard Details. Rating curves for Type 3 for values of H_C between 3.0 and 11.0 ft are not included because the weir discharge capacity between these values shows only a minor reduction.

The intermediate curves for each UFS Type are shown at one-foot increments between the minimum and maximum weir length.

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CHART A.1

WEIR RATING CURVES (UFS TYPES 1, 2, 3 and 5)

WEIR CREST HEIGHT (Hc)

Type 3: 1.833 FT

OTHERS: 0.25 FT

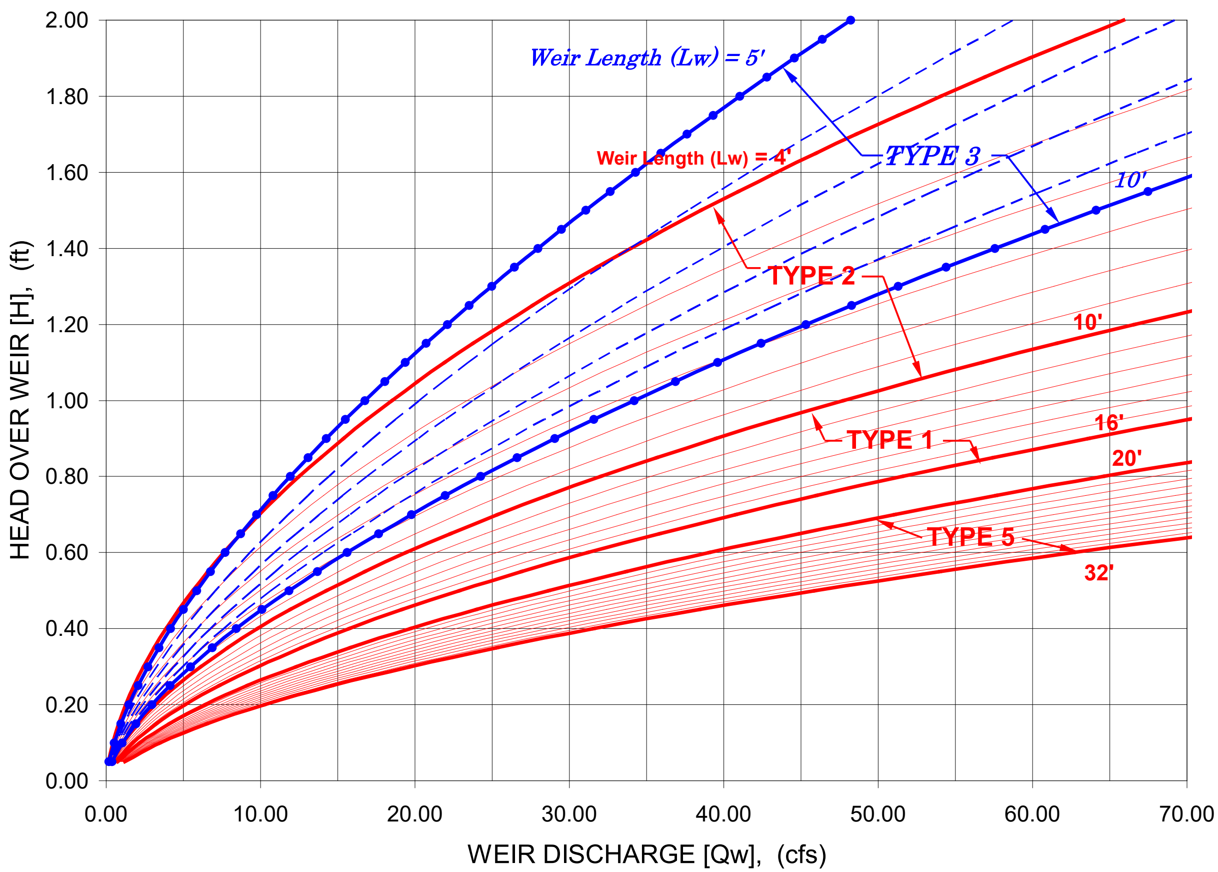

CHART A.2

WEIR RATING CURVES (UFS TYPES 1, 2, 3 and 5)

WEIR CREST HEIGHT (Hc)

Type 3: 1.833 FT

OTHERS: 0.50 FT

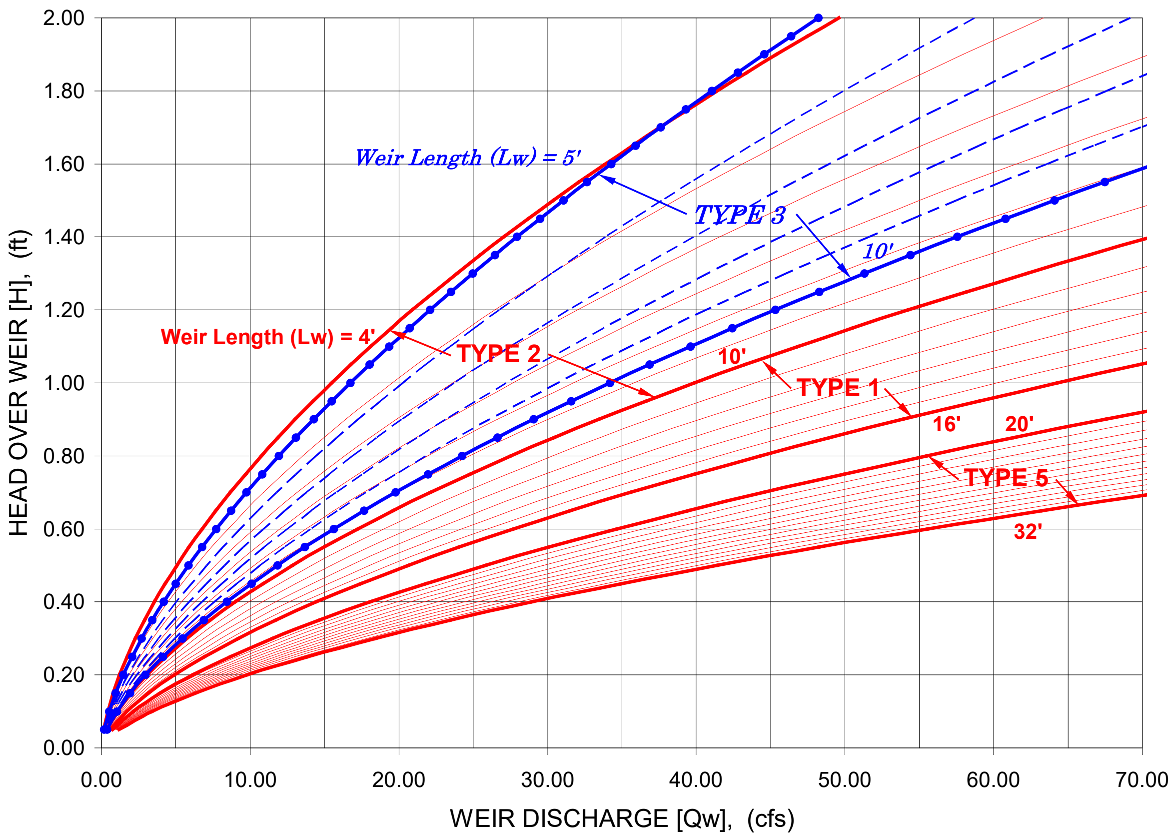

CHART A.3
WEIR RATING CURVES (UFS TYPES 1, 2, 3 and 5)

WEIR CREST HEIGHT (Hc)

Type 3: 2.0 FT

OTHERS: 1.0 FT

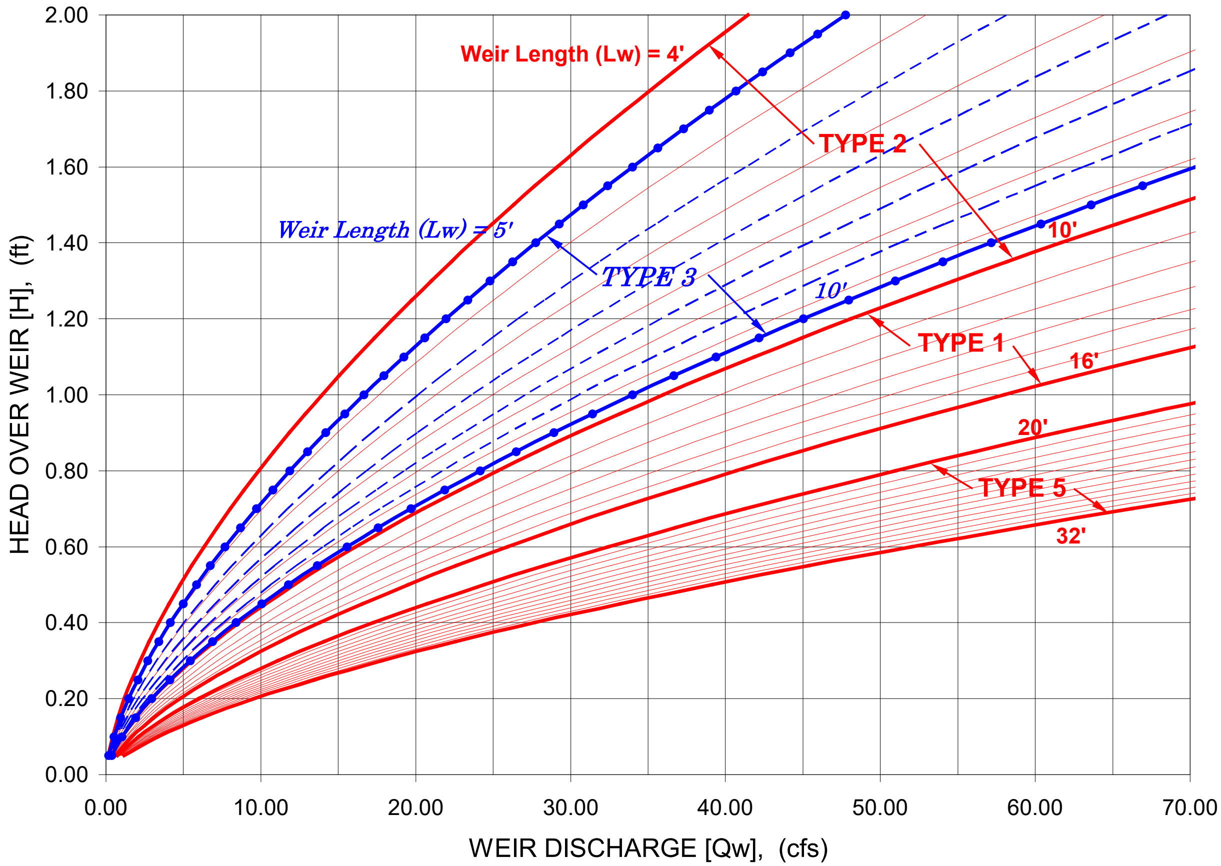

CHART A.4
WEIR RATING CURVES (UFS TYPES 1, 2, 3 and 5)

WEIR CREST HEIGHT (Hc)

Type 3: 2.5 FT

OTHERS: 1.5 FT

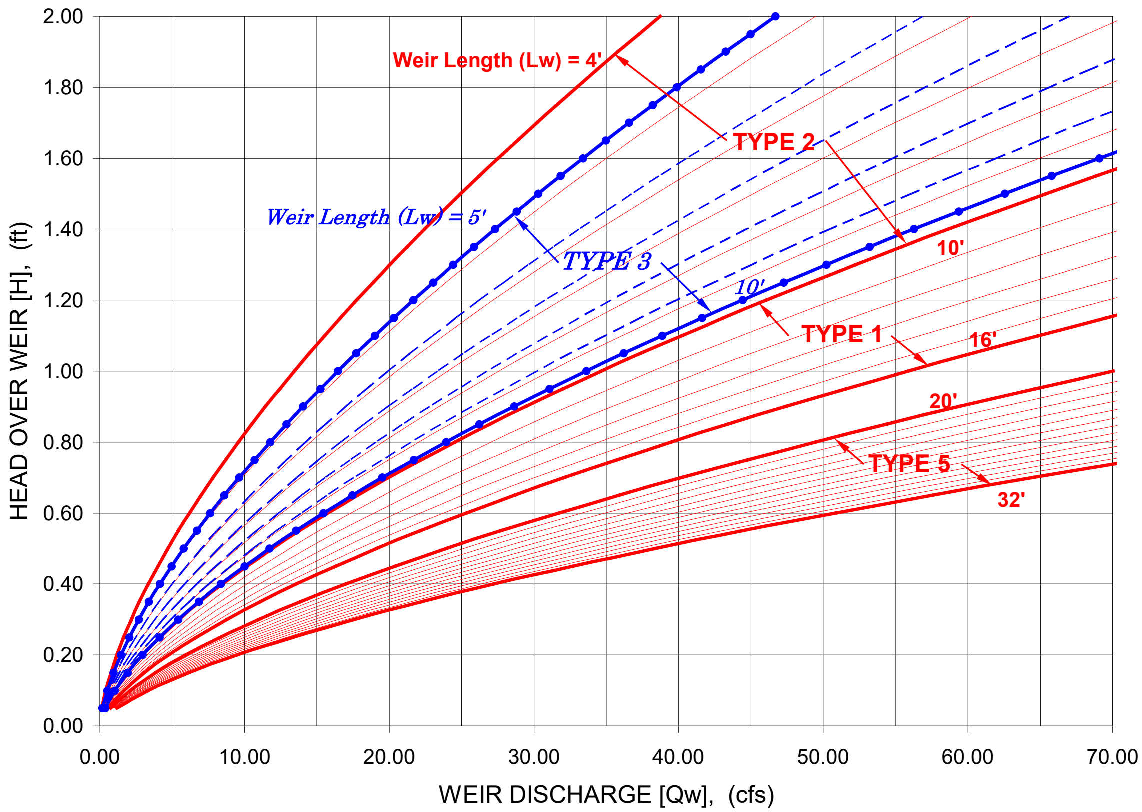

CHART A.5
WEIR RATING CURVES (UFS TYPES 1, 2, 3 and 5)

WEIR CREST HEIGHT (Hc)

Type 3: 3.0 FT

OTHERS: 2.0 FT

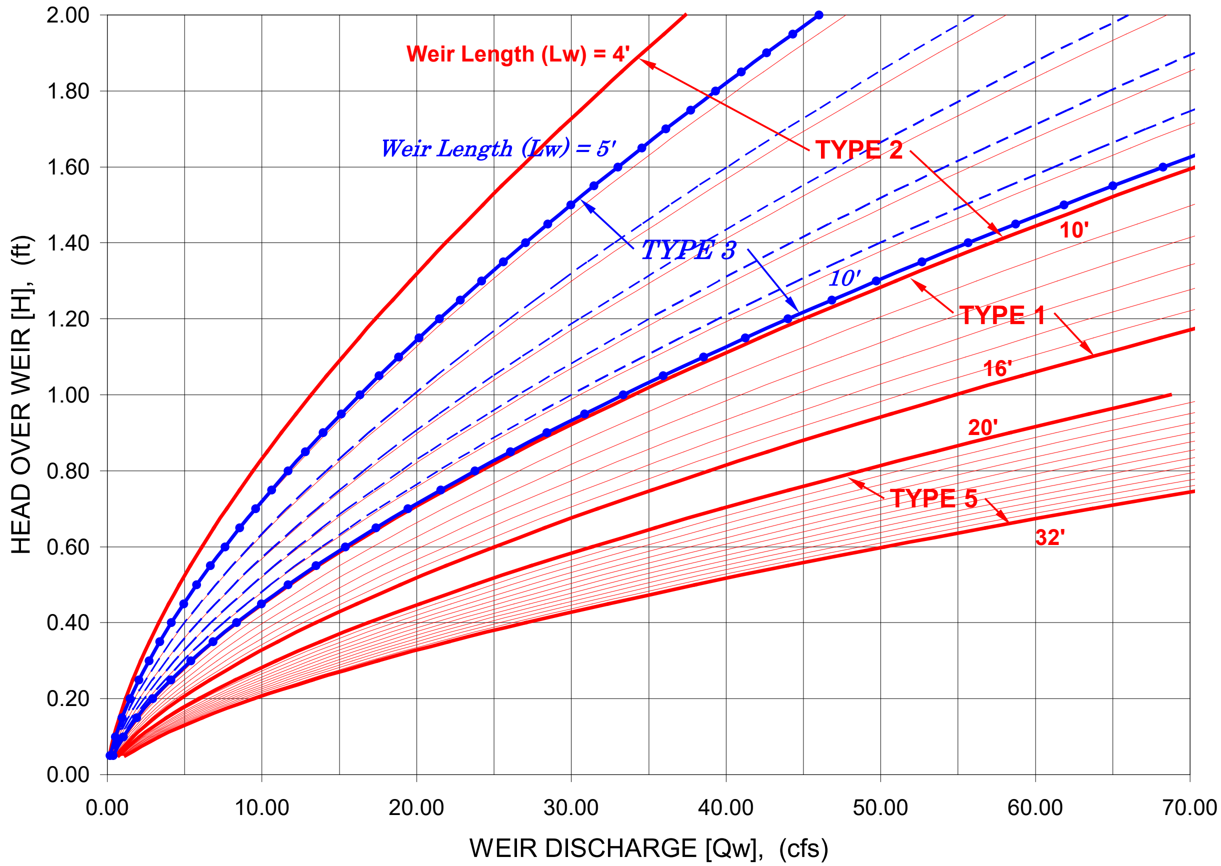

CHART A.6

WEIR RATING CURVES (UFS TYPE 3)

WEIR CREST HEIGHT (Hc)

Type 3: 11.0 FT

OTHERS: N/A