Chapter 3 Culvert Design

3-1 Introduction

A culvert is a closed conduit under a roadway or embankment used to maintain flow from a natural channel or drainage ditch. A culvert shall convey flow without causing damaging backwater, excessive flow constriction, or excessive outlet velocities.

In addition to determining the design flows and corresponding hydraulic performance of a particular culvert, other factors can affect the ultimate design of a culvert and shall be taken into consideration. These factors can include the economy of alternative pipe materials and sizes, horizontal and vertical alignment, environmental concerns, and necessary culvert end treatments.

In some situations, the hydraulic capacity may not be the only consideration for determining the size of a culvert opening. Fish passage requirements often dictate a different type of crossing from what would normally be used for hydraulic capacity. Wetland preservation may require upsizing a culvert or replacing a culvert with a bridge. Excessive debris potential may also require an increase in culvert size. Bridges and fish passage culverts are covered in more detail in Chapter 7 but require a PEO approved by the State Hydraulics Office to complete the design.

The design policy in this chapter applies only to culverts with non-fish-bearing channels. For culverts associated with fish-bearing channels, refer to Chapter 7.

Section 3-2 discusses the data acquisition and documentation required when designing culverts. Culvert design considerations are discussed in detail in Section 3-3, and various end treatments are discussed in Section 3-4. Section 3-5 covers other miscellaneous design considerations that have not been previously discussed.

3-2 Culvert Design Documentation

This section describes culvert design documentation, including hydraulic reports, required field data, and engineering analysis.

3-2.1 *Hydraulic Reports*

The PEO shall collect field data and perform an engineering analysis as described in Sections 3-2.2 and 3-2.3, respectively. Culverts in this size range shall be referred to on the contract plan sheets as “Schedule_________Culv. Pipe____in. Diam.” The PEO is responsible for listing all acceptable pipe alternatives based on site conditions. The decision regarding which type of pipe material is to be installed at a location will be left to the contractor unless a specific material type is called out in the plans and justification is provided in the hydraulic report. See Chapter 8 for a discussion on schedule pipe and acceptable alternatives.

Culverts larger than 48 inches in diameter or span will be included as part of a specialty report and are required to be designed by either the State Hydraulics Office or a licensed engineer approved by the State Hydraulics Office, as outlined in Chapter 1.

In addition to standard culvert design, the State Hydraulics Office can assist in the design of any unique culvert installation. The requirements for these structures will vary, and the State Hydraulics Office shall be contacted early in the design phase to determine what information will be necessary to complete the engineering analysis.

3-2.2 *Required Field Data*

Information and field data required to complete an engineering analysis for all new culvert installations or draining an area requiring a culvert shall be part of the hydraulic report and include the items that follow:

- Topographic map showing the contours and the outline of the drainage area
- Description of drainage area ground cover
- Fish passage requirement, if applicable; see Chapter 7
- Soils investigation per WSDOT's *Design Manual*
- Proposed roadway profile and alignment in the vicinity of the culvert
- Proposed roadway cross section at the culvert
- Corrosion zone location, pH, and resistivity of the site
- Investigate a sufficient distance upstream and downstream and any other unique features that can affect design, such as low-lying structures that could be affected by excessive headwater debris and anticipated sediment transport
- Other considerations discussed in Section 3-5

If an existing culvert does not have a history of problems and only needs to be extended or replaced, it is not necessary to gather all the information listed above to determine if it is adequately sized for the flows it receives. Attaining the history of problems at an existing culvert site may be sufficient to complete the analysis. Table 3-1 is a general outline showing the information and field data requirements for a hydraulic report and specialty report.

For culverts with spans between 4 and 20 feet, use the culvert design in this chapter. If the crossing requires fish-bearing design criteria and/or the span is greater than 20 feet, refer to Chapter 7 for further guidance.

Table 3-1 Field Data Requirements for Hydraulic Reports and Specialty Reports

Information and Field Data	New Culvert Site	Extending or Replacing	Specialty Report
Topographic survey	R	O	R
Ground cover description	R	O	R
Ground soil investigation	R	O	R
Proposed roadway profile and alignment	R	O	R
Proposed roadway cross section	R	O	R
Corrosion zone, pH, resistivity[a]	R[a]	O[a]	R[a]
Unique features	R	O	R

Notes:

O = optional.

R = required.

a. Required only if replacing with dissimilar material.

3-2.3 *Engineering Analysis*

Collected field data will be used to perform an engineering analysis. The intent of the engineering analysis is to ensure that the PEO considers several issues, including flow capacity requirements, foundation conditions, embankment construction, runoff conditions, soil characteristics, stream characteristics, potential construction problems, estimated cost, environmental concerns, and any other factors that may be involved and pertinent to the design. Additional analysis may be required, if a culvert is installed for flood equalization, to verify that the difference between the floodwater levels is less than 1 inch on either side of the culvert. The PEO should contact the State Hydraulics Office for further guidance on flood equalization. Other miscellaneous design considerations for culverts are discussed in Section 3-5.

Once the engineering analysis is completed, it will be part of the hydraulic report and shall include the following information:

1. Culvert hydrology and hydraulic calculations, as described in Section 3-3 and Table 3-2.
2. Proposed roadway stationing of the culvert location.
3. Culvert length.
4. Culvert diameter. The minimum diameter of culvert pipes under a main roadway shall be 18 inches. Culvert pipe under roadway approaches (i.e., driveway) shall have a minimum diameter of 12 inches.
5. Culvert material.
6. Headwater depths, WSELs, and flow rates (Q) for the design flow event (generally the 25-year event and the 100-year flow event).
7. Proposed roadway cross section and roadway profile, demonstrating the maximum and minimum height of fill over the culvert.

8. Appropriate end treatment as described in Section 3-4.
9. Hydraulic features of downstream controls, tailwater, or backwater (storage) conditions.

The information needed for replacement or extension of existing culverts is not the same as that required for new culverts (see Table 3-2). For a more detailed diagnostic about what is required for a specialty report for water crossings, see Chapter 7.

Table 3-2 Information for the Hydraulics and Specialty Reports for New Culverts and for Extending/Replacing Existing Culverts

Engineering Analysis Item	New Culvert Site	Extending or Replacing	Specialty Report
Culvert hydraulic and hydrology calculations	R	O	R
Roadway stationing at culvert	R	R	R
Culvert and stream profile	R	O	R
Culvert length and size	R	R	R
Culvert material	R	R	R
Hydraulic details	R	O	R
Proposed roadway details	R	O	R
End treatment	R	R	R
Hydraulic features	R	O	R

Notes:

O = optional.

R = required.

3-3 Hydraulic Design of Culverts

A complete theoretical analysis of the hydraulics of a particular culvert installation is time-consuming and complex. Flow conditions vary from culvert to culvert and can also vary over time for any given culvert. The barrel of the culvert may flow full or partially full depending upon upstream and downstream conditions, barrel characteristics, and inlet geometry. However, under most conditions, a simplified procedure is sufficient to determine the type of flow control and corresponding headwater elevation that exist at a culvert during the chosen design flow.

This section includes excerpts from FHWA's Hydraulic Design Series (HDS) 5, *Hydraulic Design of Highway Culverts*. The PEO should refer to the *Hydraulics Manual* for detailed information on the theory of culvert flow or reference an appropriate hydraulics textbook for unusual situations. The State Hydraulics Office is also available to provide design guidance.

The general procedure to follow when designing a culvert for a span width of less than 20 feet measured along the centerline of the roadway is summarized in the steps below. Culvert spans more than 20 feet wide measured along the centerline of the roadway are considered bridges and any hydraulic design for bridges is the responsibility of the State Hydraulics Office; see Section 3-3.1.2 for further guidance.

1. Calculate the culvert design flows (Section 3-3.1)
2. Determine the allowable headwater elevation (Section 3-3.2)
3. Determine the tailwater elevation at the design flow (Section 3-3.3)
4. Determine the type of control that exists at the design flow(s), either inlet control or outlet control (Section 3-3.4)
5. Calculate outlet velocities (Section 3-3.5)

3-3.1 *Culvert Design Considerations*

This section presents culvert design considerations.

3-3.1.1 Flow

The first step in designing a culvert is to determine the design flows to be used. The flow from the basin contributing to the culvert can be calculated using the methods described in Chapter 2. Generally, culverts will be designed to meet criteria for two flows: the 25-year event and the 100-year event. If fish passage is a requirement at a culvert location, contact the State Hydraulics Office (see Chapter 7). Guidelines for temporary culverts are described further in Section 3-3.1.9. The PEO will be required to analyze each culvert at each of the design flows, ensuring that the appropriate criteria are met.

3-3.1.2 Additional Requirement for Culverts over 20 Feet

Once a culvert exceeds 20 feet along the centerline of the roadway, it is defined as a bridge and all hydraulic analyses on bridges are the responsibility of the State Hydraulics Office (see Chapter 1). The federal definition of a bridge is a structure, including supports, erected over a depression or obstruction, such as water, highway, or railway, and having a track or passageway for carrying traffic or other moving loads with a clear span, as measured along the centerline of the roadway, equal to or greater than 20 feet. (i.e., a 16-foot culvert on a 45-degree skew is a bridge, a 10-foot culvert on a 60-degree skew is a bridge, and three 6-foot pipes 2 feet apart is a bridge).

The two primary types of hydraulic analysis performed on bridges are backwater and scour. As noted above, all hydraulic analysis of bridges is performed by the State Hydraulics Office or a hydraulics engineer approved by the State Hydraulics Office; however, it is the responsibility of the PEO to gather field information for the analysis. Chapter 7 contains more information about backwater and scour analysis, along with the PEO list of responsibilities.

3-3.1.3 Alignment and Grade

Culverts shall be placed on the same alignment and grade as the natural channel, especially on year-round streams. This tends to maintain the natural drainage system and minimize downstream impacts.

In many instances, it may not be possible or feasible to match the existing grade and alignment. This is especially true in situations where culverts are conveying only hillside runoff or streams with intermittent flow. If following the natural drainage course results in skewed culverts, culverts with horizontal or vertical bends, or excessive and/or solid rock excavation, it may be more feasible to alter the culvert profile or change the channel alignment upstream or downstream of the culvert. This is best evaluated on a case-by-case basis, with potential environmental and stream stability impacts being balanced with construction and function ability issues.

3-3.1.4 Allowable Grade

Concrete pipe may be used on any grade up to 10 percent. Corrugated metal pipe and thermoplastic pipe may be used on up to 20 percent grades. For grades over 20 percent, consult with the RHE or the State Hydraulics Office for design assistance.

3-3.1.5 Minimum Spacing

The use of multiple culvert openings is not allowed because of decreased efficiency and less room available to transport large woody material (LWM).

3-3.1.6 Culvert Extension

Whenever possible, culvert extensions shall be done in-kind—use the same pipe material and size and follow the existing slope. All culvert extensions shall follow the guidelines for the culvert sizes noted in Section 3-2.2 and Chapter 1. For in-kind extensions, the PEO shall follow the manufacturer's recommendations for joining pipe. For extensions of dissimilar material or box culverts, the PEO shall follow the guidelines below. For situations not listed, contact the RHE.

- Culvert pipe connections for dissimilar materials must follow Standard Plan B-60.20-02 of WSDOT's *Standard Plans*.
- For cast-in-place box culvert connections, contact the Bridge Design Office for rebar size and embedment.
- Precast box culvert connections must follow American Society for Testing and Materials (ASTM) C 1433, AASHTO M 259, M 273, and Standard Specification 6-02.3(28).

3-3.1.7 Minimum Culvert Diameter

The minimum diameter of a culvert under a main roadway must be 18 inches. Culvert pipe under roadway approaches must have a minimum diameter of 12 inches. If replacing an existing culvert, the new culvert shall have at least the same diameter as the existing culvert even if the hydraulic analysis shows that a smaller-diameter culvert would meet hydraulic design requirements in that location.

3-3.1.8 Culvert Pipe at Walls and Foundations

Culvert pipes placed within the reinforcement zone of walls or the soil-bearing zone of foundations should be coordinated with the geotechnical engineer.

3-3.1.9 Temporary Diversions

Temporary diversions for a single construction season shall be sized for the 2-year storm event, unless the PEO can provide hydrologic justification for a different storm event and receive State Hydraulics Office or RHE approval. The design storm for multiple-season construction projects shall be a risk-based decision and shall be determined by the PEO and RHE.

For design-build projects, the design and flow rate are determined by the design-builder based on the requirements of project permits.

For design-bid-build projects on fish-bearing streams, the State Hydraulics Office calculates the flow rates necessary for temporary diversions and that value is part of the contract documents. A conceptual-level plan is required for permits, but no plans for the temporary diversion system should be put into the final plan set and should not be documented in the specialty report, unless otherwise approved.

Temporary diversions for fish-bearing streams shall be designed for the following storm events:

- **Single season:** For a temporary diversion expected to be in place for a single fish window, the design flow rate shall be, at a minimum, equal to the expected 50 percent exceedance flow rate during the window when the temporary diversion is in place with a contingency plan that shall be in place within 2 hours or less to bring the system to meet the expected 10 percent exceedance flow rate during the window when the temporary diversion is in place. The expected flow rates during the window when the temporary diversion is in place can be determined through stream gage data (if available) or through an MGSFlood seasonal flow analysis (western Washington only). The flows can also be measured in the previous fish window years to get a base flow followed by an analysis for a 2-year storm based on rainfall for that fish window. If there are no data to calculate the flows during the construction window, then the expected 2-year flow rate shall be used for the design flow (contingency not necessary in this case) unless the PEO can justify a different flow if approved by the State Hydraulics Office.
- **Multiple season:** A gravity bypass is required if the stream diversion is expected to remain in place over the winter; pump bypasses will not be allowed. The culvert shall be the lesser of the size required to pass the 25-year flow event or that required to meet the existing culvert capacity. The length of the stream bypass contained within a culvert shall not be longer than the existing culvert unless otherwise approved by the State Hydraulics Office. Fish passage shall not be decreased from the existing conditions as evaluated by the *Fish Passage Inventory, Assessment, and Prioritization Manual.*

The design flood for temporary structures over water bodies shall be determined on a case-by-case basis by the State Hydraulics Office.

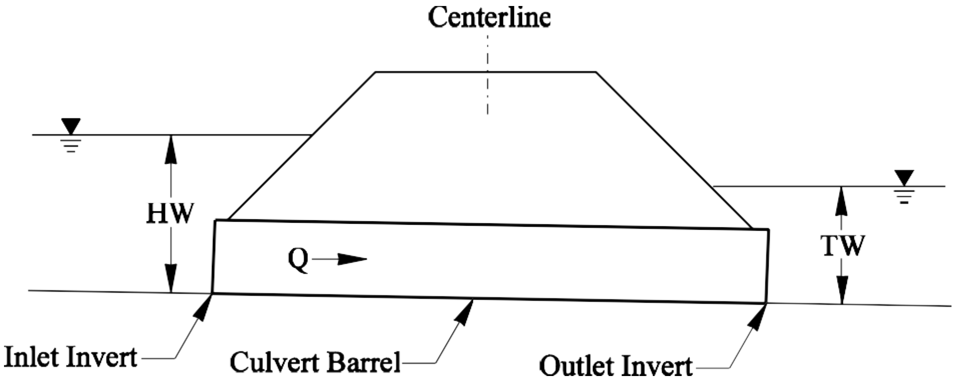
3-3.2 *Allowable Headwater*

This section presents hydraulic design criteria for allowable headwater for circular and box culverts and pipe arches and for bottomless culverts.

3-3.2.1 General

The depth of water that exists at the culvert entrance at a given design flow is referred to as the headwater. Headwater depth is measured from the invert of the culvert to the water surface, as shown in Figure 3-1. See the glossary for definitions.

Figure 3-1 Headwater and Tailwater Diagram



Limiting the amount of headwater during a design flow can be beneficial for several reasons. The potential for debris clogging reduces as the culvert size is increased. Maintenance is virtually impossible to perform on a culvert during a flood event if the inlet is submerged more than a few feet. Also, increasing the allowable headwater can adversely impact upstream property owners by increasing flood elevations. These factors must be taken into consideration and balanced with the cost-effectiveness of providing larger or smaller culvert openings.

If a culvert is to be placed in a stream that has been identified in a FEMA flood insurance study, the floodway and floodplain requirements for that municipality may govern the allowable amount of headwater. In this situation, the PEO shall contact the State Hydraulics Office for additional guidance.

3-3.2.2 Allowable Headwater for Circular and Box Culverts and Pipe Arches

Circular culverts, box culverts, and pipe arches shall be designed such that the ratio of the headwater (HW) to diameter (D) during the 25-year flow event is less than or equal to 1.25 (HW/D <1.25). HW/D ratios larger than 1.25 are permitted, provided that existing site conditions dictate or warrant a larger ratio. An example of this might be an area with high roadway fills, little stream debris, and no impacted upstream property owners. The justification for exceeding the HW/D ratio of 1.25 must be discussed with the State Hydraulics Office and, if approved by the RHE, included as a narrative in the hydraulic report.

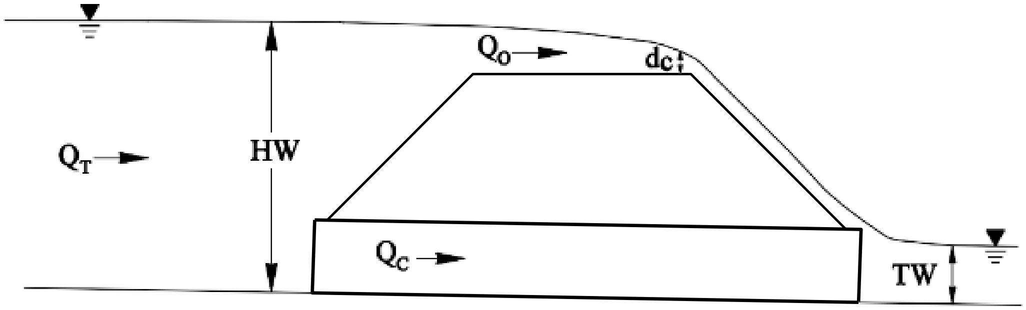
The headwater that occurs during the 100-year flow event must also be investigated. Two sets of criteria exist for the allowable headwater during the 100-year flow event, depending on the type of roadway over the culvert:

1. If the culvert is under an interstate or major state route that must be kept open during major flood events, the culvert must be designed such that the 100-year flow event can be passed without overtopping the roadway.
2. If the culvert is under a minor state route or other roadway, the culvert shall be designed such that there is no roadway overtopping during the 100-year flow event. However, there may be situations where it is more cost-effective to design the roadway embankment to withstand overtopping rather than provide a structure or

group of structures capable of passing the design flow. An example of this might be a low average daily traffic roadway with minimal vertical clearance that, if closed because of overtopping, would not significantly inconvenience the primary users.

Overtopping of the road will begin to occur when the headwater rises to the elevation of the road. The flow over the roadway will be similar to flow over a broad-crested weir, as shown in Figure 3-2. A methodology is available in HDS-5 to calculate the simultaneous flows through the culvert and over the roadway. The PEO must be mindful that the downstream embankment slope must be protected from the erosive forces that will occur. This can generally be accomplished with riprap reinforcement, but the State Hydraulics Office should be contacted for further design guidance. Additionally, the PEO should verify that the adjacent ditch does not overtop and transport runoff, causing damage to either public or private infrastructure.

Figure 3-2 Roadway Overtopping

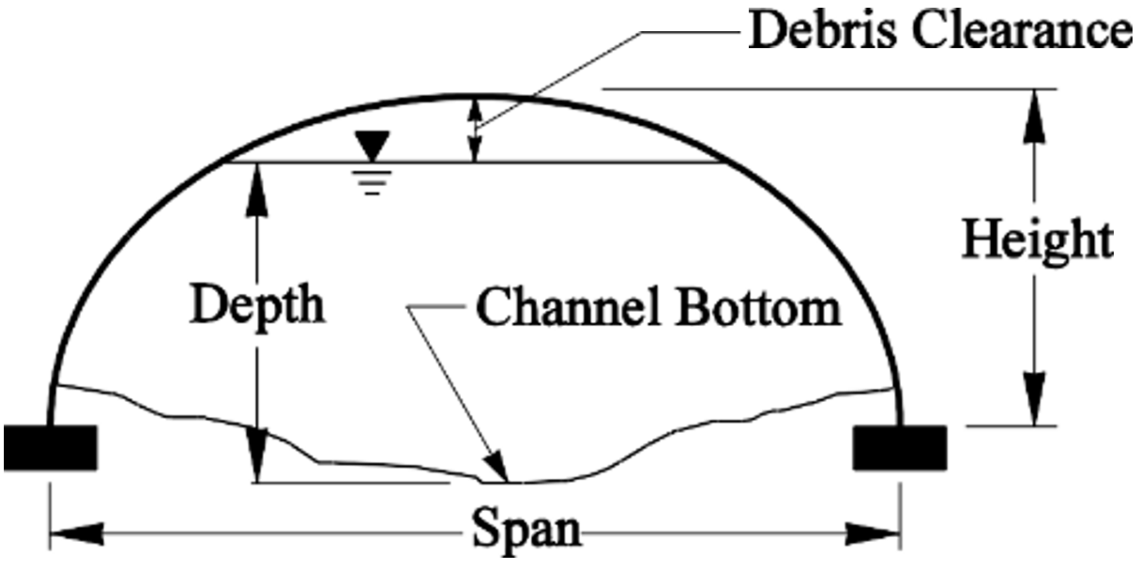


3-3.2.3 Allowable Headwater for Bottomless Culverts

Bottomless culverts with footings shall be designed such that 1 foot of debris clearance from the water surface to the culvert crown is provided during the 25-year flow event (see Figure 3-3). In many instances, bottomless culverts function similarly to bridges. They usually span the main channel and are designed to pass relatively large flows. If a large arch becomes plugged with debris, the potential for significant damage occurring to either the roadway embankment or the culvert increases.

Excessive headwater at the inlet can also increase velocities through the culvert and correspondingly increase the scour potential at the footings. Sizing a bottomless culvert to meet the 1-foot criterion will alleviate many of these potential problems. Bottomless culverts shall also be designed such that the 100-year event can be passed without the headwater depth exceeding the height of the culvert. Flow depths greater than the height can cause potential scour problems near the footings. A scour analysis shall be conducted for the footing.

Figure 3-3 Typical Bottomless Culvert



3-3.3 *Tailwater Conditions*

The depth of water that exists in the channel downstream of a culvert is referred to as the tailwater and is shown in Figure 3-1 above. Tailwater is important because it can affect the depth of headwater necessary to pass a given design flow. This is especially true for culverts that are flowing in outlet control, as explained in HDS-5. Generally, one of three conditions will exist downstream of the culvert and the tailwater can be determined as described below:

- If the downstream channel is relatively undefined and depth of flow during the design event is considerably less than the culvert diameter, the tailwater can be ignored. An example of this might be a culvert discharging into a wide, flat area. In this case, the downstream channel will have little or no impact on the culvert discharge capacity or headwater.
- If the downstream channel is reasonably uniform in cross section, slope, and roughness, the tailwater may affect the culvert discharge capacity or headwater. In this case, the tailwater can be approximated by solving for the normal depth in the channel using Manning's equation as described in Chapter 4.
- If the tailwater in the downstream channel is established by downstream controls, other means must be used to determine the tailwater elevation. Downstream controls can include such things as natural stream constrictions, downstream obstructions, or backwater from another stream or water body. If it is determined that a downstream control exists, a method such as a backwater analysis, a study of the stage-discharge relationship of another stream into which the stream in question flows, or the securing of data on reservoir storage elevations or tidal information may be involved in determining the tailwater elevation during the design flow. If a

field inspection reveals the likelihood of a downstream control, contact the State Hydraulics Office for additional guidance.

3-3.4 *Flow Type*

Refer to HDS-5 for in-depth discussions of culvert flow types.

3-3.5 *Velocities in Culverts: General*

A culvert, because of its hydraulic characteristics, generally increases the velocity of flow over that in a natural channel. High velocities are most critical just downstream from the culvert outlet and the erosion potential from the energy in the water must be considered in culvert design.

Culverts that produce velocities in the range of 3 to 10 feet per second (ft/s) tend to have fewer operational problems than culverts that produce velocities outside of that range. Varying the grade of the culvert generally has the most significant effect on changing the velocity, but because many culverts are placed at the natural grade of the existing channel, it is often difficult to alter this parameter. Other measures, such as changing the roughness characteristics of the barrel, increasing or decreasing the culvert size, or changing the culvert shape, must be investigated when it becomes necessary to modify the outlet velocity. Velocities less than 3 ft/s shall require a deviation from the State Hydraulics Office, thus needing approval from the RHE. Velocities more than 10 ft/s must be discussed with the RHE for potential solutions and final design exception approval by the RHE.

If velocities are less than about 3 ft/s, siltation in the culvert may become a problem. In those situations, it may be necessary to increase the velocity through the culvert or to provide oversized culverts. An oversized culvert will increase siltation in the culvert, but the larger size may prevent complete blocking and will facilitate cleaning. The PEO must consult with the RHE to determine the appropriate culvert size for this application.

If velocities exceed about 10 ft/s, abrasion due to bed load movement through the culvert and erosion downstream of the outlet can increase significantly. Abrasion is discussed in more detail in Chapter 8. Corrugated metal culverts may be designed with extra thickness to account for possible abrasion. Concrete box culverts and concrete arches may be designed with sacrificial steel inverts or extra slab thicknesses to resist abrasion. Thermoplastic pipe exhibits better abrasion characteristics than metal or concrete; see Chapter 8 for further guidance.

Adequate outlet channel or embankment protection must be designed to ensure that scour holes or culvert undermining will not occur. Energy dissipators can also be used to protect the culvert outlet and downstream property, as discussed in Section 3-4.7. Energy dissipators can significantly increase the cost of a culvert and should be considered only when required to prevent a large scour hole or as remedial construction.

Refer to HDS-5 for procedures used to calculate culvert velocities.

3-3.6 *Culvert Hydraulic Calculations Form*

Approval from RHE is required when using HDS-5 for culvert calculation forms, charts, and nomographs if using hand calculations for culvert design. However, the FHWA culvert design computer program HY-8 is the preferred WSDOT design method.

3-3.7 *Computer Programs*

Once familiar with culvert design theory as presented in this chapter, the PEO shall use one of several commercially available culvert design software programs. FHWA has developed a culvert design program named HY-8 that uses the same general theory presented in this chapter. HY-8 is a user-friendly, Windows-based software, and the output from the program can be printed and incorporated directly into the hydraulic report. HY-8 is free software distribution. It is available by contacting either the RHE or the State Hydraulics Office at the following link.

In addition to being user-friendly, HY-8 is advantageous in that the headwater elevations and outlet velocities calculated by the program tend to be more accurate than the values calculated using the methods presented in this chapter. HY-8 computes an actual water surface profile through a culvert using standard step-backwater calculations. The methods in this chapter approximate this approach but make several assumptions to simplify the design. HY-8 also analyzes an entire range of flows input by the user. For example, the program will simultaneously evaluate the headwater created by the Q25 and Q100 flow events, displaying all the results on one screen. This results in a significantly simplified design procedure for multiple flow applications. The HY-8 program contains a help guide accessed internally to aid in the system's operations. Additional guidance will be provided in future revisions to the *Hydraulics Manual*.

3-3.8 *Example*

Refer to HDS-5 for example culvert calculations.

3-4 Culvert End Treatments

The type of end treatment used on a culvert depends on many interrelated and sometimes conflicting considerations. The PEO must evaluate safety, aesthetics, debris capacity, hydraulic efficiency, scouring, and economics. Each end condition may serve to meet some of these purposes, but none can satisfy all these concerns. The PEO must use good judgment to arrive at a compromise as to which end treatment is most appropriate for a specific site. Treatment for safety is discussed in WSDOT's *Design Manual*.

Several types of end treatments are discussed in this section. The type of end treatment chosen for a culvert shall be specified in the hydraulic report and the contract plans for each installation.

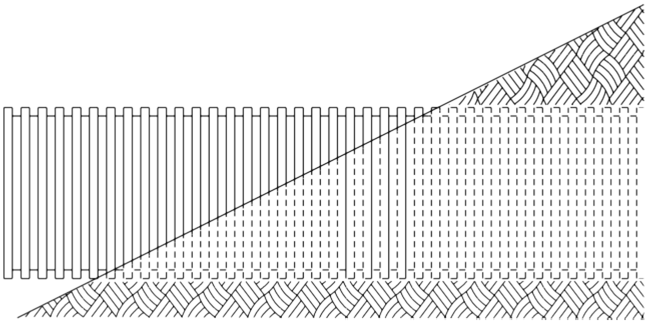
3-4.1 *Projecting Ends*

A projecting end is a treatment where the culvert is allowed to protrude out of the embankment (see Figure 3-4). The primary advantage of this type of end treatment is that it is the simplest and most economical of all treatments. Projecting ends also provide excellent strength characteristics because the pipe consists of a complete ring structure out to the culvert end.

Projecting ends have several disadvantages. For metal, the thin wall thickness does not provide flow transition into or out of the culvert, significantly increasing head losses (the opposite is true for concrete; the thicker wall provides a more efficient transition). From an aesthetic standpoint, projecting ends may not be desirable in areas exposed to public view. They should be used only when the culvert is located in the bottom of a ravine or in rural areas.

Modern safety considerations require that no projecting ends be allowed in the designated clear zone. (See WSDOT's *Design Manual* for details on the clear zone and for methods that allow a projecting end to be used close to the traveled roadway.)

Figure 3-4 Projecting End



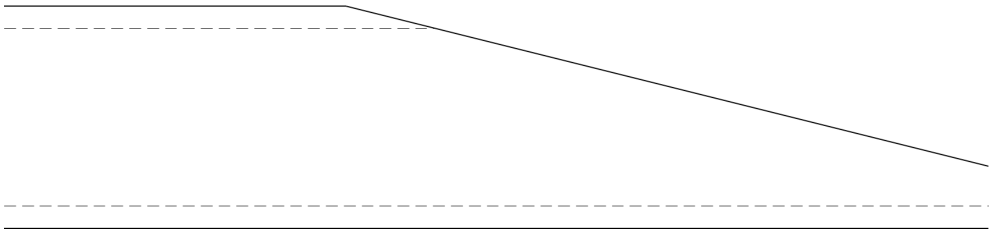
Metal culverts exceeding 6 feet in diameter but less than 10 feet in diameter, and all thermoplastic culverts, must be installed with a beveled end and a concrete headwall or slope collar as described in Sections 3-4.2 and 3-4.4. Concrete pipe will not experience buoyancy problems and can be projected in any diameter. However, because concrete pipe is fabricated in relatively short 6- to 12-foot sections, the sections are susceptible to erosion and corresponding separation at the first joint from the end.

3-4.2 *Mitered End Sections*

A mitered end treatment consisting of cutting the end of the culvert at an angle to match the embankment slope surrounding the culvert is referred to as a flush bevel. This type of bevel is preferred over others because of increased efficiency and reduced impact on the surrounding environment. For more information about bevels see HDS-5. A typical bevel schematic is shown on Standard Plan B-70.20-00 and in Figure 3-5. A beveled end provides a hydraulically more efficient opening than a projecting end, is relatively cost-effective, and is generally considered to be aesthetically acceptable.

Cutting the ends of a corrugated metal or plastic culvert structure to an extreme skew or bevel to conform to the embankment slope destroys the ability of the end portion of the structure to act as a ring in compression. Headwalls, riprap slopes, slope paving, or stiffening of the pipe may be required to stabilize these ends. In these cases, special end treatment shall be provided if needed. The State Hydraulics Office can assist in the design of special end treatments.

Figure 3-5 Beveled End Section



3-4.3 *Flared End Sections*

A metal flared end section is a manufactured culvert end that provides a simple transition from culvert to channel. Flared end sections allow flow to smoothly constrict into a culvert entrance and then spread out at the culvert exit as flow is discharged into the natural channel or watercourse. Flared ends are generally considered aesthetically acceptable because they serve to blend the culvert end into the finished embankment slope.

Flared end sections are used only on circular pipe or pipe arches. The acceptable size ranges for flared ends and other details are shown on Standard Plan B-70.60-01 for Flared End Sections. Flared ends are generally constructed out of steel and aluminum and should match the existing culvert material, if possible. However, either type of end section can be attached to concrete or thermoplastic pipe and the contractor should be given the option of furnishing either steel or aluminum flared end sections for those materials.

A flared end section is usually the most feasible option in smaller pipe sizes and should be considered for use on culverts up to 48 inches in diameter. For diameters larger than 48 inches, end treatments such as concrete headwalls tend to become more economically viable than flared end sections.

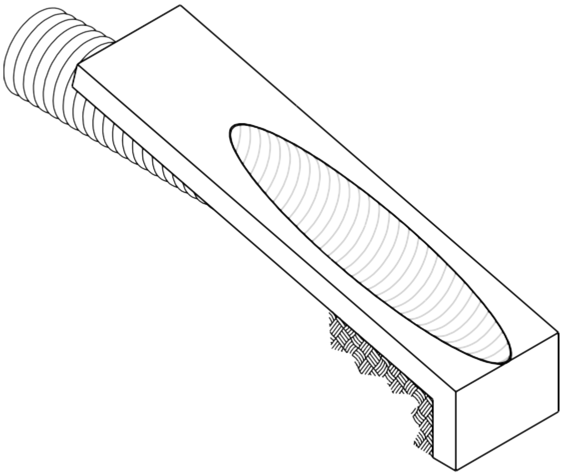
The undesirable safety properties of flared end sections generally prohibit their use in the clear zone for all but the smallest diameters (see WSDOT's *Design Manual* for culvert design). A flared end section is made of light-gage metal and, because of the overall width of the structure, it is not possible to modify it with safety bars. When the culvert end is within the clear zone and safety is a consideration, the PEO must use a tapered end section with safety bars as shown on *Standard Plans* B-80.20-00 and B-80.40-00. The tapered end section is designed to match the embankment slope and allow an errant vehicle to negotiate the culvert opening in a safe manner.

3-4.4 *Headwalls*

A headwall is a concrete frame poured around a beveled culvert end. It provides structural support to the culvert, eliminates the tendency for buoyancy and provides inlet and outlet protection. A headwall is a required end treatment for all culverts that range in size from 4 to 10 feet. Contact the RHE for direction on headwalls required for culverts smaller than 4 feet. Headwalls shall be used on all thermoplastic culverts, 30 inches in diameter and larger. A typical headwall is shown on *Standard Plans* B-75.20-03 or in Figure 3-6. When the culvert is within the clear zone, the headwall design can be modified by adding safety bars. *Standard Plans* B-75.50-01 and B-75.60-00 provide the details for attaching safety bars.

The PEO is cautioned not to use safety bars on a culvert where debris may cause plugging of the culvert entrance even though the safety bars may have been designed to be removed for cleaning purposes. When the channel is known to carry debris, the PEO shall provide an alternative solution to safety bars, such as increasing the culvert size or providing guardrail protection around the culvert end.

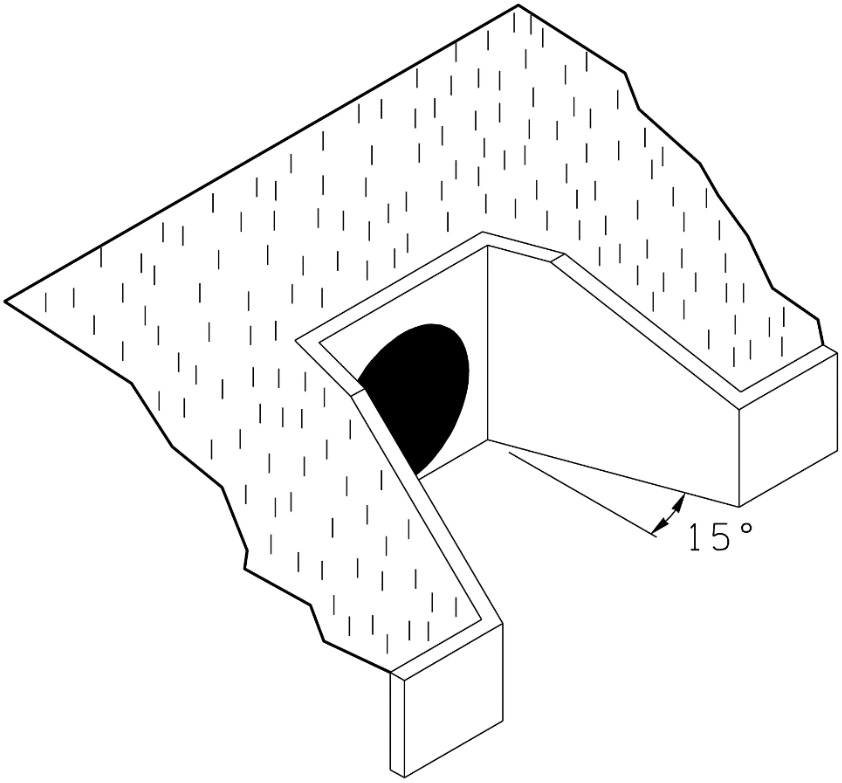
Figure 3-6 Headwall



3-4.5 *Wing Walls and Aprons*

Wing walls and aprons are required with reinforced concrete box culverts and other types of buried structures. Wing Walls shall be a minimum of 10 feet in length and shall be increased based on the potential impacts of lateral migration as assessed by the hydraulics engineer of record. In lieu of using wing walls, box culvert extensions may be acceptable if site conditions are suitable and the State Hydraulics Office agrees that they do not have a negative effect on the stream function. Their purpose is to retain and protect the embankment and provide a smooth transition between the culvert and channel. Normally, they consist of flared vertical wing walls, a full or partial apron, and bottom and side cutoff walls (to prevent piping and undercutting). Wing walls may also be modified for use on circular culverts in areas of severe scour problems (Figure 3-7). The apron will provide a smooth transition for the flow as it spreads to the natural channel. When a modified wing wall is used for circular pipe, the PEO must address the structural details involved in the joining of the circular pipe to the square portion of the wing wall. The State Hydraulics Office can assist in this design.

Figure 3-7 Modified Wing Wall for Circular Pipe



3-4.6 *Improved Inlets*

When the head losses in a culvert are critical, the PEO may consider the use of a hydraulically improved inlet. Contact the RHE for guidance when considering using a hydraulically improved inlet. These inlets provide side transitions as well as top and bottom transitions that have been carefully designed to maximize the culvert capacity with the minimum amount of headwater; however, the design and form construction costs can become quite high for hydraulically improved inlets. For this reason, their use is not encouraged in routine culvert design. It is usually less expensive to simply increase the culvert diameter by one or two sizes to achieve the same or greater benefit.

Certain circumstances may justify the use of an improved inlet. When complete replacement of the culvert is too costly, an existing inlet-controlled culvert may have its capacity increased by an improved inlet. Improved inlets may also be justified in new construction when the length of the new culvert is long (more than 500 feet) and the headwater is controlled by inlet conditions. Improved inlets may have some slight advantage for barrel- or outlet-controlled culverts, but usually not enough to justify the additional construction costs. If the PEO believes that a site might be suitable for an improved inlet, the RHE shall be contacted. Also, HDS-5 contains a significant amount of information related to the design of improved inlets.

3-4.7 *Energy Dissipators*

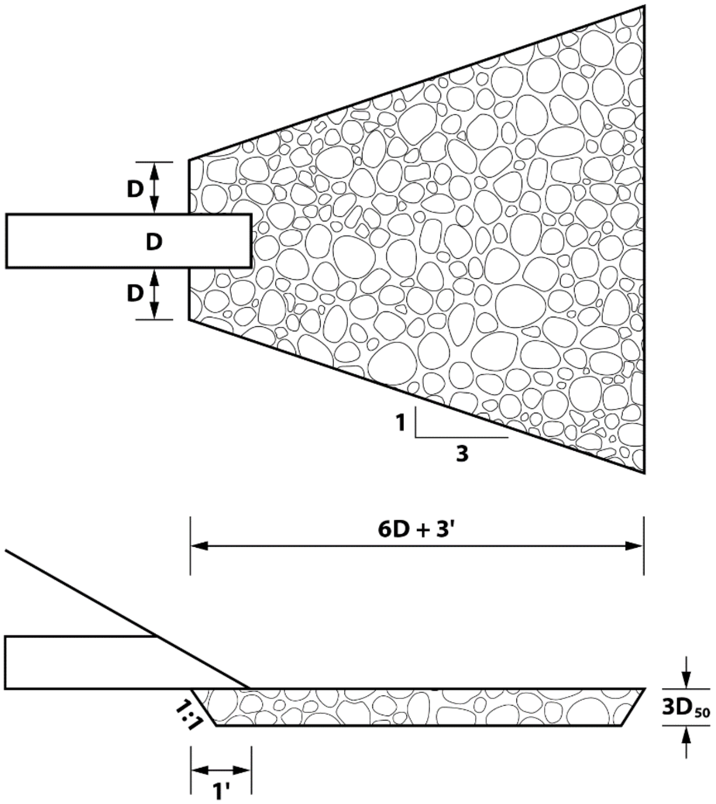
When the outlet velocities during the design-year storm event are 5 ft/s or greater, the PEO shall use an energy dissipator. Energy dissipators can be quite simple or very complex, depending on site conditions. Debris and maintenance problems should be considered when designing energy dissipators.

Energy dissipators include:

- Rock-protected outlets

  Rock is frequently hand placed around the outlet end of culverts to protect against the erosive action of the water (Figure 3-8). The material size at the outlet is dependent on the outlet velocity as determined using a full flow analysis as noted in Table 3-3. The limits of this protection would cover an area that would be vulnerable to scour holes. As an alternative to using Figure 3-8 and Table 3-3, the Hydraulic Toolbox calculator, which can be downloaded from FHWA's website, can be used to determine the area of the scour protection and the size of the riprap. Refer to Table 4-2 for the class of rock or riprap to be used. The calculation results need to be included in the Hydraulic Report. (See Section 3-4.5 for details on wing walls and aprons.)

Figure 3-8 Rock-Protected Outlet



Note: Evaluate need to extend splash pad made to suit site conditions.

Table 3-3 Outlet Protection Material Size

Outlet Velocity (ft/s)	Material
Up to 7	Quarry spalls
7–10	Rock for erosion and scour protection Class A
10–15	Rock for erosion and scour protection Class B
>15	Rock for erosion and scour protection Class C

Note:

The outlet velocities are based on full flow calculations. The PEO should provide filter fabric such as construction geotextile for permanent erosion control between the riprap protection and the existing ground for soil stabilization. In lieu of using geotextile, granular filter blanket can also be used with the gradation determined in accordance with FHWA's HEC-15. The gradation of the existing ground or base soil should be known to size the granular filter blanket.

- Other energy-dissipating structures

  Other structures include impact basins and stilling basins/wells designed according to the FHWA's HEC-14, "Hydraulic Design of Energy Dissipators for Culverts and Channels." These structures may consist of baffles, posts, or other means of creating roughness to dissipate excessive velocity. The State Hydraulics Office shall be consulted to assist in the design of these types of structures.

Energy dissipators have a reputation for collecting debris on the baffles, so the PEO should consider this possibility when choosing a dissipator design. In areas of high debris, the dissipator should be kept open and easily accessible to maintenance crews. Provisions should be made to allow water to overtop without causing excessive damage.

3-4.8 *Culvert Debris*

Debris problems can cause even an adequately designed culvert to experience hydraulic capacity problems. Debris may consist of anything from limbs and sticks to logs and trees. Silt, sand, gravel, and boulders can also be classified as debris. The culvert site is a natural place for these materials to settle and accumulate. No method is available for accurately predicting debris problems. Examining the maintenance history of each site is the most reliable way of determining potential problems. Sometimes, upsizing a culvert is necessary to enable it to more effectively pass debris. Upsizing may also allow a culvert to be more easily cleaned. The PEO must consult with the RHE for guidance on potential culvert debris issues.

3-5 Miscellaneous Culvert Design Considerations

This section presents miscellaneous culvert design considerations, including multiple culvert openings, camber, horizontal and vertical angle points, upstream ponding, and siphons.

3-5.1 *Multiple Culvert Openings*

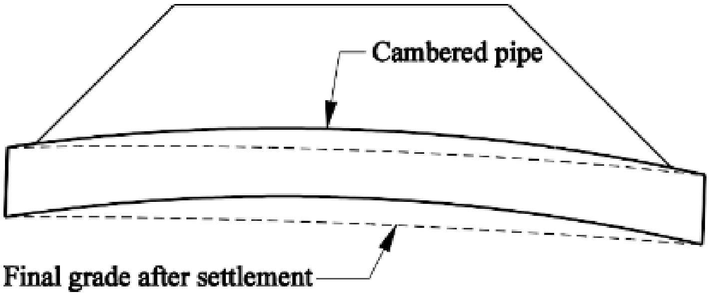
The use of multiple culvert openings is not allowed for a single water crossing. Multiple culvert openings have decreased efficiency and have less room available to transport LWM and sediment opposed to a single large hydraulic opening.

3-5.2 *Camber*

When a culvert is installed under moderate to high fills 30 to 60 feet or higher, greater settlement of the fill may occur under the center of the roadway than at the sides. This occurs because at the culvert ends there is little fill while the centerline of the roadway contains the maximum fill. The difference in surcharge pressure at the elevation of the culvert may cause differential settlement of the fill and can create a low point in the culvert profile. To correct for the differential settlement, a culvert can be constructed with a slight upward curve in the profile, or camber, as shown in Figure 3-9. This is determined by the HQ geotech.

The camber is built into the culvert during installation by laying the upstream half of the culvert on a flat grade and the downstream half on a steeper grade to obtain the design grade after settlement. The amount of expected camber can be determined by the HQ Materials Laboratory and must be shown on the appropriate profile sheet in the contract plans.

Figure 3-9 Camber under High Fills



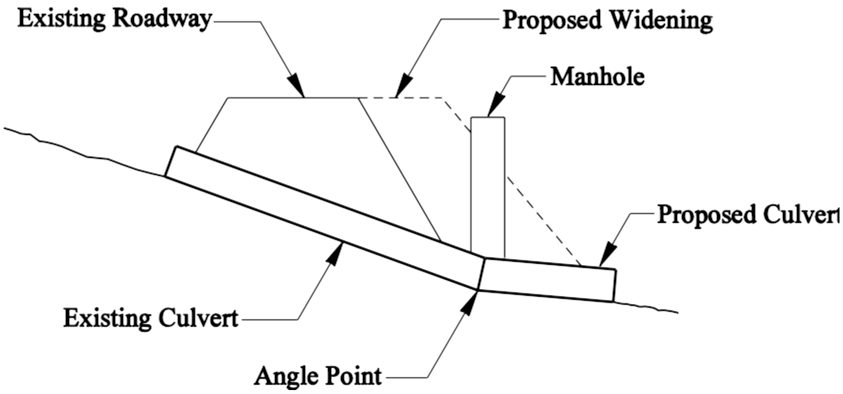
3-5.3 *Horizontal and Vertical Angle Points*

The slope of a culvert shall remain constant throughout the entire length of the culvert. This is generally easy to accomplish in new embankments. However, in situations where existing roadways are to be widened, it may be necessary to extend an existing culvert at a different slope. The location where the slope changes is referred to as the angle point.

If the new culvert is to be placed at a flatter grade than the existing culvert, a manhole shall be incorporated into the design at the angle point, as shown in Figure 3-10. The PEO shall contact the RHE regarding the incorporation of a manhole. The change in slope tends to create a location in the culvert that will catch debris and sediment. Providing access with a manhole will facilitate culvert maintenance.

If the new culvert is to be placed at a steeper slope than the existing culvert, the manhole can be eliminated at the angle point if debris and sedimentation have not historically been a concern at the existing culvert.

Figure 3-10 Culvert Angle Point



3-5.4 *Upstream Ponding*

The culvert design methodology presented in Section 3-3 assumes that the headwater required to pass a given flow through a culvert will be allowed to fully develop upstream of the culvert inlet. Any peak flow attenuation provided by ponding upstream of the culvert inlet is ignored. If a large enough area upstream of the inlet is available for ponding, the design headwater will not occur, and the culvert will not pass the full design flow. However, by ignoring any ponding effects, the culvert design is simplified, and the final results are conservative. Most culverts should be designed using these assumptions.

If it is determined that the ponding characteristics of the area upstream of the inlet need to be taken into consideration, the calculation of flow becomes a flood routing problem, which entails a more detailed study. Essentially, the area upstream of the inlet acts as a detention pond and the culvert acts as an outlet structure. The culvert can be designed using flood-routing concepts similar to designing a stormwater detention pond, but that methodology is beyond the scope of the *Hydraulics Manual*. Because the need for this type of culvert design is rare, the RHE shall be contacted for further assistance.

3-5.5 *Miscellaneous Design Considerations: Siphons*

Siphon designs require review and concurrence by the State Hydraulics Office per Table 1-1. Also, the siphon design may need to be reviewed and approved by the owner of the features being crossed. A siphon carries the flow under an obstruction such as a depressed railroad, roadway, stream, sanitary sewer, water main, or any other structure or utility line that is in the path of the storm drain line. The storm drain invert is lowered at the obstacle and is raised again after the crossing. The siphon will remain full when there is no flow. AASHTO recommends a minimum of two barrels with 3 ft/s velocity. One of the barrels is designed to have a weir-type obstruction placed at the inlet and outlet structures to keep the normal flow in one barrel to provide the required minimum velocity for self-cleaning and servicing. The elevation of the weir crests is based on the depth of normal flows in the upstream storm drain. Maintenance access is to be provided at both the inlet and outlet chambers. Figure 3-11 illustrates a typical twin-barrel inverted siphon.

The following considerations from HEC-22, Chapter 6 (1) are important to the efficient design of siphons:

- Self-flushing velocities should be provided under a wide range of flows
- Hydraulic losses should be minimized
- Provisions for cleaning should be provided
- Sharp bends should be avoided
- The rising portion of the siphon should not be so steep as to make it difficult to flush deposits (some agencies limit the rising slope to 15 percent)
- There should be no change in pipe diameter along the length of the siphon
- Provisions for drainage should be considered

Additional information related to the design of siphons is provided in HEC-22 (1) and United States Bureau of Reclamation (USBR) Design of Small Canal Structures (6), which includes a design example.

Figure 3-11 Typical Twin-Barrel Inverted Siphon