

Chapter 7

Culverts



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Table of Contents

7.1 Introduction 7

7.2 Culvert Design Software 7

7.3 Deviations from Design Standards 8

7.4 Culvert Design Documentation 8

7.4.1 Hydraulic Reports and Memos 8

7.5 Hydraulic Design of Culverts..... 9

7.5.1 Culvert Design Considerations..... 9

 7.5.1.1 Site Risk Assessment..... 10

 7.5.1.2 Alignment and Grade..... 11

 7.5.1.3 Horizontal Alignment 12

 7.5.1.4 Skewed Culverts..... 12

 7.5.1.5 Vertical Alignment..... 15

 7.5.1.6 Minimum Culvert Size 19

 7.5.1.7 Culvert Barrel Material and Shape 20

 7.5.1.8 Culvert End Treatments and Extensions 20

 7.5.1.9 Multiple Culverts Openings..... 20

 7.5.1.10 Fire Design Measures..... 21

 7.5.1.11 Debris 22

 7.5.1.12 Piping 23

 7.5.1.13 Pipe Buoyancy..... 23

 7.5.1.14 Camber 27

 7.5.1.15 Temporary Culverts 28

7.5.2 Culvert Design and Analysis..... 28

7.5.3 Alternative Analysis and Design..... 29

7.5.4 Allowable Headwater..... 30

 7.5.4.1 FEMA Regulations..... 31

 7.5.4.2 Flood Event Design..... 31

 7.5.4.3 Check Flood Event 31

7.5.4.4	Roadway Overtopping.....	32
7.5.5	Tailwater Conditions.....	33
7.5.6	Performance Curves.....	34
7.5.7	Flow Regimes.....	35
7.5.7.1	Critical Depth.....	36
7.5.8	Flow Control Types.....	38
7.5.9	Inlet Control.....	39
7.5.9.1	Inlet Control Hydraulics.....	40
7.5.9.2	Inlet Control Performance.....	41
7.5.10	Outlet Control.....	42
7.5.10.1	Outlet Control Hydraulics.....	43
7.5.11	Outlet Velocities.....	48
7.5.12	Culvert Hydraulic Form and Nomographs.....	48
7.6	Culvert End Treatments.....	49
7.6.1	Clear Zone End Treatments.....	50
7.6.2	Headwalls with Bevels.....	50
7.6.3	Mitered End Section.....	50
7.6.4	Cut-off Walls.....	51
7.6.5	Projecting Ends.....	51
7.6.6	Prefabricated.....	52
7.6.7	Improved Inlets.....	52
7.6.8	Tide Gates.....	53
7.7	Specialized Culverts.....	53
7.7.1	Fish passage.....	53
7.7.2	Long Span Culverts.....	53
7.7.3	Slope Pipes.....	53
7.7.4	Broken Back Culverts.....	54
7.7.5	Sag Culvert.....	55
7.8	Abandoned Culvert Guidelines.....	55

7.9 Culvert Identification Markers 57

7.9.1 Type 1 Culvert Marker 58

7.9.2 Type 2 Culvert Marker 58

7.9.3 Culvert DFI Parameters..... 58

7.9.4 Requesting a Culvert DFI..... 59

7.10 References..... 60

List of Figures

Figure 7 - 1 Skewed Culverts.....	12
Figure 7 - 2 Channel Bends.....	14
Figure 7 - 3 Design Profile.....	15
Figure 7 - 4 Geomorphic Transitions.....	17
Figure 7 - 5 Vertical Adjustment – Incised Channel.....	18
Figure 7 - 6 U.S. 395 - Canyon City Fire, 2015.....	22
Figure 7 - 7 Weight of Soil.....	26
Figure 7 - 8 Free Body Diagram.....	26
Figure 7 - 9 Pipe Camber.....	27
Figure 7 - 10 Headwater Elevation.....	30
Figure 7 - 11 Roadway Embankment Overtopping.....	32
Figure 7 - 12 Overtopping I-84, Region 5 yr. 2020.....	33
Figure 7 - 13 Performance Curve.....	34
Figure 7 - 14 Performance Curve with Roadway Overtopping.....	35
Figure 7 - 15 Critical Depth – Inlet Control.....	37
Figure 7 - 16 USGS Inlet Control Flow Type 1 – Unsubmerged Inlet.....	39
Figure 7 - 17 USGS Inlet Control Flow Type 5 – Submerged Inlet.....	39
Figure 7 - 18 Inlet Control Curve.....	40
Figure 7 - 19 Beveled Edges.....	41
Figure 7 - 20 Entrance Contraction.....	42
Figure 7 - 21 USGS Outlet Control Flows – Unsubmerged Inlet.....	42
Figure 7 - 22 USGS Outlet Control Flow Types – Submerged Inlet.....	43
Figure 7 - 23 Full flow EGL and HGL.....	45
Figure 7 - 24 Free Surface Flow.....	48
Figure 7 - 25 Partial Full Flow.....	48
Figure 7 - 26 Mitered Collar.....	50
Figure 7 - 27 CMP Flared-End.....	52
Figure 7 - 28 Cleanout Gate and Slope Pipe.....	54

Figure 7 - 29 Broken Back Culverts 54
Figure 7 - 30 Guidelines for Culvert Abandonment 57

List of Tables

Table 7 - 1 Hydraulic Reporting Requirements 9
Table 7 - 2 Culvert Design Considerations 10
Table 7 - 3 Site Assessment Key Factors 11
Table 7 - 4 Alignment Attributes and Hydraulic Effects 13
Table 7 - 5 Minimum culvert sizes 19
Table 7 - 6 Minimum culvert size based on fill heights 20
Table 7 - 7 Post Fire Design 21
Table 7 - 8 Buoyancy Analysis 24
Table 7 - 8 Buoyancy Mitigation Measures 27
Table 7 - 9 Require Hydraulic Analysis 28
Table 7 - 10 Culvert Design Procedures 29
Table 7 - 11 Alternative Analysis Factors 30
Table 7 - 12 Design Flood Allowable Headwater Criteria 31
Table 7 - 13 Check Flood Allowable Headwater Criteria 32
Table 7 - 14: Water Surface Profile Method 34
Table 7 - 15 Factors Influencing Culvert Design 38
Table 7 - 16 Entrance Loss Coefficients 46
Table 7 - 17 End Treatment Design Policy 49
Table 7 - 18 Potential Impacts 55
Table 7 - 19 DFI Parameters 59
Table 7 - 20 Culvert DFI Information 60

7.1 Introduction

The culvert chapter covers the key design principles for culverts, including design considerations, hydraulic analysis, hydraulic capacity, and performance in accordance with established standards and policies. These standards are based on both state and federal guidelines, ensuring that culverts meet safety, environmental, and performance requirements. The methodology is intended for use by those with an understanding of hydrologic and hydraulic methods and experience in the design of hydraulic structures.

A culvert is a closed conduit designed to convey water along and/or beneath the highway system, or past flow obstructions. Proper culvert design is essential to ensure efficient water flow, prevent roadway flooding, and protect the surrounding properties and the environment.



Sections marked with this icon indicate a Required Design Policy. These policies are mandatory and must be followed in all designs. The icon serves as a visual reminder to highlight design requirements.

Additionally, hydraulic capacity may not be the only consideration in sizing of a culvert. Consider potential impact on surrounding properties, post wildfire hydrological responses, and fish passage. Give special attention to wetlands and estuaries where designs must minimize disruption to natural water flow and support ecosystem health. For culvert design associated with fish-bearing channels refer to the [Fish Passage Chapter](#).

7.2 Culvert Design Software

There are three FHWA approved software programs for the evaluation and design of culverts on ODOT projects. ODOT utilizes FHWA's HY-8 software as the standard tool for culvert analysis and design.

HY-8 provides detailed hydraulic analysis for a range of culvert types and configurations, allowing for thorough evaluation of performance under various flow conditions. The program calculates key parameters such as headwater and tailwater elevations, inlet and outlet velocities, and a water surface profile through the culvert using standard step-backwater calculations. For overtopping analysis, HY-8 balances the culvert discharge and the surcharge over the roadway. HY-8 performs culvert hydraulic analyses based on the procedures outlined in [Hydraulic Design of Highway Culverts: HDS-5](#) ensuring compliance with established hydraulic design standards.

U.S. Bureau of Reclamation, in collaboration with FHWA developed SRH-2D which is useful for culvert design and analysis. SRH-2D is best used in complex projects involving floodplain interaction and overland flow analysis. HY-8 is coupled with SRH-2D allowing 1D culvert modeling within the 2D framework.

U.S. Corps of Engineers HEC-RAS program can also analyze culvert flow. HEC-RAS is useful for fish passage projects modeling water surface profiles, velocities, and analyzing sediment transport and retention in the culvert.

7.3 Deviations from Design Standards

Design deviations from the standards and requirements of this chapter require approval by the State Hydraulic Engineer. The deviation must provide justification and supporting documentation that the proposed alternative is designed in accordance with acceptable engineering practices. The following is a list of common deviations from standards:

- Reducing design and/or check flood
- Replacement “in-kind” without hydraulic analysis
- Exceeding allowable headwater and/or overtopping of roadway
- Not meeting culvert minimum size requirements
- Installation of sag culvert under the highway
- Installation of permanent multiple culvert openings
- Eliminating end treatment requirements
- Eliminating or reducing embankment scour protection
- Use of unapproved culvert analysis software

Follow procedures for submitting design deviations outlined in [Policy Chapter](#). Obtain the hydraulics design deviation approvals as early as possible and prior to the design acceptance package (DAP).

7.4 Culvert Design Documentation



Hydraulic documentation is essential for recording engineering recommendations and providing information required for planning, environmental review, subsequent design phases, and quality control. The [Policy Chapter](#) provides detailed guidance on documentation and procedures and refers to other reference documents such as the [Hydraulic Engineering QA/OC Work Plan](#).

7.4.1 Hydraulic Reports and Memos



Hydraulic reports serve as a comprehensive documented record containing the engineering justification and recommendations. These reports contain in-depth analysis, modeling, and recommendations for culvert installations and modifications resulting from projects.

A Hydraulic Design Summary (HDS) Memo is a concise, less formal document that communicates key findings or updates from hydraulic analysis or design. This memo summarizes project engineering decisions and results without the need for a full, detailed

hydraulic report. Table 7-1 outlines reporting requirements by project type and level of hydraulic analysis. Depending on project complexity, select the appropriate documentation.

Table 7 - 1 Hydraulic Reporting Requirements

Culvert Project	HDS Memo	Report
New culvert installations	✗	✓
Culvert replacements	✗	✓
Culverts in tidal influenced areas	✗	✓
Culverts within a floodplain or floodway	✗	✓
Culvert extensions - all	✓	✓
Culvert rehabilitation / repair	✓	✓
Replacement / end treatment modification	✓	✓

7.5 Hydraulic Design of Culverts

A complete theoretical analysis of culvert flow is complex as the flow is usually nonuniform with regions of both gradually and rapidly varying flow. An accurate analysis involves backwater and drawdown calculations, energy and momentum balance, and application of the results of hydraulic model studies. With the complexities involved in culvert analysis, FHWA developed a more simplified method described in [HDS-5](#).

The approach presented in HDS-5 analyzes a culvert for various types of flow control and then designs for the control which produces the minimum performance. Designing for minimum performance ignores transient conditions which might result in periods of better performance. The benefits of designing for minimum performance are ease of design and assurance of adequate performance under the least favorable hydraulic conditions.

The following section incorporates guidance from HDS-5 and presents key design considerations and procedures for culvert hydraulic design and analysis.

7.5.1 Culvert Design Considerations

Prior to beginning the culvert design and analysis process, other design elements must be evaluated for potential inclusion. Table 7 - 2 provides a list of design considerations that ensure hydraulic performance, long-term functionality, and safety when integrated into the design.

Collecting relevant data during the site assessment is essential for identifying these elements early and supporting informed decision making throughout the culvert design process.

Table 7 - 2 Culvert Design Considerations

Steps	Design Considerations	References and Design Notes
1	Site Risk Assessment	Section 7.5.1.1
2	Alignment and Grade	Section 7.5.1.2 - 7.5.1.5
3	Minimum Culvert Size	Section 7.5.1.6
4	Culvert Material	Section 7.5.1.7
5	Culvert Extensions & End Treatments	Section 7.5.1.8
6	Multiple Openings	Section 7.5.1.9
7	Fire Design Measures	Section 7.5.1.10
8	Debris	Section 7.5.1.11
9	Piping	Section 7.5.1.12
10	Buoyancy	Section 7.5.1.13
11	Camber	Section 7.5.1.14
12	Temporary Culverts	Section 7.5.1.15

7.5.1.1 Site Risk Assessment

Conducting a site risk assessment is an important step in the hydraulic design of culverts, allowing for the early identification and mitigation of key factors and potential risks during the scoping and design phases. A properly designed culvert design must consider various essential aspects, including hydrology, hydraulics, regulatory compliance, and long-term maintenance. Table 7 - 3 outlines some key factors and associated risks that should be evaluated during the site assessment.

Performing a risk assessment and incorporating mitigation measures into the design helps minimize the probability of structural failures, flooding risks, and regulatory impacts. Additionally, the assessment improves the culvert’s performance under diverse conditions, enhancing safety and longevity.

Table 7 - 3 Site Assessment Key Factors

Key Factors	Potential Risks
Hydrology	Climate Resilience: Increased frequency and intensity events Increased sediment transport Wildfire hydrologic response time Change in land use: Deforestation and agricultural expansion Urbanization and increased impervious surfaces
Hydraulic	Floodplain - Federal Emergency Management Agency (FEMA) Scour and energy dissipation Hydraulic efficiency, debris, and blockage
Stream Stability	Lateral instability Depositional or degrading systems Potential for head cutting Sediment transport material and abrasion of culvert material
Regulatory compliance	State and Federal (e.g. Federal: U.S. Army Corp, Clean Water Act, Wildlife and Fisheries; Oregon: Department State Lands, Department of Environmental Quality, Department of Fish and Wildlife).
Maintenance and operational	Frequency required to remove debris and sediment Repair of embankments from scour Material durability for pH and resistivity

7.5.1.2 Alignment and Grade

The following two sections discuss the importance of culvert alignment and grade, focusing on horizontal and vertical placement relative to the natural stream channel. These factors are essential to ensure hydraulic efficiency, stream stability, and constructability. Establishing a proper alignment and grade helps prevent outlet scour, reduces stream erosion, minimizes sediment buildup inside the culvert, and lowers maintenance needs.

Matching the existing grade and alignment may not always be feasible. In such cases, modifying the culvert profile or adjusting the channel alignment upstream or downstream may be more practical. This is especially true when the natural drainage course results in skewed culverts, bends, or excessive excavation. Evaluate modifications on a case-by-case basis, balancing environmental and stream stability impacts with construction and long term performance. Refer to the [Fish Passage Chapter](#) for stream profile design for fish passage.

7.5.1.3 Horizontal Alignment

Horizontal alignment is the orientation of the structure relative to both the road and the stream channel. Where possible, the culvert should follow the natural stream alignment to maintain hydraulic efficiency, reduce sediment deposition and scour, and minimize the risk of debris blockage.

When a roadway crosses a straight uniform channel at right angles, the upstream and downstream channel reaches can be connected through a straight crossing. However, most crossings involve skewed alignments or are located along sinuous channels.

7.5.1.4 Skewed Culverts

Poor alignment of the culvert with respect to the stream (skew) can result in energy losses, upstream backwatering, and sediment deposition, even in the absence of an obstructed inlet. Skewed inlets reduce the hydraulic performance of the culvert under inlet control conditions. The differences can be minor and are incorporated into HY-8. A skewed inlet or outlet can also direct water to one side of the channel leading to inlet scour, bank erosion, and increased risk of channel instability.

Erosion and sediment transport are most active during high flows. Potential risks such as scour, sediment buildup, and channel instability are most apparent during these conditions. Assessing culvert alignment under high-flow conditions supports a more stable and efficient design.

Aligning the culvert parallel to the upstream channel can minimize these risks but may result in a skew relative to the roadway. This can often require a longer culvert, installing headwalls or wingwalls, or the need for a bridge crossing. These trade-offs must be considered early in the design process. Figure 7 - 1 presents common alignments where the road crosses the stream at an acute angle.

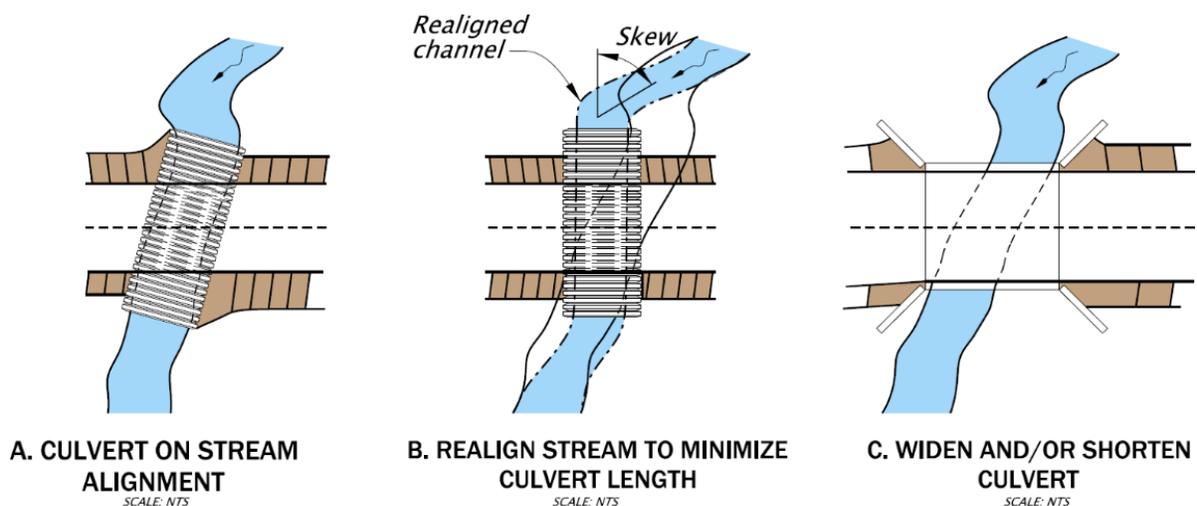


Figure 7 - 1 Skewed Culverts

Three primary alignment options can be considered for acute stream crossings:

- Matching culvert alignment to stream alignment
- Realigning the stream to minimize culvert length and skew
- Widening or shortening the culvert

Designs may also combine these strategies. In some cases, relocating the road or using a wider-span bridge may provide better overall outcomes. Minor skews are not likely to have impacts on the stream hydraulics or stability.

Where stream-to-roadway skew exceeds 35 degrees, evaluate alternative roadway alignments, stream realignment, or structure types, as illustrated in Figure 7 - 1C. These measures are intended to reduce scour potential and long-term maintenance. Figure 7 - 1B entails the greatest risk and should be avoided. For crossings with significant skew, use Table 7 - 4 to evaluate and compare the hydraulic performance of the three alignment options. Select the option that provides the most stable and efficient hydraulic conditions.

Table 7 - 4 Alignment Attributes and Hydraulic Effects

Alignment	Attributes	Hydraulic Effects
Crossing on stream alignment	Match culvert alignment to stream alignment.	✓ Low debris and sediment blockage risk.
	Culvert is skewed to road.	! Reduces hydraulic performance of culvert under inlet control. Increases length of culvert.
Realign channel	Inlet/outlet is skewed to channel.	! Higher blockage risk from debris/sediment. ! Higher risk of culvert failure. ! Increased maintenance for removal of sediment/debris. ! Higher risk of lateral mitigation and bank erosion.
Widen and/or shorten culvert	Match culvert alignment to stream alignment.	✓ Low debris and sediment blockage risk.
	Larger conveyance area.	✓ Higher culvert capacity with low failure risk. ✓ Greater passage opportunity for aquatic and terrestrial organisms.
	Minimal channel impacts.	✓ Lower risk of lateral mitigation/erosion.

Culverts at Channel Bends

Crossings located near bends require additional design attention due to changes in flow direction and velocity. Designs must account for any anticipated lateral channel migration over the service life of the culvert. Figure 7 - 2 presents common alignment options for stream crossings located at channel bends.

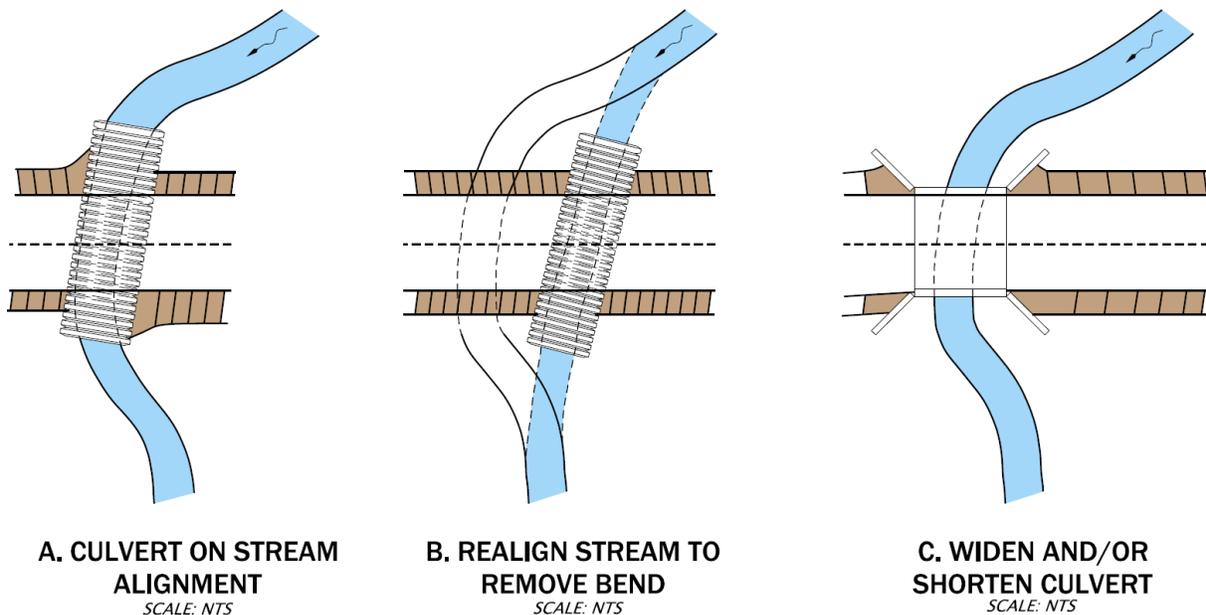


Figure 7 - 2 Channel Bends

Avoid sharp bends immediately upstream or downstream of culvert ends. These transitions increase head loss and can cause outer-bank erosion and inner-bank sediment deposition, undermining the structure's performance and lifespan. Design options for accommodating expected lateral changes include the following:

- Widening the culvert and offsetting in the direction of meander movement.
- Bank stabilization measure (see [Bank Protection Chapter](#)).
- Training structures such as rock weir, barbs, or vanes (see [Bank Protection Chapter](#)).

Stream realignment is sometimes necessary to improve crossing geometry, reduce culvert length, or resolve conflicts between the road and natural stream path. Realignment should maintain continuity of flow and sediment transport and avoid abrupt transitions at the culvert inlet or outlet.

Minor channel relocations can be successful, particularly when the original channel is stable. However, any modification to the stream course must be evaluated for long-term channel behavior, potential habitat impacts and permitting constraints.

In highly sinuous streams, realignment may reduce skew and improve hydraulic function, but environmental and regulatory impacts must be assessed early. Wherever possible, the design should preserve or enhance stream stability and habitat quality.

7.5.1.5 Vertical Alignment

Vertical channel alignment refers to the elevation and slope of a culvert in relation to the natural streambed. This alignment directly influences culvert hydraulics, sediment transport, fish passage, and long-term channel stability. Poor vertical placement can result in outlet scour, sediment buildup, perched conditions, and structural damage.

This section provides guidance on evaluating and designing vertical alignment for culverts by considering existing, design, and long-term streambed profiles. The guidance also addresses channel slope transitions and the potential for head-cutting, both of which can compromise channel stability and hydraulic performance.

Design Profile

The design profile forms the basis of the construction plans, representing the anticipated streambed profile after culvert installation. Modifications to the existing channel profile may include installing or removing grade controls, adding or excavating streambed material, or placing roughening elements to enhance fish passage. The design should reflect the natural stream gradient and morphology to maintain sediment transport continuity.

A longitudinal profile is important for establishing the appropriate channel elevation, determining the design gradient through the culvert, and assessing the potential for long-term streambed degradation. This profile should extend sufficiently upstream and downstream to capture the general channel characteristics, including any significant grade breaks. Refer to Figure 7 - 3 for an example of a design profile.

An important element of the design profile is matching the culvert invert slope with the natural streambed slope. Installing a culvert on a slope significantly flatter than the channel may result in sediment accumulation inside the barrel. Conversely, placing the culvert on a steeper slope can increase flow velocity, cause outlet scour, and impair fish passage. When matching the

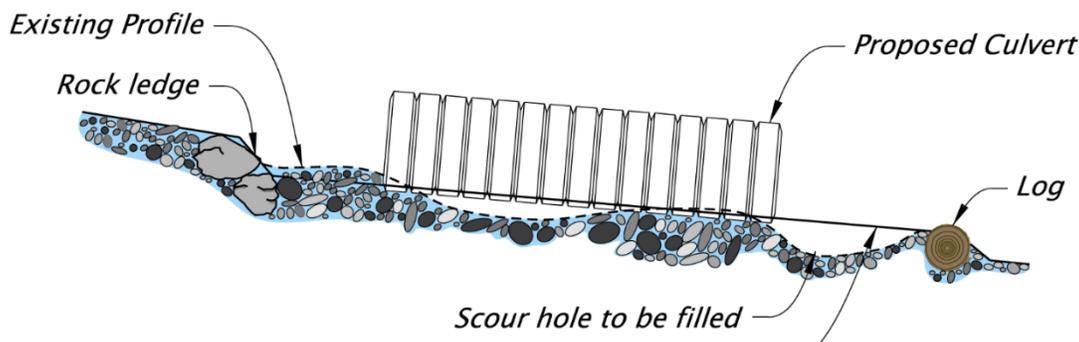


Figure 7 - 3 Design Profile

stream slope is not feasible, design measures such as culvert embedment, roughened channels, or grade control structures should be incorporated.

Key elements typically shown in a vertical design profile include:

- Existing and proposed streambed elevations along the culvert alignment
- Culvert inlet and outlet elevations
- Culvert slope and length
- Roadway surface and subgrade elevations above the culvert
- Hydraulic control points and any grade control structures

Long-Term Profile

The long-term profile represents projected streambed changes over the culvert's design life, driven by geomorphic processes such as incision, aggradation, degradation, or bedform shifts. Influencing factors include sediment supply, sediment transport capacity, channel confinement, and large-scale changes or land use shifts.

Geomorphic Transitions

Many highways intersect streams at geomorphic transitions—natural terrain breaks such as the base of a hillslope or a stream terrace. These breaks can create abrupt slope changes that affect sediment continuity and alter how the channel profile responds over time. To support long-term channel stability, the design must account for these transitions and their effects on sediment transport and stream profile adjustment.

Uniform: A uniform profile has no slope transitions, making this the ideal stream crossing. However, aggradation can still occur upstream of an undersized culvert, reducing the local slope. Field indicators of upstream aggradation include elevated gravel deposits in the center of the channel, upstream bar formation with finer sediment, and channel widening or division. Aggraded reaches may also appear more homogenous, as sediment can bury features like steps or pools (See Figure 7 - 4A).

Concave: An abrupt steep-to-flat slope transition, typically occurring at valley floors. These areas are natural deposition zones where culverts are prone to sediment accumulation, reducing hydraulic capacity. Sediment deposition may block the channel, causing the stream to divert and form a new channel. Excavation for a new culvert that extends into the steeper upstream reach without grade control may trigger head cutting and additional sediment deposition (See Figure 7 - 4B).

Convex: A profile with a transition from mild to steeper slope. When a crossing is placed near the grade break, flow acceleration from the culvert or construction disturbance can destabilize downstream bed controls. This may initiate a head cut that migrates upstream and through the culvert, potentially undermining the structure (See Figure 7 - 4C).

Complex: A profile that includes both a convex and concave transitions. These reaches may exhibit upstream deposition typical of concave profiles and downstream incision, or instability associated with convex profiles (See Figure 7 - 4D).

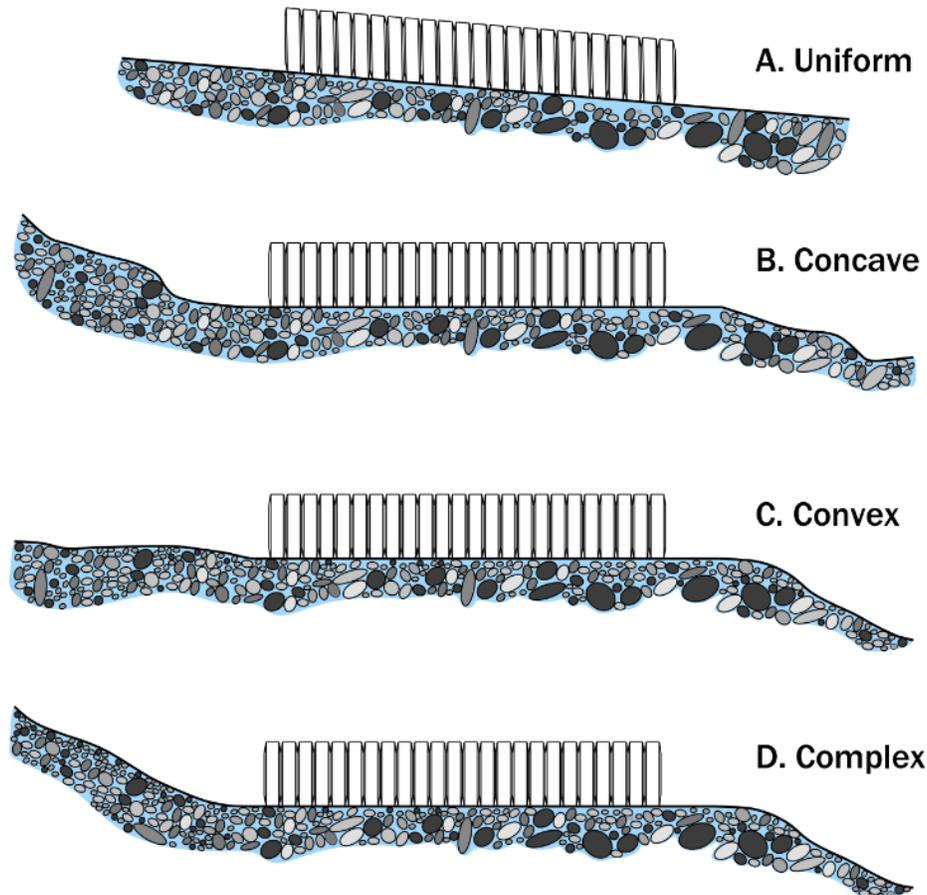


Figure 7 - 4 Geomorphic Transitions

Vertical Adjustments

Effective culvert design requires consideration of both current and potential long-term changes to the streambed profile. Designing for long-term profile stability involves anticipating potential adjustments caused by natural processes or human modifications. The following considerations support evaluation of potential future changes to the streambed elevation and the implications for design:

- **Review existing conditions** – Determine the long profile of the waterway and evaluate the impacts of any existing drainage structures. Document current streambed elevations, slopes, and features that could influence the culvert’s performance.
- **Review the design profile** to assess potential changes from the removal or addition of features such as weirs, dams, or log steps. Use relevant geomorphic and hydraulic factors and plot any estimated changes on the profile.

- **Account for upstream-migrating head cuts**, especially where downstream grade control is absent or vulnerable. Anticipate how a head cut might progress through the culvert and modify the streambed elevation. Reflect these possible adjustments in the profile.
- **Aggradation or degradation** over time can significantly impact culvert performance; draw two bounding lines on the longitudinal profile – one for potential aggradation (upper bound) and one for potential degradation (lower bound). See Figure 7 - 5. These lines define the vertical range of anticipated streambed adjustment during the culvert's service life. Reference [HEC-20 Stream Stability at Highway Structures](#).
- **Compare the design profile to current field conditions** for replacement culverts. Identify signs of aggradation, degradation, scour, or debris accumulation. Adjust the culvert's type, size, or location as needed to accommodate long-term changes.

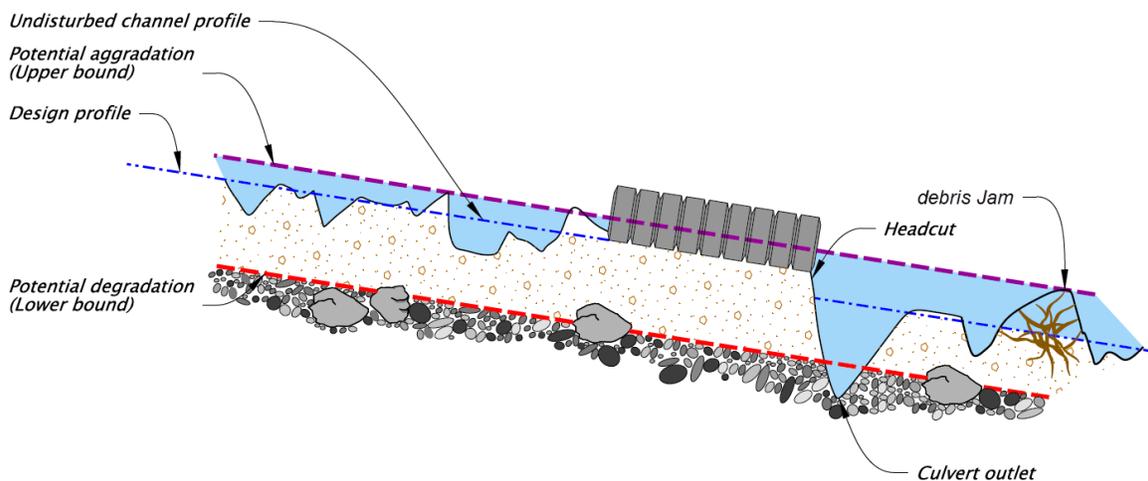


Figure 7 - 5 Vertical Adjustment – Incised Channel

The incised channel in Figure 7 - 5 shows a head-cut that migrated up from downstream and was stopped by the existing culvert. The incised channel profile is lower than the undisturbed (upstream) channel profile projected downstream. Here, if the culvert were not in place, the head-cut would likely continue to upstream causing further channel incision.

Channel Head-Cuts

Upstream migration of a head-cut can damage infrastructure, destabilize streambanks, alter aquatic habitat, and create barriers to fish passage. When head-cutting is anticipated, designers must decide whether to allow natural progression, slow it with grade control, or prevent upstream migration entirely, weighing potential impacts against the benefits of a self-sustaining channel.

Replacing an undersized or perched culvert with a larger or an embedded culvert can mobilize upstream sediment, initiating a head-cut. In some cases, the resulting channel response is minor. In others, particularly, where the downstream channel is incised or lacks grade control,

head-cutting can become severe and extend far upstream. The designer must assess several factors to determine whether to prevent, slow, or allow upstream incision to occur naturally:

- **Estimate the depth and upstream extent of potential head-cutting** if no grade controls are implemented. The reach of head-cut depends on the stream slope, sediment supply and mobility, and grade control features.
- **Determine whether prevention of head-cutting is necessary** to protect upstream infrastructure, such as culverts, bridges, utilities, or property.
- **Assess whether temporary grade control measures are necessary** to slow head-cutting.
- **Evaluate potential impacts on streambed morphology and bank stability.**
- **Evaluate whether the resulting channel changes will impact fish passage.**

Head-cutting is generally less extensive in coarse-grained or debris-laden channels due to stable grade controls that inhibit upstream progression. Channels with a greater supply of mobile bed material typically reach equilibrium more rapidly than those with limited sediment supply. Designers must consider the physical, biological, and infrastructure impacts of head-cutting and balance allowing natural stream adjustment with mitigating risks to stability, habitat, and adjacent infrastructure. For detailed information on fish passage design, refer to the [Fish Passage Chapter](#). For detailed information on stream morphology, see the [Geomorphology Classification of Rivers](#) (Buffington & Montgomery, 2013).

7.5.1.6 Minimum Culvert Size



Selection of culvert size and shape is based on engineering design and criteria related to site conditions. Minimum sizes ensure access for cleaning, passage of debris, and provide capacity for future pipe rehabilitation methods. Refer to Table 7 - 5 for the minimum diameters required by application. Land-use or environmental regulations may require culverts larger than hydraulic analysis indicates, such as for wildlife or fish passage.

Table 7 - 5 Minimum culvert sizes

Location	Minimum Diameter	Notes
Median culverts	18 inches	15 inches with grated inlet or catch basin.
Roadway approach culverts	15 inches	Apply to driveways, minor access roads, etc.
Roadway cross culverts	24 inches	Apply to heights under 15 feet.
Interstate cross culverts	36 inches	Apply to heights under 15 feet.

For cross pipes from drop inlet structures and stormwater facilities follow guidelines for [Storm-Roadway Drainage](#). For culverts under deep fills use the minimum diameters in Table 7 - 6.

Table 7 - 6 Minimum culvert size based on fill heights

Minimum Capacity Size	Fill Section Greater than 15 feet
18 inches	24 inches or equivalent
24 inches	30 inches or equivalent
30 inches	36 inches or equivalent
36 inches	48 inches or equivalent
42 inches	54 inches or equivalent
48 inches	60 inches or equivalent

7.5.1.7 Culvert Barrel Material and Shape

Culvert barrels are constructed from a variety of materials. Material selection is based on hydraulic and structural requirements, resistance to corrosion and abrasion, facility design life, and wildfire resilience. In addition to material choice, the shape of the culvert influences capacity, installation requirements, and performance. Key factors in determining shape include available cover, channel width, debris passage, and maintenance access. The [Pipe Materials Chapter](#) provides design guidance and policy on material selection, required field testing, and design life.

7.5.1.8 Culvert End Treatments and Extensions

Selecting a more efficient inlet can improve the hydraulic capacity especially in inlet control conditions. The provision of a more gradual flow transition will lessen the energy loss and create a more hydraulically efficient inlet condition. Refer to Section 7.6 for information on several types of end treatments and ODOT design policy.

Before extending an existing culvert, conduct a thorough evaluation of the pipe’s existing hydraulic performance and structural integrity. Design the culvert extension using the same pipe material, size, and match the existing alignment and grade. If necessary, connect dissimilar pipe materials using concrete encasements as shown in [Standard Drawing RD306](#).

Pipe rehabilitation or replacement may be required if the existing culvert has exceeded the service life. Refer to [Trenchless Chapter](#) for renewal options and methods.

7.5.1.9 Multiple Culverts Openings



The use of multiple culvert openings for a single water crossing is not allowed except for temporary installations during construction. Investigate other engineered alternatives at site

locations with limited cover height between the roadway and stream bed. Significant problems associated with the use of multiple culverts include:

- Sedimentation and debris. In irregular channels, normal flows tend to pass through one of the barrels, while sediment and debris collect in the others.
- Hydraulic jumps occur when the approach velocity is high, particularly during supercritical flow.
- High maintenance costs.
- Potential barriers for fish passage.

If multiple barrel culverts are necessary for temporary installations, minimize the above problems by:

- Installing the culverts normal to the channel flow.
- Placing one barrel lower to handle smaller flows.
- Designing special inlet treatments to avoid the adverse effects of a hydraulic jump.

This guidance applies to adjacent, closely spaced culvert barrels. Multiple culverts that are spaced along a braided channel to accommodate separate flow paths may be designed where hydraulically justified.

7.5.1.10 Fire Design Measures

Designing culverts for post wildfire hydrologic responses and selecting the appropriate pipe material in wildfire-prone areas is important to reduce the potential impacts on human safety and the highway infrastructure. See the [Pipe Material Chapter](#) for policy and guidance on culvert material section based on wildfire hazard zones.

Post Fire Responses

The effect of wildfire on the hydrological processes and response times can be substantial. Wildfires can dramatically alter vegetation cover, change soil hydraulic properties leading to reduced infiltration rates, increase in erosion, and water quality issues. These effects lead to altering the hydrologic response of a watershed to the extent that even modest rainstorms can produce dangerous flash floods and debris flows (Dunn & McEvoy, 2024).

Table 7 - 7 Post Fire Design

Post Fire Design Measures	Hazard Score	Description
Increase culvert size	High - Medium	Manage increased runoff
Increase hydraulic clearance (freeboard)	High - Medium	To pass increased sediment and woody debris



Figure 7 - 6 U.S. 395 - Canyon City Fire, 2015

The [Wildfire Hazard Map](#) is a valuable tool for post-fire hydrologic design by identifying areas with elevated burn probability and fire intensity. Culverts located within high and moderate hazard zones are more likely to be impacted by post-wildfire hydrologic changes, including increased runoff, sediment transport, and debris flows. Table 7 - 7 lists design mitigation measures to reduce the impact of wildfire on culverts. Refer to the [Pipe Materials Chapter](#) for additional details on the development and application of the Wildfire Hazard Map.

7.5.1.11 Debris

Accumulation of debris at the culvert inlet can adversely affect the capacity of the culvert and cause damage to the highway, culvert, and upstream property. Contacting maintenance personnel, neighboring landowners, and site examination can determine the presence and extent of an existing debris passage problem.

[FHWA's HEC-9 "Debris Control Structures"](#) circular provides guidelines for analyzing impacts associated with debris accumulation and design guidelines for selecting debris control countermeasures. Countermeasure options include both non-structural and structural measures. A non-structural option would include upsizing the culvert to pass debris more effectively and reducing the need for maintenance cleaning.

7.5.1.12 Piping

Piping is the process of water seepage moving along the exterior of the culvert barrel, eroding the surrounding backfill material. This movement of water removes fine soil particles, creating voids that reduce the ability of the soil arch, around the pipe, to effectively redistribute loading. Overtime, piping will undermine the structural integrity of the pipe leading to collapse or failure of the culvert and roadway embankment.

Water typically enters the embankment from open joints along the pipe or through holes caused from material deterioration or damage. Water can also enter at the interface between the barrel and the embankment at the culvert inlet. The designer must take into consideration and ensure the proposed pipe or existing pipe is sufficiently watertight to accommodate the hydrostatic pressure resulting from the design headwater. Design element options to help prevent piping include:



Headwalls, collars, cut-off walls, and impervious bedding materials at the upstream end of a culvert reduce the potential for piping. Cut-off walls are very effective when constructed on undisturbed natural ground. Excavation for the cut-off wall should not extend below the wall bearing surface, to ensure the wall is poured on competent, undisturbed material.

Properly constructed cut-off walls limit subsurface flow during low-flow conditions and reduce the likelihood of foundation and bedding material removal during higher flows. Where pressure flow conditions are anticipated, watertight joints should be used in conjunction with these design elements to minimize seepage and piping potential.

7.5.1.13 Pipe Buoyancy

Buoyancy is the upward force acting on a culvert when partially or fully submerged. When this upward force exceeds the combined weight of the pipe and backfill, the culvert may float or heave. Sections of pipe subjected to a buoyant force experience a bending stress, potentially leading to structural failure or compromised connections.

Projecting end sections subjected to high headwater or backwater elevations are highly susceptible to buoyance forces and often experience upward bending. A buoyancy analysis

should be performed whenever groundwater or flood conditions may cause uplift or flotation of the culvert. Typical conditions requiring analysis are summarized in the following table.

Table 7 - 8 Buoyancy Analysis

Scenario	Notes
High groundwater Culverts below water table	Groundwater fluctuation that may rise to or above the pipe crown. Pipe invert or portions of the culvert lie below groundwater levels.
Shallow cover	Backfill depth is insufficient to resist buoyant forces (less than pipe diameter).
Inlet controlled and steep slopes	High headwater potential -inlets without end treatment providing anchorage.
Projecting ends & flexible pipe materials	Ends extending beyond the fill are less confined and more susceptible to flotation.

Temporary construction and detour culverts are particularly vulnerable to buoyancy-related issues. These installations often lack sufficient anchoring or backfill, increasing the likelihood of pipe flotation or deformation under high water levels.

Buoyancy Analysis

The buoyancy of pipe depends upon the weight of the pipe, the weight of the volume of water displaced by the pipe, the weight of the water carried by the pipe, and the weight of the backfill. As a conservative practice in analysis, consider the pipe empty, so the weight of any potential water provides an additional safety factor.

Buoyancy Force

The risk of pipe flotation exists when the buoyant force on the pipe exceeds the downward forces of the pipe.

$$F_B \geq W_P + W_S \tag{Equation 7- 1}$$

Where:

- F_B = buoyancy force pounds force per linear foot (lbf/ft)
- W_P = weight of pipe in pounds per linear foot (lb/ft)
- W_S = weight of backfill per linear foot, pounds (lb./ft)

Calculate the upwards buoyancy force, F_B , by using the equation below:

$$F_B = \frac{\pi}{4} D_o^2 \rho_w \tag{Equation 7- 2}$$

Where:

D_o = outside pipe diameter, feet (ft)

ρ_w = density of water, pounds per cubic foot (lb/ft³)

Weight of Pipe

Pipe manufacturers often publish the weight of the pipe, W_p , along with the product's dimensions. Calculate the weight of the pipe using Equation 7- 3 below:

$$W_p = \frac{\pi}{4} (D_o^2 - D_i^2) \rho_m \quad \text{Equation 7- 3}$$

Where:

D_o = outside pipe diameter, feet (ft)

D_i = inside pipe diameter, feet (ft)

ρ_m = density of pipe material, pounds per cubic foot (lb/ft³)

Weight of Soil

For buried pipelines, the weight of the soil contributes significantly to mitigating against pipeline floatation. The total soil load, W_s , acting on the pipe at various water depths is the sum of the dry soil, W_D , plus the saturated soil load, W_I .

$$W_s = W_D + W_I = \rho_d H_d D_o + (\rho_i - \rho_w) \left(H_i D_o + \frac{(4 - \pi)}{8} D_o^2 \right) \quad \text{Equation 7- 4}$$

Where:

ρ_d = density of dry soil, pounds per cubic foot (lb./ft³)

H_d = depth of dry soil, feet (ft)

ρ_i = density of saturated soil, pounds per cubic foot (lb/ft³)

H_i = depth of saturated soil above crown of pipe, feet (ft)

If the density of the dry soil and wet soil is unknown, the density of the of the dry soil and specific gravity, SG , can be used to determine the weight of soil.

$$W_s = W_D + W_I = \rho_d H_d D_o + (w_i) \left(H_i D_o + \frac{(4 - \pi)}{8} D_o^2 \right) \quad \text{Equation 7- 5}$$

Where:

w_i = average unit weight of saturated soil, pounds per cubic foot (lb./ft³)

$$w_i = \rho_d \left(1 - \frac{1}{SG} \right) \quad \text{Equation 7- 6}$$

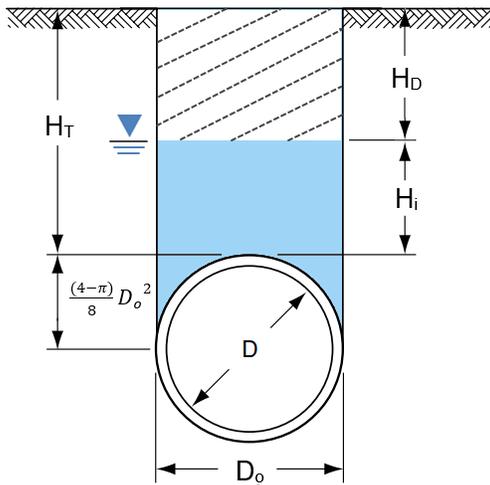


Figure 7 - 7 Weight of Soil

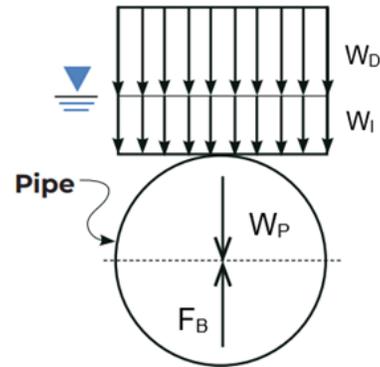


Figure 7 - 8 Free Body Diagram

Factor of Safety

The factor of safety is applied to decrease the downward force of the backfill. Construction soils are noted for lack of uniformity. Depending on the extent of information of the proposed backfill material and site condition, a minimum factor of safety 1.1 is recommended. If the set factor of safety is not met, implement a mitigation design to resist buoyancy. For unburied pipe sections use Equation 7- 7:

$$FS = \frac{[W_P]}{F_B} \quad \text{Unburied pipe sections} \quad \text{Equation 7- 7}$$

For buried pipe sections use Equation 7- 8:

$$FS = \frac{[W_P + W_S]}{F_B} \quad \text{Buried pipe sections} \quad \text{Equation 7- 8}$$

Buoyancy Mitigation

If the buoyancy analysis results indicate there is a tendency of the pipe to float, appropriate mitigation must be put in place. In selecting buoyancy mitigation measures, consider factors such as cost, ease of installation, and soil type. Table 7 - 8 lists potential buoyancy mitigation measures.

Table 7 - 9 Buoyancy Mitigation Measures

Scenario	Mitigation Options	Notes
Unburied Pipes Ends	Mitered slope paved Mitered collar Headwall	Rip rap is not a suitable buoyancy mitigation.
Buried Pipes	Increase thickness of pipe Increase pipe depth Saddle pipe anchors Saddle bags Inline concrete collars	Sizing the anchoring system and placement is a function of the pipe diameter and height of the water table. Saddles and collar spacing should accommodate potential pipe deflection between anchors.

7.5.1.14 Camber

Placing culverts on compressible foundation materials under a moderate to high embankment may result in differential settlement. The difference in consolidation of the foundation material at the culvert midpoint versus the ends is greater. This differential settlement creates a low point in the culvert profile below the original grade line. To prevent this from occurring, place the culvert with a camber or a slightly elevated midsection.

A structure designed with proper camber will settle near the flowline grade and elevation when final settlement is reached. The required camber depends on the load imposed on the foundation material and the compressibility of the material. Since these factors vary, consult the project Geotechnical Engineer to determine the proper camber of the culvert. Include a profile showing the designed camber in the plans.

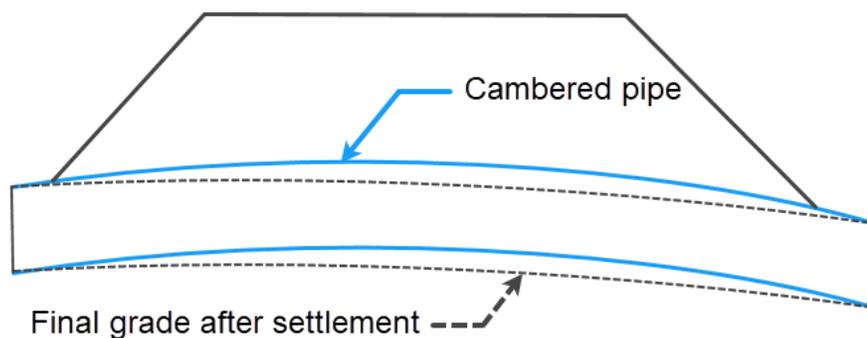


Figure 7 - 9 Pipe Camber

7.5.1.15 Temporary Culverts

For detailed guidance on the design and implementation of temporary culverts, refer to the [Temporary Water Management Chapter](#).

7.5.2 Culvert Design and Analysis

The design process involves both culvert design and culvert analysis. Culvert design is an iterative process in determining the appropriate size, shape, material, slope, and placement. The goal is to confirm that the culvert meets performance requirements and performs safely and effectively under various flow conditions. Culvert analysis is the process of evaluating the performance and hydraulic behavior of the culvert based on the design. This analysis is used to ensure the culvert meets ODOT design policy and functions properly under various conditions.

Culverts that meet any of the conditions given in Table 7 - 9 of this guidance will require a hydraulic analysis and submitted for review.

Table 7 - 10 Require Hydraulic Analysis



Culvert Project	Required Analysis
New culvert installations	✓
Culvert replacements	✓
Culverts in tidal influenced areas	✓
Culverts within a floodplain or floodway	✓
Culvert fish passage projects	✓
Culvert extensions - all	✓
Culvert rehabilitation / repair	✓
Replacement / end treatment modification	✓

The following design procedures in Table 7 - 10 provides a convenient and organized method for the design and analysis of culverts with a constant discharge, considering inlet and outlet control. A well-planned data collection program and integration of important design considerations lead to a more orderly and effective analysis and design.

Table 7 - 11 Culvert Design Procedures

Steps	Design Procedures	References and Design Notes
1	Site Data and Hydrology Method(s)	Data Collection , Hydrology Chapters.
2	Determine Design and Check Flood	Policy Chapter
3	Design Considerations	Section 7.5.1
4	Select Initial Design Alternative	Section 7.5.3
5	Determine Allowable Headwater	Section 7.5.4
6	Determine Tailwater elevation	Section 7.5.5
7	Plot Performance Curve	Section 7.5.6
8	Determine Flow Regimes and Flow Control Type	Section 7.5.7 & Section 7.5.8
9	Calculate outlet velocity and depth	Section 7.5.9 & Energy Dissipator Chapter
10	Compare alternative design(s)	Reevaluate steps 3- 9 above if needed

7.5.3 Alternative Analysis and Design

An alternative analysis for culverts involves evaluating various designs, functional, and environmental options with a focus on overall performance, resilience and safety. The goal is to provide an analysis that considers the full range of impacts a culvert might have on the surrounding environment, infrastructure, and communities.

Each alternative analysis needs to follow design policies in this manual, documented in the hydraulic report and analyzed for 1) hydraulic performance 2) material and design 3) cost and risk, 4) environment 5) regulatory compliance and 6) community impacts.

Each of these factors should be carefully weighed to determine the most suitable culvert alternative that balances engineering, environmental, and economic needs. The selected alternative must conform with all structural and hydraulic design policies, standards, and the analysis factors listed in Table 7 - 11.

Table 7 - 12 Alternative Analysis Factors

Alternative Analysis Factors	Notes
Hydraulic Performance	Capacity, headwater, velocity, energy losses, resilience to climate change.
Material and Design	Materials based on environment, longevity, and load capacity, construction feasibility.
Cost and Risks	Initial construction costs, operational and maintenance costs, risk to property, risk of failure, public safety.
Environmental Compliance and Impacts	Fish and wildlife passage and connectivity, wetlands, sensitive habitats.
FEMA Regulatory Compliance	Applicable local, state, and federal laws and permitting actions for floodplain or floodways, revision of the floodplain maps.
Social and Community	Aesthetic integration and any impact to local communities.

7.5.4 Allowable Headwater

The headwater elevation at a given design flow is defined as the water-surface elevation at the culvert entrance and is measured from the culvert invert to the water surface. The design headwater should not exceed the allowable headwater. Reducing the allowable headwater elevation at a culvert crossing can offer several benefits: 1) reduce the potential for debris and blockage with increased culvert size, 2) improves accessibility for maintenance during large storm events, and 3) decrease outlet velocities and severe scour that would otherwise require an energy dissipater. See Table 7-12 for allowable headwater criteria.

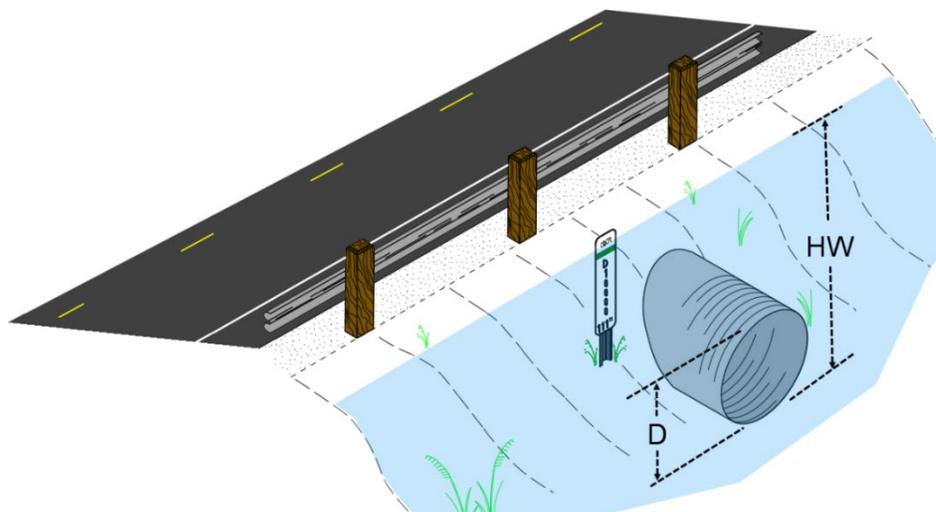


Figure 7 - 10 Headwater Elevation

7.5.4.1 FEMA Regulations

Coordinate with local jurisdictions and FEMA in situations where administrative determinations are needed involving a regulatory floodway. Further guidance can be found through FEMA, local agencies’ land development code, and the [Policy Chapter](#) in this manual.

- Any culvert placed within a floodplain or floodway needs to be consistent with applicable local, state, and federal laws and permitting actions.
- In some circumstances there may be a need for a revision of the floodplain map. Guidelines to perform these actions are available through [FEMA](#).

7.5.4.2 Flood Event Design

There are three sets of criteria used to determine the allowable headwater elevation: 1) ratio of headwater depth (HW) to culvert diameter (D), 2) roadway embankment freeboard and 3) site-constraints. The analysis that results in the lowest headwater elevation should govern the culvert design. Refer to [Policy Chapter](#) for the design and base event floods for culverts.

Table 7 - 13 Flood Design Allowable Headwater Criteria

Criteria	Description
HW/D - New Culverts	HW/D ratio is less than or equal to 1.25 ($HW/D \leq 1.25$).
HW/D – Existing culvert repairs (Shallow Embankments)	¹ HW/D ratio up to 1.5 ($HW/D \leq 1.5$) is permitted for pipe rehabilitation/renewal when: 1) Embankment height of 5 feet or less and 2) If there is sufficient freeboard.
Site Constraints and Freeboard	Elevations that limit potential damage to upstream and adjacent property while reducing disruption to property owners. Elevations that prevent diversion of flow from the culvert crossing. Regulatory constraints.

¹ Water pooled at the culvert inlet can cause considerable hydrostatic pressure on the upstream side of the roadway embankment, exceeding the original design. Avoid high headwater in these locations. Consult with the project geotechnical engineer for a stability analysis of the roadway embankment.

7.5.4.3 Check Flood Event

The headwater that occurs during the check flood event must also be investigated. The purpose of this check is to assess the potential effects of inundation from floods that exceed the design event. The check flood is the most frequent occurrence of either the 500-year flow event, the incipient roadway overtopping event, or the higher headwater elevations of the two events.

Two sets of criteria exist for the allowable headwater during the check flood: 1) highway classification, and 2) site constraints.

Table 7 - 14 Check Flood Allowable Headwater Criteria

Criteria	Description
NHS, State Priority Routes	Design the culvert passing the check flood event without overtopping the roadway.
State Highways	¹ Design the culvert passing the check flood event without overtopping the roadway.
Site Constraints	Elevations that limit potential damage to upstream and adjacent property or inconvenience to owners. Elevations that prevent diversion of flow from the culvert crossing. Prevention of overflow to a different drainage basin. Regulatory Constraints.

¹For crossings under 200 acres, designing the roadway embankment to resist overtopping may be more cost-effective than a culvert for the check flood. Limit these designs to low-ADT State highways. Example: a low-ADT road with limited vertical clearance where closure would not significantly inconvenience the public, or impact nearby property, or homes.

7.5.4.4 Roadway Overtopping

Overtopping of the road will begin to occur when the headwater rises to the elevation of the road. The overtopping will usually occur at the low point of a sag vertical curve on the roadway. The flow over the roadway is similar to flow over a broad-crested weir, as shown in Figure 7 - 11. Calculating overtopping at culvert, the roadway overflow plus the culvert flow

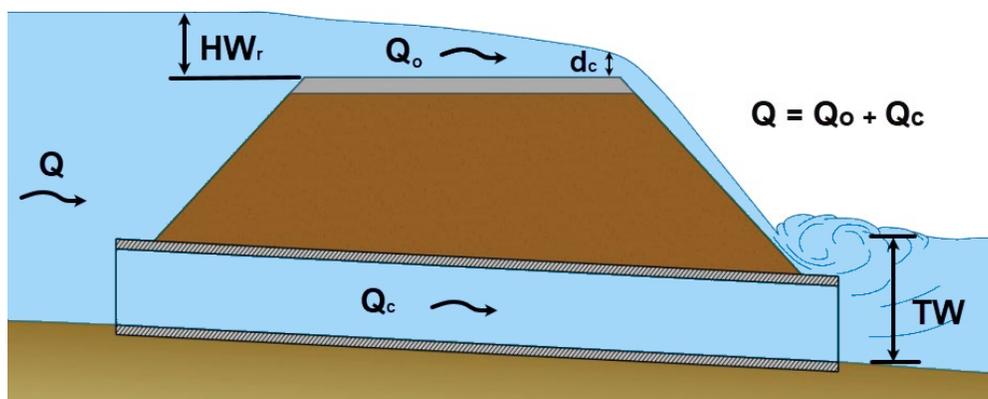


Figure 7 - 11 Roadway Embankment Overtopping

must equal the total design flow. HY-8 will complete an overtopping analysis for a crossing(s), and, if overtopping occurs, will display the corresponding flow values. Guidance is also available in [HDS-5](#).



Figure 7 - 12 Overtopping I-84, Region 5 yr. 2020

Ensuring protection of the downstream embankment slope from erosive forces is essential. With low tail water, the flow will accelerate down the slope with high velocity and shear stress associated with supercritical flow, see Figure 7 - 12. Erosion typically initiates near the toe of the embankment, regardless of the presence of a hydraulic jump. [HEC-23 Volume 2: Design Guideline 5](#) provides riprap design for embankment overtopping.

7.5.5 Tailwater Conditions

The depth of water downstream of the culvert measured from the outlet invert is defined as tailwater and shown in Figure 7 - 11 above. Tailwater is an important factor in determining culvert capacity under outlet control conditions. The tailwater depth is based on the characteristics of the downstream channel at the given design discharge.

The tailwater depth is either assumed to be critical depth near the culvert outlet or the downstream channel depth, whichever is higher. Use Manning's equation to solve for the normal depth as described in the [Channels Chapter](#).

The premise of normal depth changes when conditions arise that could lead to elevated tailwater levels during flood events. If the tailwater at the culvert site is affected by downstream controls such as natural stream constrictions, obstructions, tidal effects or junctions with other watercourses a more detailed water surface profile is required. This profile can be determined by performing a step backwater analysis using HEC-RAS.

If an SRD-2D model is already available, the model can be used to refine the culvert water surface profile. Designers are not required to develop a 2-D model solely for this purpose. For more information on this method, refer to the [Channels Chapter](#).

Table 7 - 15: Water Surface Profile Method

Down Stream Conditions	Water Surface Profile Method
Natural stream constrictions, obstructions	Step backwater analysis
Stream confluences and statistically independent events	Estimate joint probabilities of design coincident flows. Use greater tailwater depth. See Hydrology Chapter .
Tidal effects	Use the mean high tide

7.5.6 Performance Curves

Performance curves are representations of flow rate versus headwater depth or elevation for a given flow control. The resulting curve is useful in evaluating the hydraulic capacity of a culvert for various headwaters and displays the consequences of higher flow rates at the site. With a more efficient inlet configuration, the culvert performance can be increased to take advantage of the culvert barrel capacity. Figure 7 - 13 illustrates a typical culvert performance curve.

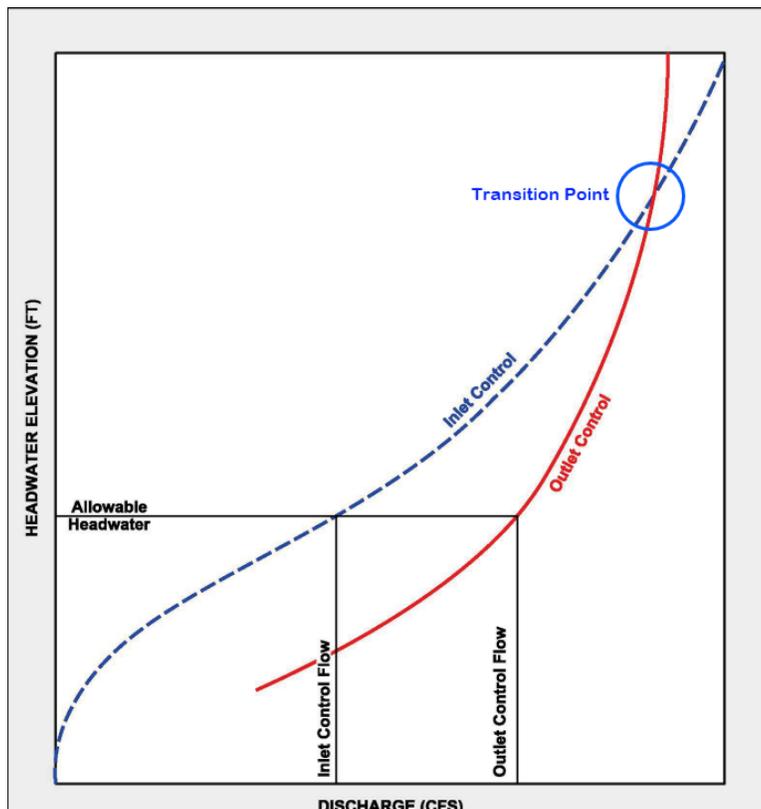


Figure 7 - 13 Performance Curve

Culvert performance curves have several possible control sections: inlet, outlet, (barrel), and roadway. A given culvert installation will have a performance curve for each control section and one for roadway overtopping. The overall culvert performance curve is made up of the controlling portions of the individual performance curves for each control section. Figure 7 - 14 illustrates a performance curve for a culvert with roadway overtopping.

Using the combined culvert performance curve, the headwater elevation may be established for any flow rate or to visualize the performance of the culvert installation over a range of flow rates. When roadway overtopping begins, the rate of headwater increase will flatten severely. The headwater will continue to rise very slowly from that point.

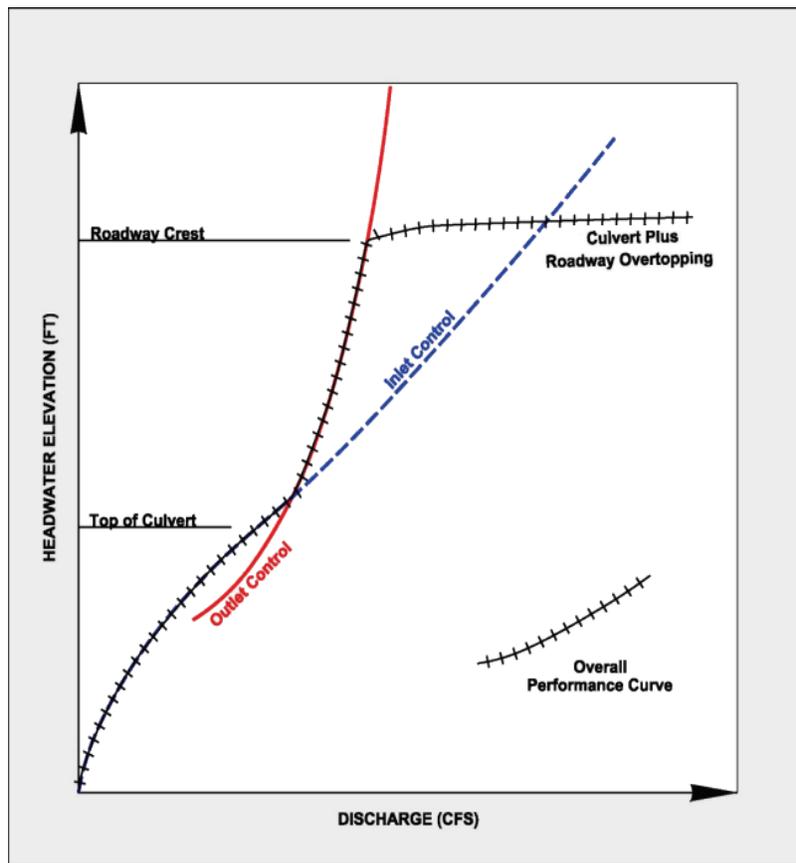


Figure 7 - 14 Performance Curve with Roadway Overtopping

7.5.7 Flow Regimes

Flow regimes in free surface flow (partially full culverts) play an important role in determining flow behavior. The three primary flow regimes—subcritical, critical, and supercritical are classified based on the dimensionless Froude number, which compares inertial and gravitational forces in the flow.

$$F_r = V/\sqrt{gy} \quad \text{Equation 7- 9}$$

Where:

- V = average velocity in feet per second
- g = gravitational acceleration in feet per second squared.
- y = equivalent depth or the hydraulic depth in feet.

The equivalent depth is commonly used to represent the characteristic depth in a circular section and is determined as the square root of half the cross-sectional flow area, expressed as $(A/2)^{0.5}$. The hydraulic depth for other shapes is calculated by dividing the cross-sectional flow area by the width of the free water surface, given by A/T (T = channel top width at the water surface in feet).

- **Subcritical flow** is primarily influenced by gravitational forces, resulting in a tranquil, deep, and controlled flow. In this flow condition, the Froude number is less than 1.0.
- **Critical flow** occurs when inertial and gravitational forces are in equilibrium, taking place at a specific depth called critical depth. In this state, the Froude number is equal to 1.0.
- **Supercritical flow** occurs when the velocity is high and gravitational forces are minimal, resulting in rapid, shallow, and turbulent flow. In this state, the Froude number is greater than 1.0.

7.5.7.1 Critical Depth

Critical depth serves as a valuable tool in hydraulic analysis, allowing for the determination of the flow profile type inside the culvert and at the outlet. Critical depth is defined as the depth for which the specific energy (sum of the flow depth and velocity head) of a given discharge is at a minimum. A slight change in specific energy can result in a significant rise or fall in the water depth when flow is at or near critical depth. As a result, critical depth is an unstable condition and rarely persists over any distance along a water surface profile.

$$D_c = 0.420 \left(\frac{Q^{0.5}}{D^{0.25}} \right) \quad \text{Circular Section} \quad \text{Equation 7- 10}$$

$$D_c = \left(\frac{0.176Q}{S} \right)^{2/3} \quad \text{Rectangular Section} \quad \text{Equation 7- 11}$$

Where:

- D_c = critical depth in a circular section in feet
- Q = flow in cubic feet per second
- D = diameter in feet.
- S = span of box section in feet.

Flow at critical depth is common, occurring during the transition between flow regimes. Notably, flow passes through critical depth when transitioning from subcritical conditions—where the normal depth exceeds the critical depth—to supercritical conditions, where the normal depth is lower than the critical depth. This transition commonly takes place in areas of flow contraction, whether horizontal or vertical, such as at culvert inlets and outlets.

Figure 7 - 15 illustrates flow through a steep culvert flowing partly full. In this situation, critical depth occurs at the culvert inlet, subcritical flow exists in the upstream channel, and supercritical flow exists in the culvert barrel. Subcritical flow characteristics, such as depth and velocity, can be affected by downstream control sections.

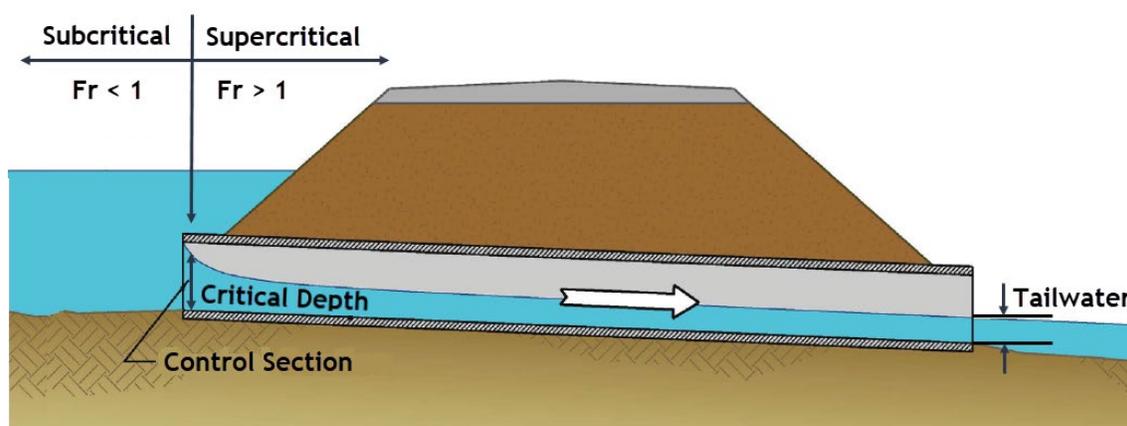


Figure 7 - 15 Critical Depth – Inlet Control

When the calculated critical depth in a culvert exceeds the diameter, the culvert is flowing full and experiences surcharge. This means the water surface is above the top of the culvert, preventing open channel flow. Although the calculated critical depth may not physically occur, the value is useful for signifying the culvert is flowing full with a surcharge.

Critical flow in a culvert occurs at critical depth, meaning the flow depth corresponds to the minimum specific energy for a given discharge and the Froude number is equal to one. Use Equation 7- 12 to determine the discharge at which critical flow occurs for a given flow area and top width at critical conditions.

$$Q_c = \left(\frac{A^3 g}{T} \right)^{1/2} \tag{Equation 7- 12}$$

Where:

- Q_c = discharge at critical depth in cubic feet per second
- g = acceleration of gravity (32 ft/second) (32.2 ft per second squared)
- A = flow area in square feet.
- T = top width of flow in feet.

Understanding and calculating discharge at critical depth is important to maintain efficient flow, prevent backwater effects, and reduce the risk of erosion. This analysis further supports the optimization of hydraulic structures, the balancing of flow energy, and the prediction of flooding.

7.5.8 Flow Control Types

Inlet and outlet control are the two types of flow control. The characterization of pressure, subcritical, and supercritical flow regimes play an important role in determining the location of the control section and thus the type of control. The hydraulic capacity of a culvert depends upon a different combination of factors for each type of control. The influencing factors that must be considered in culvert design for inlet and outlet control are shown in Table 7 - 15.

A control section is a location where there is a unique relationship between the flow rate and the upstream water surface elevation. Many different flow conditions exist over time, but at a given time the flow is either governed by the inlet geometry (inlet control); or by a combination of the culvert inlet configuration, the characteristics of the barrel, and the tailwater (outlet control). Control may oscillate from inlet to outlet control, however, the concept of “minimum performance” will ensure the culvert will never operate at a lower level of performance than calculated.

Table 7 - 16 Factors Influencing Culvert Design

Influencing Factors	Inlet Control	Outlet Control
Headwater	✓	✓
Inlet Configuration - Edge	✓	✓
Inlet Area	✓	✓
Inlet Shape	✓	✓
Barrel Slope	✓	✓
Barrel Length	✗	✓
Barrel Roughness	✗	✓
Barrel Area	✗	✓
Barrel Shape	✗	✓
Tailwater Depth	✗	✓

7.5.9 Inlet Control

Most culverts operate under inlet control, which occurs when the culvert barrel can carry more flow than the inlet will accept. The control section of a culvert operating under inlet control is located just inside the entrance. Critical depth occurs at or near this control section, and the flow regime down barrel from this control is supercritical. Upstream water surface elevation and the inlet geometry represent the major flow controls. Figure 7 - 15 illustrates the control section and critical depth in relation to the inlet geometry. Headwater elevation is calculated with respect to the inlet invert, and the tailwater elevation has no influence on performance. When the outlet is submerged under inlet control, a hydraulic jump may occur downstream of the inlet.

The United States Geological Survey (USGS) flow type depends on the submergence of the inlet and outlet ends of the culvert. Refer to Figure 7 - 16 and Figure 7 - 17 below.

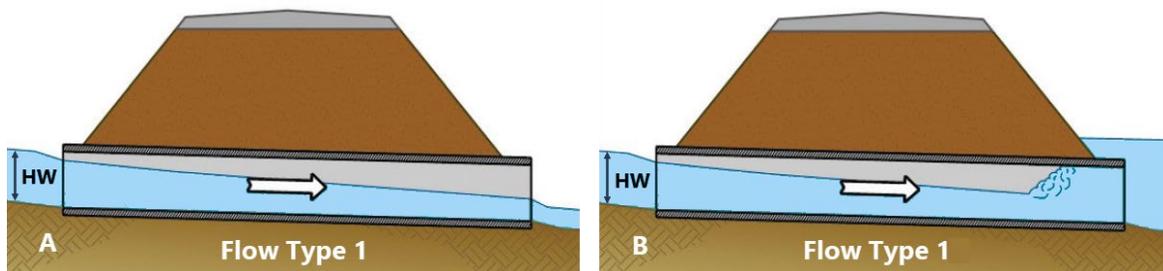


Figure 7 - 16 USGS Inlet Control Flow Type 1 – Unsubmerged Inlet

Figure 7 - 16A illustrates a scenario in which both the inlet and outlet are unsubmerged. The flow transitions through critical depth just beyond the culvert entrance, resulting in supercritical flow within the barrel. The barrel flows partially full over the entire length and the flow approaches or has reached normal depth at the outlet end.

In Figure 7 - 16B shows submergence of the outlet does not assure outlet control. In this case, the flow just downstream of the inlet is supercritical and a hydraulic jump forms in the culvert barrel.

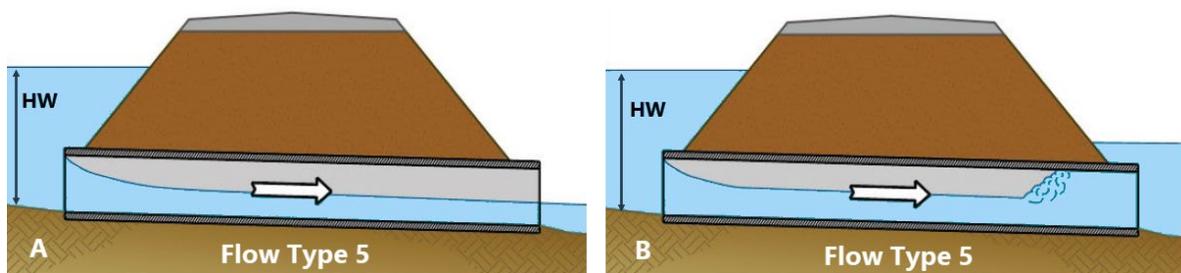


Figure 7 - 17 USGS Inlet Control Flow Type 5 – Submerged Inlet

Figure 7 - 17A is a more typical design situation. The inlet end is submerged, and the outlet end flows freely. The flow is supercritical and the barrel flows partially full over the entire length. Critical depth is located just downstream of the culvert entrance, and the flow is approaching or has reached normal depth at the downstream end of the culvert.

Figure 7 - 17B is an unusual condition illustrating the fact that even submergence of both the inlet and the outlet end of the culvert does not assure full flow. In this case, a hydraulic jump will form in the barrel. If the barrel is not vented, sub-atmospheric pressures could develop. This may create an unstable condition during which the barrel would alternate between full flow and partly full flow.

7.5.9.1 Inlet Control Hydraulics

Inlet control performance is defined by the three regions of flow shown in Figure 7 - 18: unsubmerged, transition and submerged. Under low headwater conditions (see Figure 7 - 16A and Figure 7 - 16B), the entrance of the culvert operates as a weir. For headwaters submerging the culvert entrance (see Figure 7 - 17A and Figure 7 - 17B), the entrance of the culvert operates as an orifice.

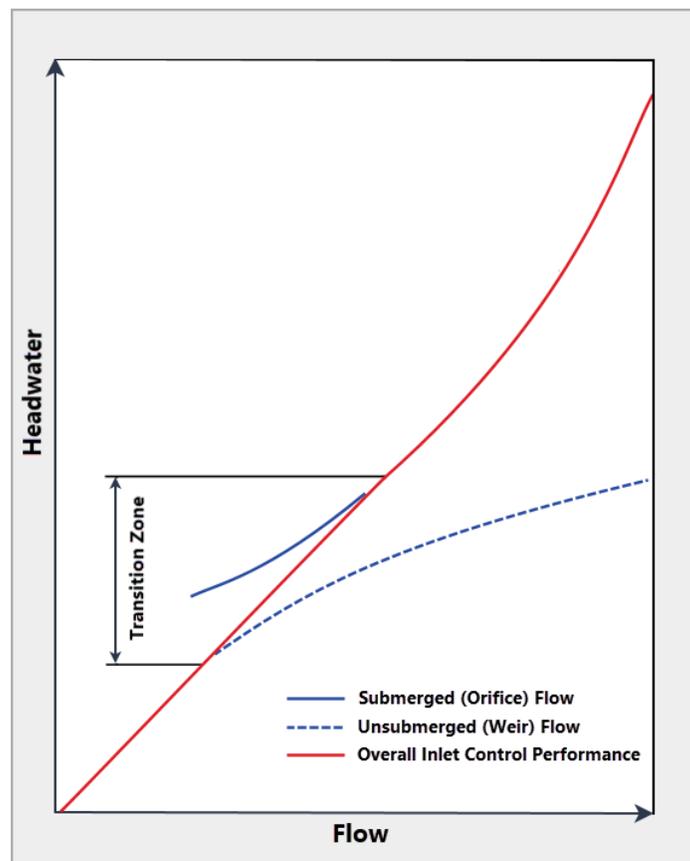


Figure 7 - 18 Inlet Control Curve

The flow transition zone between the low headwater (weir control) and the high headwater (orifice control) flow conditions are poorly defined. This zone is approximated by plotting the unsubmerged and submerged flow equations and connecting them with a line tangent to both curves. The inlet control equations developed by FHWA are discussed in the Appendix A of [HDS-5](#).

7.5.9.2 Inlet Control Performance

The inlet edge configuration is a major factor in inlet control performance and can be modified to improve performance. As the inlet edge condition improves, the flow contraction at the inlet decreases. The reduced flow contraction increases inlet performance and allows more flow through the barrel for the same headwater.

A method of increasing inlet performance is the use of beveled edges at the entrance of the culvert. Beveled edges reduce the contraction of the flow by effectively enlarging the face of the culvert. Although any beveling will improve the hydraulic efficiency, inlet configurations are available for two bevel angles, 45 degrees and 33.7 degrees in HY-8.

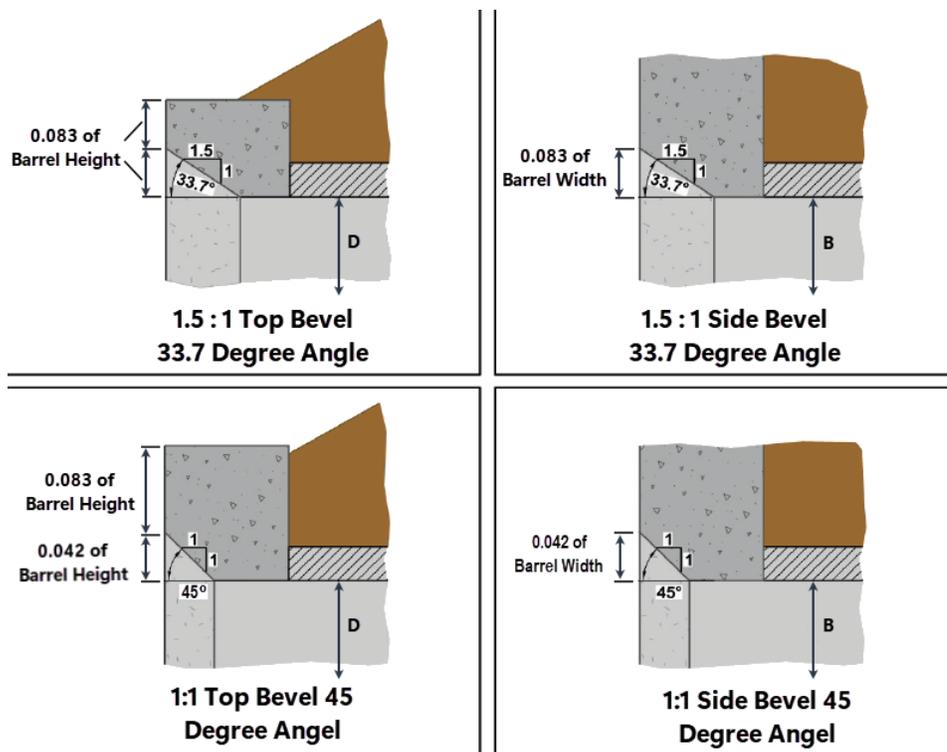


Figure 7 - 19 Beveled Edges

The smaller, 45-degree bevel requires very minor structural modification of the culvert headwall and increases both inlet and outlet control performances. Therefore, the use of 45-degree bevels is required on all culverts that have a headwall, whether in inlet or outlet control.

Since the groove end or bell end of a concrete pipe provides about the same performance as a beveled edge, a bevel is not needed if the groove is preserved at the inlet.

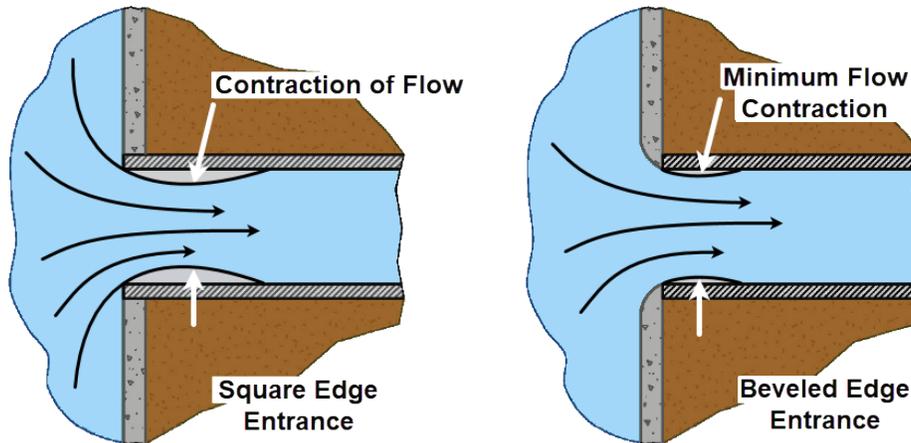


Figure 7 - 20 Entrance Contraction

7.5.10 Outlet Control

Outlet control occurs when the hydraulic capacity of the culvert barrel is not capable of conveying as much flow as the inlet opening will accept. This condition limits the overall discharge through the culvert barrel. The control section of a culvert operating under outlet control is located at the barrel exit or further downstream. The flow regime within the culvert barrel is typically subcritical; however, pressure flow may develop depending on the relative elevations of the headwater and tailwater.

All of the geometric and hydraulic characteristics of the culvert in Table 7 - 15 play a role in determining the capacity. Headwater elevation is calculated with respect to the outlet invert, and the difference between headwater and tailwater elevation represents the energy that carries the flow through the culvert. The USGS flow type depends on the submergence of the inlet and outlet ends of the culvert. Refer to Figure 7 - 21 and Figure 7 - 22 below.

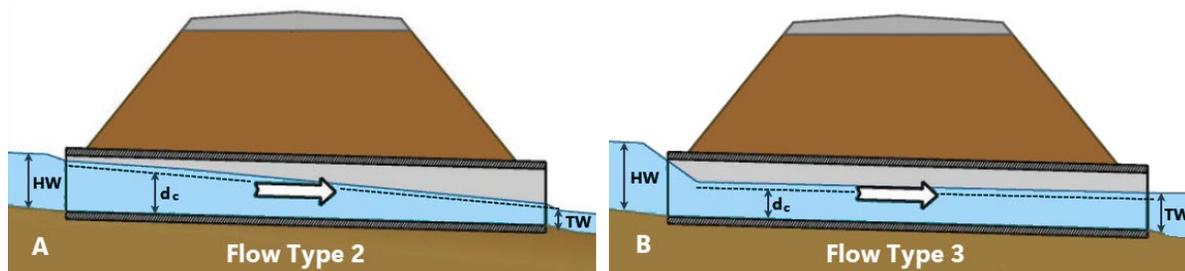


Figure 7 - 21 USGS Outlet Control Flows – Unsubmerged Inlet

Figure 7 - 21 illustrates two scenarios in which both the inlet and outlet are unsubmerged. The headwater is shallow so that the inlet crown is exposed as the flow contracts into the culvert. The barrel flows partly full over its entire length and is subcritical. For flow type 2 (Figure 7 - 21A), the flow passes through critical depth at the outlet. For flow type 3 (Figure 7 - 21B), the tailwater is higher than critical depth.

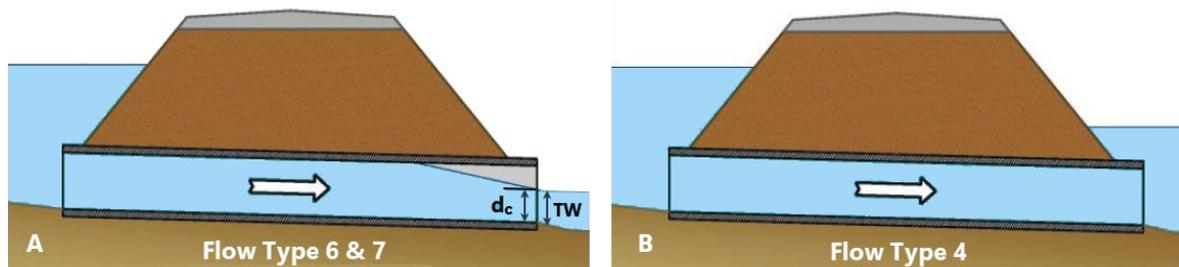


Figure 7 - 22 USGS Outlet Control Flow Types – Submerged Inlet

Figure 7 - 22A shows the culvert entrance is submerged by the headwater, and the outlet end is unsubmerged. The flow passes through either critical depth just upstream of the outlet or the tailwater depth, if higher. For flow type 6, the barrel is assumed to flow full for most of the length. For flow type 7, the barrel flows partly full over at least part of the length.

Figure 7 - 22 B illustrates a full flow condition, where both inlet and outlet are submerged. The barrel is in pressure flow throughout the length and can also occur when the exit is unsubmerged by tailwater. Flow type 4 is a rare condition requiring either an extremely high headwater to maintain full barrel flow with no tailwater or critical depth that is higher than the culvert.

7.5.10.1 Outlet Control Hydraulics

This section presents the principles of outlet control under full barrel flow and partial full flow conditions in relation to the balance of energy. Additional information regarding these flow regimes, and the application of the conservation of energy are provided in Chapter 3 of [HDS-5](#).

Full Barrel Flow

Full flow in the culvert barrel, as shown in Figure 7 - 22, is the most suitable flow type for describing the computation of outlet control hydraulics. The total energy (H_L) required to pass the flow through the culvert barrel is the sum of the entrance loss (H_e), the friction losses through the barrel (H_f), and the exit loss (H_o). The difference between headwater and tailwater elevation represents the energy that carries the flow through the culvert.

$$H_L = H_e + H_f + H_o \quad \text{Equation 7- 13}$$

Include other losses as appropriate, including bend losses (H_b), losses at junctions (H_j), and losses at grates (H_g). Chapter 5 of [HDS-5](#) discusses these losses.

Entrance Loss (H_e)

The entrance loss is a function of the velocity head in the barrel, ($V^2/2g$) and can be expressed as a coefficient times the velocity head. The velocity head is the difference between energy grade line and the hydraulic grade line.

$$H_e = k_e \left(\frac{V^2}{2g} \right) \quad \text{Equation 7- 14}$$

Where:

k_e = entrance loss coefficient

V = velocity of full flow in the culvert barrel in feet per second

g = acceleration of gravity, 32.2 feet per second squared

Refer to Table 7 - 16 for values of k_e based on various inlet configurations and HDS-5 for more detail.

Barrel Friction Loss (H_f)

The friction loss in the barrel is also a function of the velocity head. Based on the Manning equation, the friction loss is:

$$H_f = \left[\frac{29n^2L}{R^{1.33}} \right] \frac{V^2}{2g} \quad \text{Equation 7- 15}$$

Where:

n = Manning roughness coefficient

L = length of the culvert barrel in feet

R = hydraulic radius of the full barrel

Exit Loss (H_o)

The exit loss is a function of the change in velocity at the outlet of the culvert barrel and the downstream channel. The downstream velocity is usually neglected, in which case the exit loss is equal to the full flow velocity head in the barrel. Equation 7-16 is the standard option in HY-8.

$$H_o = H_v = \frac{V^2}{2g} \quad \text{Equation 7- 16}$$

The Utah State University method is an alternative for applications like irrigation channels where a small amount of energy is lost in the transition back to the channel.

$$H_o = \frac{(V - V_d)^2}{2g}$$

Equation 7- 17

Where: V_d = velocity in downstream channel in feet per second

Head Loss (H_L)

Inserting the above relationships for entrance loss, friction loss, and exit loss into Equation 7- 13, the following equation for head loss is obtained.

$$H_L = \left(1 + k_e + \frac{29n^2L}{R^{1.33}} \right) \frac{V^2}{2g}$$

Equation 7- 18

Figure 7 - 23 shows the energy grade line and the hydraulic grade line for full flow in a culvert barrel. The energy grade line represents the total energy at any point along the culvert barrel. HW_o is the depth from the inlet invert to the energy grade line. The hydraulic grade line is the depth to which water would rise in vertical tubes connected to the sides of the culvert barrel. In full flow, the energy grade line and the hydraulic grade line are parallel straight lines separated by the velocity head except in the vicinity of the inlet where the flow passes through a contraction.

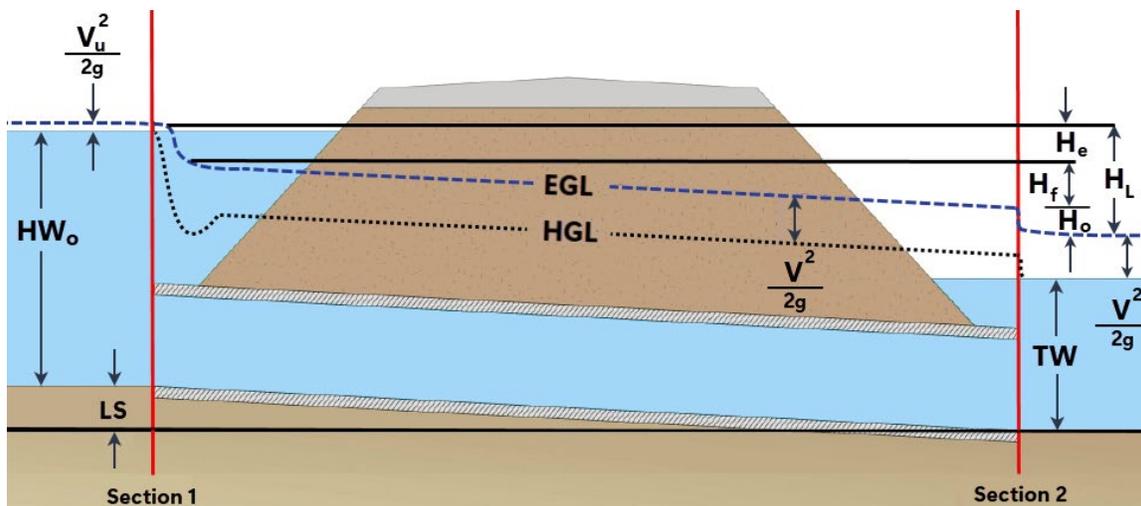


Figure 7 - 23 Full flow EGL and HGL

Refer to Figure 7 - 23 for an example of headwater and tailwater conditions, along with the entrance, friction, and exit losses. Equating the total energy at sections 1 and 2, upstream and downstream of the culvert barrel the following relationship results:

$$HW_o + LS + \frac{V_u^2}{2g} = TW + \frac{V_d^2}{2g} + H_L \quad \text{Equation 7- 19}$$

Where:

- HW_o = headwater depth above the entrance invert in outlet control in feet
- V_u = approach velocity in feet per second
- TW = tailwater depth above the outlet invert in feet
- V_d = channel velocity downstream of the culvert in feet per second
- H_L = sum of head loss in feet
- LS = drop through the culvert in feet

In most instances, the approach velocity is low, and the approach velocity head is neglected. However, the velocity head can be considered part of the available headwater and used to convey the flow through the culvert. Likewise, the velocity downstream of the culvert V_d is usually neglected. When both approach and downstream velocities are neglected, Figure 7 - 23 simplifies to:

$$HW_o = TW + H_L - LS \quad \text{Equation 7- 20}$$

In this case, H_L is the difference in elevation between the water surface elevation at the outlet (tailwater elevation) and the water surface elevation at the inlet (headwater elevation).

Table 7 - 17 Entrance Loss Coefficients

Type of Structure and Design of Entrance ¹	Coefficients k_e
Common Shared End Types	--
Beveled edge entrance, 33.7° or 45° bevels	0.2
Side- or slope-tapered inlet	0.2
² End section conforming to fill slope	0.5
Mitered to conform to fill slope (paved or unpaved)	0.7
Pipe, Concrete	--
Projecting from fill, socket end (groove-end)	0.2
Projecting from fill, square cut end	0.5
Headwall or headwall and wingwalls	
Socket end of pipe (groove end)	0.2
Rounded radius of [1/12 (D)]	0.2
Square-edge	0.5

Type of Structure and Design of Entrance ¹	Coefficients k_e
Pipe, or Pipe-Arch, Corrugated Metal	--
Headwall or headwall and wingwalls square edge	0.5
Projecting from fill (no headwall)	0.9
Box, Reinforced Concrete	--
Side- or slope-tapered inlet	0.2
Headwall parallel to embankment (no wingwalls)	0.2
Rounded on 3 edges to radius of [1/12 (D)]	0.2
Beveled edge entrance on 3 side	0.5
Square-edged entrance on 3 edges	0.5
Wingwalls at 30° to 75° to barrel	0.2
Crown edge entrance rounded to radius of [1/12 (D)]	0.2
Beveled top entrance edge	0.4
Square-edged entrance at crown	0.5
Wingwalls at 10° to 25° to barrel - Square-edged at crown	0.5
Wingwalls parallel (extensions of sides) - Square-edged at crown	0.7

¹ See section 7.6 Culvert End Treatments for design policy.

² Note: "End Section conforming to fill slope," are sections available from manufacturers. Limited hydraulic tests indicate they operate equivalently to a headwall in both inlet and outlet control.

Partial Flow

To accurately determine the headwater depth for the free surface and partial full flow conditions shown in Figure 7 - 24 and Figure 7 - 25, the water surface profile through the culvert barrel must be calculated.

The calculation starts at the water surface at the downstream end of the culvert and proceeds upstream to the culvert entrance. The downstream water surface is based on critical depth at the culvert outlet or the tailwater depth, whichever is higher. If the calculated backwater profile intersects the top of the barrel, as in Figure 7 - 25, a straight, full flow hydraulic grade line extends from that point upstream to the culvert entrance.

HY-8 is the most effective method for calculating the headwater elevation for partial flows in outlet control. The software estimates backwater elevations using principles based on conservation of energy, not by computing full water surface profiles. If the outlet is submerged, HY-8 uses the energy equation to determine the hydraulic grade line. Once the hydraulic grade line falls below the crown of the culvert, HY-8 uses the direct step method to determine the remainder of the profile.

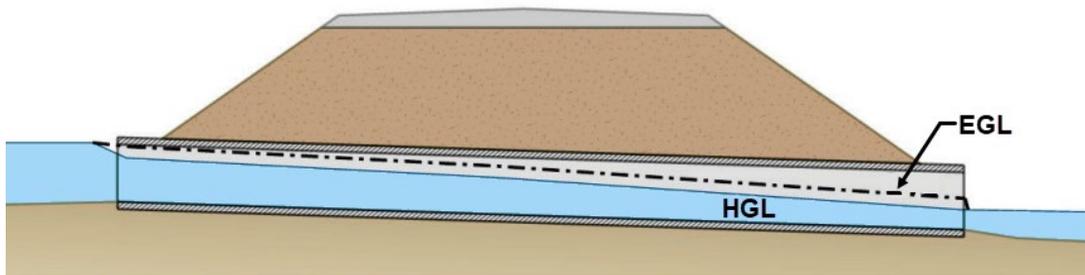


Figure 7 - 24 Free Surface Flow

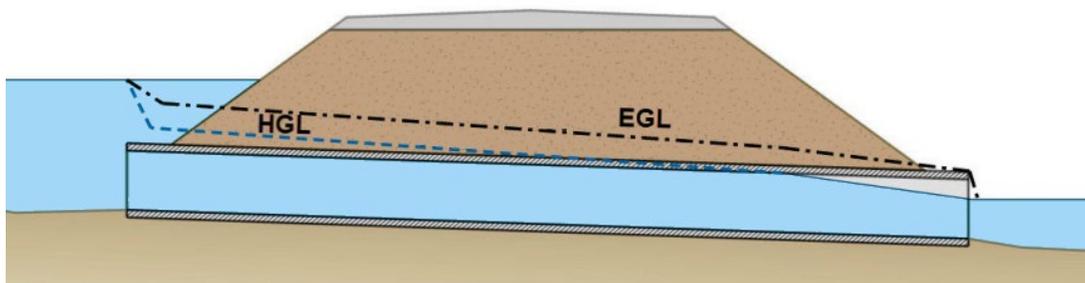


Figure 7 - 25 Partial Full Flow

7.5.11 Outlet Velocities

Calculating culvert outlet velocities is essential for evaluating the potential for downstream erosion and determining the need for protective measures. Since culverts often discharge at higher velocities than natural stream flows, unprotected outlets can cause channel erosion, scour holes, and structural instability.

Design modifications can help reduce outlet velocities and improve culvert performance. Varying the culvert's grade generally has the most significant impact on velocity changes. However, since many culverts are installed at the natural grade of the existing channel, altering this parameter is often challenging. When modifying the outlet velocity is necessary, consider increasing the barrel's roughness, adjusting the culvert size, or changing the shape.

If design modifications are insufficient to reduce outlet velocities, use mitigation measures like an energy dissipator or rip rap to prevent downstream scour. For guidance on selecting and designing suitable energy dissipation measures, refer to the [Energy Dissipator Chapter](#).

7.5.12 Culvert Hydraulic Form and Nomographs

Refer to [HDS-5](#) for inlet and outlet nomographs. These nomographs are sufficiently accurate for most design purposes. They are not, however, as accurate as the equations in HY-8. In

formulating inlet and outlet control design nomographs a certain degree of error is introduced into the design process. This error is due to the fact that the nomograph construction involves graphical fitting techniques resulting in scales which do not exactly match the equations.

7.6 Culvert End Treatments

In certain flow conditions, end treatments can provide a more gradual flow transition by reducing energy losses associated with flow contraction. This is particularly important under inlet control where the discharge capacity can be improved.

End treatments also enhance embankment stability, roadside safety, and aesthetics. Design considerations must account for potential buoyancy, reduced structural integrity when materials are mitered to the slope, and the potential of end section separation. This section discusses several types of end treatments, along with ODOT design practice and policy as referenced in Table 7 - 17.



Table 7 - 18 End Treatment Design Policy

Criteria	End Treatment Design Policy
Clear Zone	--
Exposed pipe ends within the safety clear zone	See Highway Design Manual and criteria below
All pipe 48 in. diameter (or equivalent) and greater	
Mitered collar or Headwall	Design with an bevel entrance of 45° or 33.7°
Pipe less than 48" in. diameter or equivalent	
Thermoplastic Pipe	
Paved end section	Design paved end section, mitered collar, and headwall with a 45° or 33.7° bevel entrance
Mitered collar or headwall	
Projecting	Projecting: not allowed for thermoplastic
Concrete Pipe	
Projecting	¹ Use tie-bar at the first two and last two pipe joints
Paved end slope	Design paved end section, paved mitered collar, and headwall with a 45° or 33.7° bevel entrance
Mitered collar or headwall	
Metal Pipe	
Projecting end	Not recommended
Paved end slope	Design paved end section, paved mitered collar, and headwall with a 45° or 33.7° bevel entrance
Mitered collar or headwall	

¹ Tie-bar installation see [Standard Drawing RD318](#)

Headwalls, mitered end sections, and cut-off walls are categorized as Other Structures. Designers should notify the Bridge section early in the project that these elements are included.

7.6.1 Clear Zone End Treatments

The exposed end of a culvert or culvert headwall represents an unyielding barrier to vehicles leaving the roadway. Roadside safety standards provide distance from pavement limitations based on speed and other factors protect occupants of vehicles. When culvert ends are within the safe recovery area, appropriate inlet and outlet design may reduce the danger they represent. Mitering the inlet and outlet to conform to the fill slope will reduce the obstruction to a vehicle. Refer to ODOT's [Highway Design Manual](#) Section 404 for end treatment design within the safety clear zone.

7.6.2 Headwalls with Bevels

A headwall is a structural component installed at the inlet and/or outlet of a culvert constructed from reinforced concrete. They are designed to retain the roadway embankment, prevent erosion at the culvert ends, and provide structural stability. Headwalls are often designed with or without wingwalls, depending on hydraulic and site-specific requirements.

Design and construct all headwalls with beveled edge entrances, as specified in Table 7 - 17. Headwalls are one of the most hydraulically efficient end treatments. The designed cutoff walls protect the culvert ends from undermining due to scour, and they are efficient at passing debris. However, the primary disadvantages of headwalls are their relatively higher construction complexity and cost compared to other end treatment options.

7.6.3 Mitered End Section

Mitered end sections are preferred as they are more hydraulically efficient than metal and thermoplastic projecting ends. A mitered culvert end is formed when the culvert barrel is cut to conform to the plane of the embankment slope. These types of ends also benefit maintenance operations by reducing contact with equipment.

Cutting the pipe to match the slope often reduces wall strength, particularly for metal and thermoplastic pipes, increasing vulnerability to buoyant uplift, debris impact, and damage from maintenance activities. To mitigate these risks and ensure long-term stability, all mitered ends must include a special end treatment as specified in Table 7 - 17.



Figure 7 - 26 Mitered Collar

7.6.4 Cut-off Walls

Cut-off walls are required on all headwalls and mitered collar end treatments. These walls provide protection from erosion, at the inlet and outlet of a culvert. They can also be the first step in controlling piping or seepage problems, prior to considering more extensive anti-seep collars.

7.6.5 Projecting Ends

A projecting end is a treatment where the culvert inlet or outlet extends beyond the face of the roadway embankment. The primary advantages are the simplicity and cost when installing. Projecting ends also provide excellent strength characteristics because the pipe consists of a complete ring structure out to the culvert end.

Projecting ends do have several disadvantages:

- For **metal and thermoplastic**, the thin wall does not provide a smooth flow transition at the inlet or outlet, significantly increasing head losses. In contrast, concrete culverts feature a socket or groove end, which provide a more hydraulically efficient transition.
- **Metal and thermoplastic** pipes with projecting ends are especially vulnerable to uplift from buoyant forces, especially under submerged or high-flow conditions.
- **Pipe segments** near the inlet and outlet are vulnerable to joint separation if embankment scour occurs, compromising structural integrity.
- **Projecting ends** are vulnerable to debris impact and vehicular damage, which can increase maintenance requirements.
- From an **aesthetic perspective**, projecting ends may be undesirable in locations visible to the public or within scenic corridors.

7.6.6 Prefabricated

Prefabricated end sections are end treatments available for both corrugated metal and concrete pipe. They are designed to reduce embankment erosion and typically experience less damage from maintenance activities. When used with projecting metal pipe ends, prefabricated end sections can enhance hydraulic efficiency and improve the overall appearance of the installation. Hydraulically, prefabricated end sections perform comparably to headwalls.

There are limitations and conditions on prefabricated end section use. These end sections can be used for culverts 36 inches in diameter or smaller. They are also susceptible to buoyancy and may require anchors to resist hydrostatic uplift forces. Prefabricated concrete end sections do not include cut-off walls and are vulnerable to scour unless a cut-off wall is constructed beneath the edges of their aprons. These end treatments are not recommended in roadside ditches, as routine maintenance activities can damage or displace the structure.



Figure 7 - 27 CMP Flared-End

7.6.7 Improved Inlets

Improved inlets significantly increase hydraulic performance for culverts under inlet control. They feature a flared entrance with an enlarged face section and a hydraulically efficient throat section. Side-tapered and slope-tapered inlets are commonly called tapered inlets, see Figure 7 - 19. When considering the use of a tapered inlet the designer should evaluate the increased construction cost of the taper section. For this reason, they are seldom used in typical culvert design. Often increasing the culvert diameter size can achieve the same hydraulic efficiency with a lower cost. Refer to [HDS-5](#) for the hydraulic design of these inlets.

Improved inlets may be justified under certain conditions. For example, when replacing an entire culvert is cost-prohibitive, the capacity of an existing inlet-controlled culvert can be increased by retrofitting with an improved inlet. For new construction projects, improved inlets can be justified for exceptionally long culverts, and the headwater is controlled by inlet conditions.

Besides the high construction costs, improved inlets are unsuitable for fish passage and are more susceptible to clogging in areas with heavy debris. This can increase maintenance costs and reduce long-term reliability.

7.6.8 Tide Gates

The Oregon Department of Transportation has established Policy (MAI 06-04). This policy discontinues the installation, maintenance, or repair of tide gates unless they directly benefit public highways or are required by a written agreement.

7.7 Specialized Culverts

The preceding sections of this chapter cover the basics of culvert location and design. This section provides additional guidance on culverts used in special applications that require additional design considerations and analysis.

7.7.1 Fish passage

For culvert design associated with fish-bearing channels refer to the Fish Passage Chapter.

7.7.2 Long Span Culverts

Long span culverts include both open-bottom culverts and closed-bottom culverts that are classified as National Bridge Inventory (NBI) structures. A culvert qualifies as NBI culvert if the span is 20 feet or greater, measured along the centerline of the highway. This classification includes multiple culvert barrels with a combined span of 20 feet or more, provided the distance between openings is less than half the width of the larger opening.

Scour evaluation, mitigation measures, and footing protection are required for all open-bottom culverts and NBI single-span culverts. Detailed guidance is provided in the [Bridge Hydraulic Chapter](#).

7.7.3 Slope Pipes

Sloped pipes are commonly used to convey water down embankments when open channel flow is impractical due to steep slopes or erosion concerns. Surface installation of slope pipes is preferred, as this method provides easier access for inspection, maintenance, and repair.

Structural anchorage is required to resist uplift and potential pipe movement along steep slopes. Where slope instability is anticipated, a slip joint may be incorporated to accommodate differential movement and reduce stress on the pipe. A clean-out gate is required at the outlet end of the cross culvert, just before the slope break. The gate allows for convenient access to remove accumulated sediment or debris before entering the slope pipe helping maintain system performance. ODOT has multiple standard drawings and details that provide guidance on the design and installation of sloped pipes, including the cleanout gate.

Energy dissipation measures at the outlet, such as impact basins, riprap pads, or stilling basins, are essential for reducing flow velocity. These features help mitigate scour at the toe of the embankment and protect downstream infrastructure. Refer to the [Energy Dissipator Chapter](#) and [HEC-14 Hydraulic Design of Energy Dissipators, Chapter 7](#), for guidance design and protection.

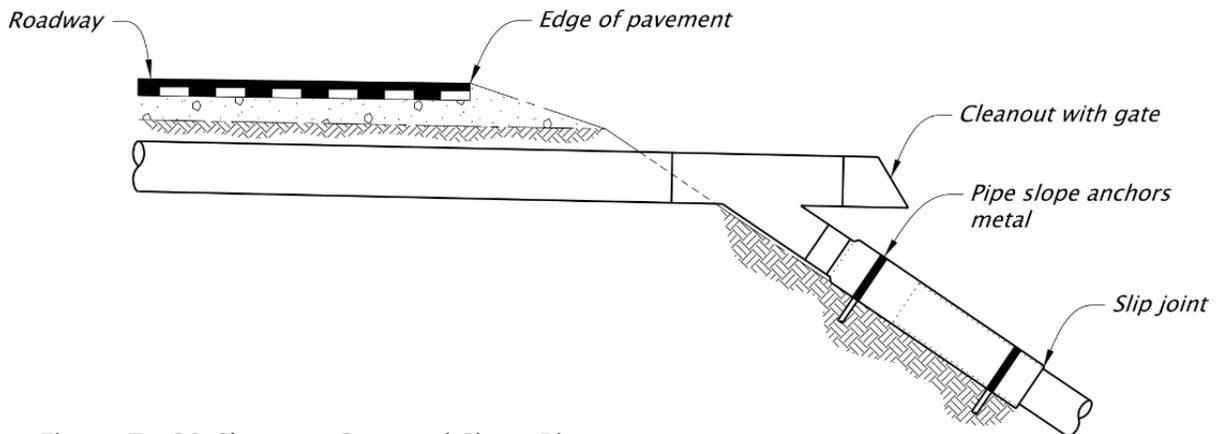


Figure 7 - 28 Cleanout Gate and Slope Pipe

7.7.4 Broken Back Culverts

Broken-back culverts reduce excavation costs and force a hydraulic jump for energy dissipation and scour prevention in the downstream channel. They provide an alternative to a uniformly steep culvert by featuring a steeper inlet section followed by a flatter or horizontal runout section.

The sections for a single broken-back culvert are referred to as 'Upper' and 'Runout' sections. For a double broken-back culvert, the sections are referred to as 'Upper', 'Steep', and 'Runout' sections as shown in Figure 7 - 29. For proper performance, there must be sufficient tailwater, and sufficient friction and length in the runout section. To achieve this, use one or more devices, such as roughness baffles, to create a tailwater that is high enough to force a hydraulic jump.

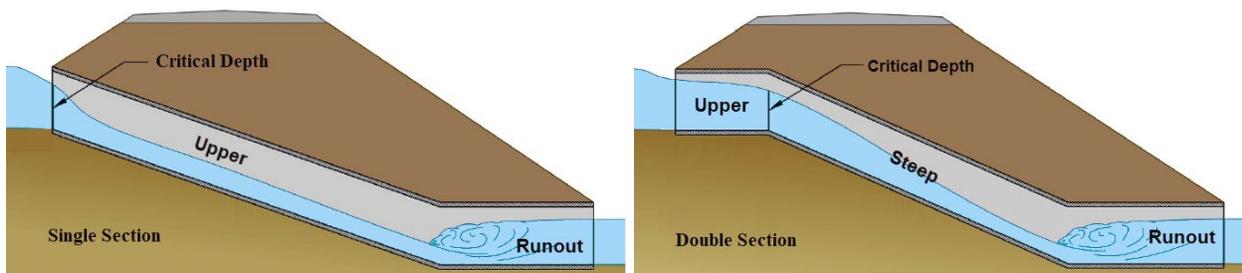


Figure 7 - 29 Broken Back Culverts

HY-8 supports single and double broken-back culverts. The equations for broken-back culverts used in HY-8 are not valid for culvert sections with slopes greater than 55 degrees and should not be used in such cases. Applying these equations to very steep slopes will give in unrealistic results. Refer to the [Energy Dissipator Chapter](#) and [HEC-14 Hydraulic Design of Energy Dissipators, Chapter 7](#) for outlet protection.

7.7.5 Sag Culvert

A sag culvert, often called an inverted siphon, is used extensively to carry irrigation water under highways. The elevation changes at each end of the culvert occur in reinforced concrete boxes called “siphon boxes” where the end pipes enter the box at higher elevations than the center pipe. They are used infrequently for highway drainage and should be avoided on intermittent or alluvial streams because of problems with siltation and stagnation.

The design of sag culverts is beyond the scope of this manual. Information on sag culverts can be found in the Association of State Highway and Transportation Officials (AASHTO) Model Drainage Manual, AASHTO Highway Drainage Guidelines, and [HEC-22 Urban Drainage Design](#).

7.8 Abandoned Culvert Guidelines



All abandoned culverts are required to be filled with a flowable controlled low strength material or sealed at both ends depending on material type and site conditions. Following established abandonment procedures ensures the safety of the roadway, protects the environment, and minimizes long-term infrastructure costs. Culverts left in place without following established best practices can become safety hazards. Refer to Table 7 - 18 for potential consequences of not following established best practices.

Table 7 - 19 Potential Impacts

Conditions	Potential Impacts
Continuing material deterioration	Settlement leading to cracks in the roadway. Structural failure and possible roadway failure.
Piping and waterflow	Potential undermining of roadway; voids and potholes; possible flooding.
Maintenance	Invest time and resources to correcting problems, often resulting in higher long-term costs. Disruptions in transportation services.
Environmental	Transporting contaminants or eroding surrounding soil into nearby streams or wetlands.

Abandoning a culvert in place is an important process that requires planning and proper implementation. The process involves several important steps, from assessing the condition of the culvert to final documentation. Below are five key steps to properly abandon a culvert and a decision tree as shown in Figure 7 - 30:

- Step 1. **Assessment of Culvert Condition and Site:** Inspect the culvert to determine the condition and suitability for abandonment. Assess factors like material degradation, structural integrity, and whether there are existing or potential issues such as groundwater flow, potential voids in the highway embankment, or settlement.
- Step 2. **Filling the Culvert (If required):** Fill the entire culvert with flowable controlled low strength material to prevent future subsidence or the formation of voids that can cause settlement.
 - If voids are identified in the highway embankment, drilling holes in the pavement or shoulder may be required to introduce flowable controlled low strength material.
 - Grouting may be performed within larger culverts using injection ports to fill any voids around the culvert exterior.
- Step 3. **Culvert Sealing and Plugging (If required):** Seals should be water-tight to prevent water from infiltrating the abandoned culvert.
- Step 4. **End Treatments:** Remove or modify all end treatments within the safety clear zone or interfere with future road construction.
- Step 5. **Documentation:** To maintain a record for the future, show locations on the construction plans and document the abandonment process in the hydraulic report or memo. Forward the information to Hydraulic Engineering Section for inclusion into the hydraulics asset system.

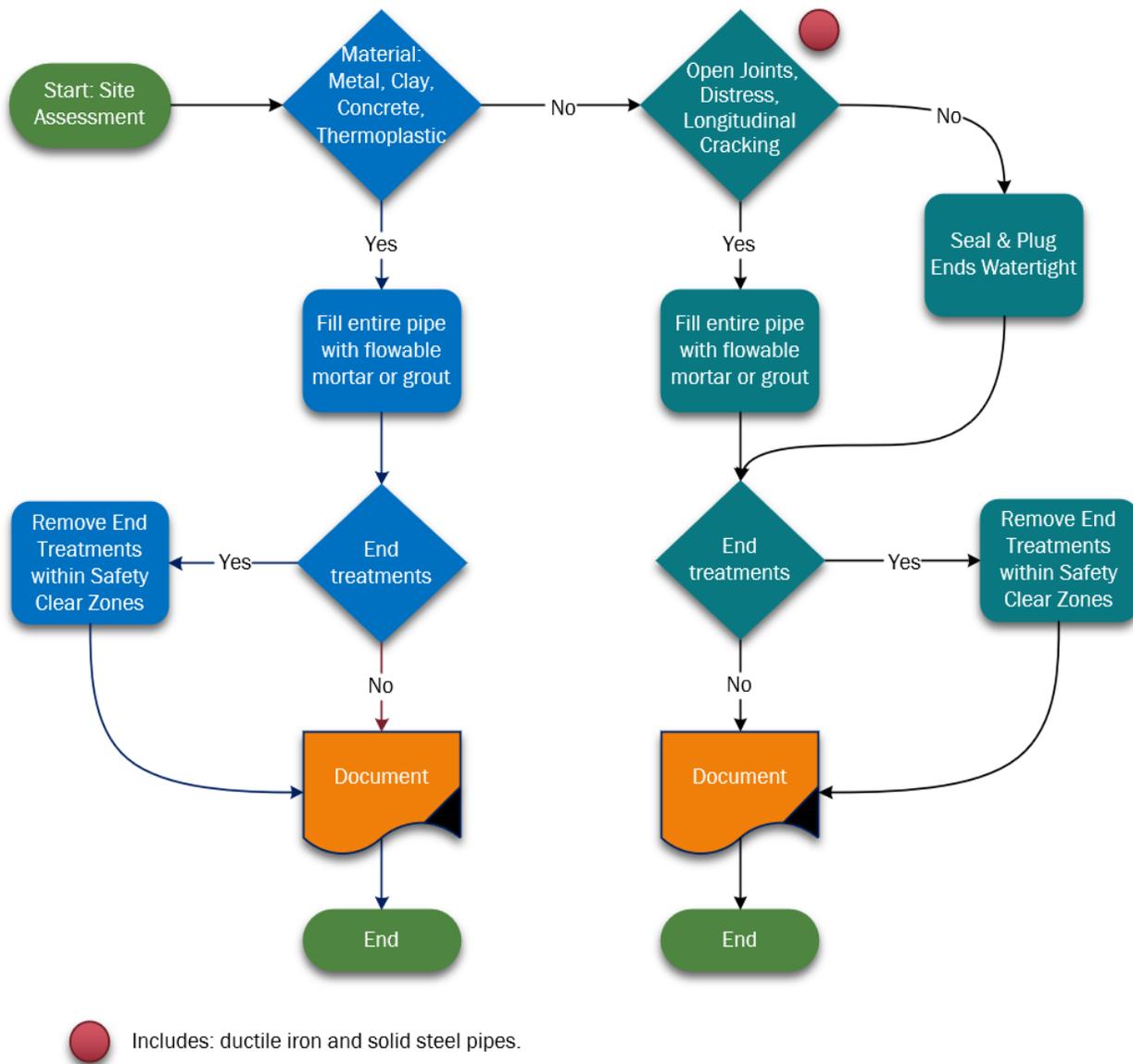


Figure 7 - 30 Guidelines for Culvert Abandonment

7.9 Culvert Identification Markers

The Hydraulic Engineering Section (HES) is responsible for inspecting, maintaining asset information, and assigning drainage facility identification number (DFI) for culverts that range

from 12 inches to under 20 feet in culvert span. The purpose of the culvert marker is to set a statewide standard for locating and properly identifying culverts along the State's highway system.

A unique DFI on the culvert marker helps aid in the accurate identification for maintenance, scoping, construction, and inspection personnel. Standard Drawing [RD398](#) and the Oregon Standard Specification [00842](#) describe the material, installation, and placement of the culvert markers.

7.9.1 Type 1 Culvert Marker

The Type 1 culvert marker is a green preformed fused thermoplastic tape that measures from six to twelve inches in length by four inches wide and does not need a DFI for installation. Place the Type 1 culvert marker along the inlet edge of the pavement for quick identification from the road surface.

7.9.2 Type 2 Culvert Marker

Type 2 culvert markers consist of a non-reflective aluminum paddle with a white background and black lettering. Each paddle is marked with the culvert DFI and features a green strip near the top. All Type 2 culvert markers must have an approved DFI and mile point from HES and be accompanied by a Type 1 culvert marker.

Note that Type 2 markers are not part of the mile point or road delineator systems. Install the culvert markers in locations where they are not conspicuous to the traveling public. Do not attach Type 2 markers directly to any historic structures.

7.9.3 Culvert DFI Parameters



Only use culvert markers for culverts that cross under the highway and pipes adjacent to the highway system. Refer to Table 7 - 19 for the required culvert DFI parameters listed by size, structure type, and application.

- When replacing an existing culvert, a new DFI is required.
- For all repairs and rehabilitation methods use the existing DFI.
- For new culverts, a DFI is required.

The Hydraulic Engineering Section assigns all the DFI's, while the Bridge Engineering Section assigns all bridge structure numbers. For guidance on markers and DFI's for stormwater features refer to the [Field Marker](#) chapter.

Table 7 - 20 DFI Parameters

Culvert DFI Parameters	DFI Required	Structure Number Required:
Culvert span between 12" and less than 20 ft	--	--
Under highway travel lanes and shoulder	✓	✗
Culverts parallel or adjacent to the highway	✓	✗
Single grate or drop inlet with an open end at the outlet	✓	✗
Structure Type	--	--
Culverts with a manufactured bottom that meet size the criteria above	✓	✗
Box culverts of any size	✗	✓
Open bottom culverts of any size	✗	✓
Rigid frames	✗	✓
Equipment and pedestrian structures	✗	✓
Application	--	--
Culverts under private approaches	✗	✗
Culverts connected to systems by manholes or inlets	✗	✗

7.9.4 Requesting a Culvert DFI

Provide the following information, along with the plan sheet and pipe data sheet for each facility needing a DFI and submit to the Hydraulic Engineering Section using the [Project Design Process Form](#). When replacing an existing culvert, a new DFI is required. For all repairs and rehabilitation methods use the existing DFI.

Table 7 - 21 Culvert DFI Information

Culvert DFI Information	Example
ODOT highway number and mile point Frontage / Connection ID if needed	Hwy 001 Hwy 001AB
Barrel Rise, Span	Rise: 48" & Span: 60"
Shape	Circular, Box, Arch
Material	CMP, Concrete, Thermo-Plastic, Wood, Iron/Steel
Orientation	Cross, adjacent right, adjacent left
Inlet side	Right / left looking in the increasing mile point direction
Height of Cover (crown to paved shoulder)	Inlet: 12ft & Outlet: 20ft
Facility Usage	Roadside Drainage, Stream, Animal Passage, Overflow, Siphon, Irrigation, Slough, Utilities
Stream Name	Official name from Video Log
Requester, Project Name, & Key Number	John Smith, US101 Culverts, K01234

7.10 References

Buffington, J., & Montgomery, D. (2013). *Geomorphic Classification of Rivers*. Retrieved from U.S. Forest Service: https://www.fs.usda.gov/rm/pubs_other/rmrs_2013_buffington_j001.pdf

Dunn, C., & McEvoy, A. (2024). *Technical Guide: Mapping Wildfire Hazard and the*. Retrieved from Developing Oregon’s Statewide Wildfire Hazard Map: https://hazardmap.forestry.oregonstate.edu/sites/default/files/OSU_2025_HazardMapMethods.pdf