**Chapter 7  Fish Passage**

### 7-1 Introduction

This chapter covers the design requirements for water crossings on state highways over fish bearing waters. See Chapter 3 for the design of non-fish bearing culverts. Most rivers and creeks in Washington State contain one or more species of fish during all or part of the year. This chapter has been updated to reflect the requirements for fish passage projects on WSDOT highways from current WAC Hydraulic Code Rules; the 2017 USACE, Seattle District, Nationwide Permit Regional Conditions; and the 2013 Federal Court Injunction for Fish Passage. This chapter is specific to WSDOT projects. For non-WSDOT projects, it is up to the project owner to determine whether the guidance in this chapter is followed or other guidance is followed to obtain project permits and follow state law. WSDOT is actively monitoring completed fish passage projects and will update this chapter as new information becomes available. See Section 7-7 for more information.

All fish-bearing water crossings within Washington State must meet the requirements of WAC’s Hydraulic Code Rules (apps.leg.wa.gov/wac/default.aspx?cite=220-660), and the requirements of the *Hydraulics Manual*, unless a deviation is approved by the HQ Hydraulics section. In Water Resource Inventory Areas (WRIAs) 1 through 23, the design must also meet the requirements of the 2013 Federal Court Injunction for Fish Passage. This chapter uses the WDFW’s 2013 Water Crossing Design Guidelines (WCDG) as reference. Other published manuals and guidelines may be used with the approval of the HQ Hydraulics Section and permitting agencies. A list of approved manuals and guidelines can be found on the WDFW Fish Passage Program website (https://wdfw.wa.gov/conservation/habitat/fish_passage/guidance_standards.html).

New bridges and fish-bearing culverts must be designed to meet current fish passage standards and WAC to ensure they do not hinder fish use or migration. WAC requires a person to design water-crossing structures in fish-bearing streams to allow fish to move freely through them at all flows that fish are expected to move.

WSDOT and WDFW have cooperated in a Fish Passage Barrier Removal Program since 1991. PEOs can check the fish barrier database (www.wsdot.wa.gov/Projects/FishPassage/default.htm) or contact the HQ Environmental Services Office biology branch to determine whether the project has any fish barriers within its limits and whether or not the crossing will need to be included as part of the project. All water crossings over fish-bearing waters shall be designed by the HQ Hydraulics Section or by an individual approved by the HQ Hydraulics Section (see Chapter 1).

Section 7-2 discusses requirements for assessing and documenting existing conditions to design a successful and fish-passable water crossing. Section 7-3 provides a discussion of hydraulic analyses required for the design, and Sections 7-4 and 7-5 discuss the design process, considerations, and criteria. Section 7-6 provides guidance on temporary diversions, Section 7-7 describes the WSDOT monitoring process, and Section 7-8 concludes the chapter with a discussion of additional resources.

This chapter uses the term Stream Designer(s) to denote work that either the HQ Hydraulics Section or the individual approved by the HQ Hydraulics Section performs and to separate that work from the work that the PEO would do in the rest of the manual. This chapter assumes the Stream Designer has knowledge of WAC, WDFW’s 2013 WCDG, and hydrology...
and river hydraulics, and, as a result, does not cover every topic in thorough detail. This chapter will outline the process that the HQ Hydraulics Section follows in designing a stream crossing, and what is expected on WSDOT projects. These designs require a specialty report. Additional requirements about specialty reports can be found in Chapter 1. The template used by WSDOT will be provided in a future update.

7-2  **Existing Conditions**

The first step to designing a water crossing is understanding the behavior of the existing system. A thorough investigation of the site and adjacent stream reach, its history, and any known problems should be performed prior to the field visit and confirmed during the field visit. Prior to the first field visit, the Stream Designer(s) should complete the following:

- Determine whether the project is within a FEMA-mapped floodplain
- Evaluate the watershed conditions/landcover (past, current, and future)
- Investigate the type of soils that are in the basin
- Look at historic aerial photographs, if available, for evidence of lateral migration, avulsion, debris flows, sediment pulses, LWM interactions, significant erosion, etc.
- Discuss site history with WSDOT area maintenance
- Review any available survey data and available historical as-builts
- Confirm pre-field visit investigations and conclusions or document differences
- Review any available watershed studies, watershed analyses, hydrology/drainage studies, reach assessments, sediment budget, and transport investigations, etc.

Through site visits, the Stream Designer will perform the following:

- Determine the reference reach
- Measure bankfull width (BFW)
- Determine sediment size using either a Wolman Pebble Count or a grab sample (as appropriate)
- Investigate channel geometry
- Note any channel-forming features
- Note the presence and function of LWM
- Note the presence and function of large cobbles or boulders

Multiple site visits may be required, both before and after survey has taken place, to ensure all the necessary features were surveyed. The Stream Designer will benefit by reviewing the survey request in the field with the survey crew. The information listed above shall be photographed or otherwise recorded for report documentation and design discussions. The Stream Designer shall coordinate with the PEO for the attendance of the resource agencies and interested Tribes during the reference reach selection and BFW determination.

7-2.1  **Reference Reach**

The following process outlines several steps for locating the best reference reach possible while recognizing that many streams near roadway crossings are modified by human processes and thus are not perfect natural analogs. If a system is highly modified, contact the HQ Hydraulics Section for additional guidance. Figure 7-1 depicts a flow chart that describes the steps below.
7-2.1.1 Examine Adjacent Reaches

Examine the reaches with project stakeholders immediately upstream and downstream from the project reach and evaluate the following:

1. Does the average stream gradient change significantly between upstream and downstream?
2. Are there signs of significant erosion or deposition?
3. Are there any man-made features within the active channel? Within the floodplain?
4. Are there any sudden changes in sediment size distribution?

In evaluating the project reach for the above points, the Stream Designer is trying to determine whether the morphological attributes (gradient, confinement, planform, shape, bed materials, etc.) of the reach reflect what would be expected in the vicinity of the site, and how/to what extent these attributes are modified by artificial features, constraints, or conditions.

Significant changes in gradient is an indication that sediment supply may be a concern, or the crossing is in a transition zone, etc. Large amounts of deposition or erosion have an impact on the overall channel slope and shape that may not be sustainable in the long term. Man-made features within the channel and/or floodplain such as riprap, piers, foundations, levees, or mechanically altered channels could cause the reach to not reflect what the channel would look like under natural conditions. However, if the channel is mechanically altered, mimicking the channel shape is recommended; in these instances, contact the HQ Hydraulics Section for additional guidance.

If the answer to any of the above questions is yes, proceed to Section 7-2.1.2. If the answers to all of the above questions are no, proceed to Section 7-2.1.3

7-2.1.2 Similar Reference Reach

If the adjacent reach is not representative, a similar reference reach will need to be located. A reach within the same watershed is preferable, but if one cannot be located, another watershed may need to be investigated. Locate a similar reference reach using the following steps:

1. Examine a topographic map at the 1:24,000 scale (or finer) for reaches farther upstream and downstream of the culvert reach with similar slope, watershed characteristics, and channel confinement.
2. When a new reach with similar slope, watershed characteristics, and channel confinement is identified, determine the size of the contributing watershed area. Is it similar (+/-20 percent) to the contributing area above the project reach?

If the reach meets criteria a and b, go to Section 7-2.1.3. If it does not, look to adjacent watersheds with similar aspect, elevation, and geology and go back to step (a).

7-2.1.3 Reference Reach Data Collection

After locating an appropriate reference reach, collect data for the specialty report. At a minimum, collect the following information:

- Stage of channel evolution at the project reach
- Water surface slope during non-flood event
• Channel sinuosity and radius of curvature
• Presence and residual depth of pools
• BFW in at least three representative locations; compare to those measured at project reach
• Pebble counts or grab samples in at least three locations on riffles or pool tailouts (Wolman 1954)
• Note riparian zone vegetation, canopy density
• Note presence and function (or absence) of LWM, especially key pieces (see Chapter 10)
• Record geographic coordinates of reference reach
• Note anthropogenic impacts to the reach

7.2.1.4 Project Constraints

If it is determined that a constraint is present requiring a design reference reach, contact the HQ Hydraulics Section for concurrence requirements for the use of a design reference reach.

Figure 7-1 Reference Reach Determination

- Is the system highly modified (i.e., agricultural ditch, highly urbanized)?
  - Yes → Contact the HQ Hydraulics Section
  - No → Examine adjacent reference reaches using the qualifications in Section 7-2.1-1. Are they appropriate for use?
  - Yes → Use adjacent reference reach
  - No → Examine drainage basin for a similar reference reach following the steps in Section 7-2.1-2. Can a similar reference reach in the same drainage basin be found?
    - Yes → Follow steps in 7-2.1.3 to collect reference reach data
    - No → Examine similar drainage basins for a similar reference reach following the steps in Section 7-2.1.2. Can a similar reference reach in a similar drainage basin be found?
      - Yes → Use similar reference reach in similar basin
      - No → Contact the HQ Hydraulics Section for assistance
7-2.2 **Bankfull Width**

An accurate BFW is critical as it is a driving factor for the minimum required structure size per **Section 7-4.3**. Appendix C of WDFW's 2013 WCDG is a useful reference in determining an appropriate BFW. A minimum of three measurements shall be used when computing the average BFW. Measure widths that describe prevailing conditions at straight channel sections and outside the influence of any culvert, bridge or other artificial or unique channel constriction.

If there are significant differences between measured and modeled BFW, further evaluation or justification will be required. Hydraulic modeling shall be utilized to verify the appropriate measured BFW by using the 2-year flow top width. Typically, the 2-year top width is equal to or slightly wider than the BFW. WDFW has created a regression equation used for estimating BFW that can be found in Appendix C of the 2013 WCDG and shall only be used as a check to determine what a reasonable measurement is on streams within the limitations of that equation. Additional guidance will be provided in future revisions to the *Hydraulics Manual*.

It is not always evident where the influence of an undersized structure ends. On a low gradient system that has a high headwater at the crossing, the backwater during high flow events can extend upstream for hundreds of feet and result in an artificially wide BFW measurement. Once the existing conditions model is created the bankfull measurement locations should be checked to confirm they are outside the influence of the existing structure. If the BFW measurements are determined to be within the influence of the structure, additional site visits are required for reevaluating BFW measurements.

7-2.3 **Watershed and Land Cover**

Understanding the past, current, and potential future conditions of a watershed is important for the long-term success of a project.

Historical and current aerial photographs should be examined to determine what type of land cover the watershed has now and how that has changed over time. Verifying whether the system is in an urban setting, within an urban growth area, or in an active forest will also help determine what the land cover could look like in the future and may increase the design flows expected during the design life and create the need for a larger structure. Understanding of how the watershed has changed over time will help the Stream Designer create a crossing that will be successful.

If a watershed has a high potential for future forest fires or has been recently affected by a forest fire, this shall be documented and taken into consideration when determining the final structure size.

7-2.4 **Geology and Soils**

The soil types in the drainage basin not only assist the Stream Designer in understanding what is happening at the crossing, but also can impact the calculated hydrology at the site location if a continuous simulation method, such as MGSFlood, is utilized to determine flow rates.

The surrounding geology will have an impact on lateral migration and may influence where a new crossing is placed. It may also influence sediment load and size distribution in the channel. Generalized soil types may be found in Soil Surveys produced by the National Resources Conservation Service. Surficial geology maps are also useful in determining soil information.
7-2.5 Fluvial Geomorphology

Fluvial geomorphology is an integral part of determining where the crossing should be placed, how the stream or river should be aligned, and where the stream or river may end up in the future and is a primary determinant of the appropriate design of the channel. The channel should be examined to determine if there are signs of lateral and vertical stability or instability and how the stream may be impacted in the future. Delineation of channel migration zones should be investigated (and may be required by local jurisdictions). The potential for channel avulsion should also be assessed.

7-2.5.1 Channel Geometry

Streams have often been straightened or moved, resulting in shorter crossings that are perpendicular to the roadway. Roadway as-builds and old ROW plans are good sources for determining what the crossing looked like prior to roadway construction. Old aerials may give a good indication of the channel alignment over time, depending on tree cover. LiDAR, if available, is also a good resource to provide insight into general down-valley slopes and help identify grade breaks beyond the limits of the survey. LiDAR can also identify relic channel features, such as side channels, scroll bars, avulsions, and alluvial fans.

Many WSDOT roads were built at the edge of stream and river valleys. As a result, it is not uncommon for the reach through the roadway prism to be within a transition zone between an upstream reach and a downstream reach. Oftentimes, this leads to a historic slope steeper than the adjacent reaches. Culvert crossings at roadways can serve as grade controls, which have been in place in some instances for many years and may have had an effect on the channel upstream and downstream of the crossing. Having a good understanding of sediment supply and general transport regime with and without the existing crossing within the system is important in determining the long-term potential for channel slope change over time.

The channel slope and changes in the channel slope should be documented, both in the reference reach and near the culvert. These slopes shall be measured in the field or determined by survey data.

The channel shape, changes in vegetation, cross section break lines, and other well-defined features should be noted, as well as any low flow paths. It is important to verify that the survey matches what is in the field and represents the natural conditions in the hydraulic modeling.

7-2.5.2 Potential for Aggradation, Incision, and Headcutting

Note channel conditions within the reference reach. Look for the potential for aggradation/degradation within the channel, and note the channel planform and any channel incision.

Dams or undersized culverts within the drainage system can also have a lasting impact on the creek. A dam or undersized culvert upstream may cause deposition of sediment in the upper reach and starve the sediment load transported downstream, resulting in degradation downstream. This may affect the BFW and/or create a perched culvert. Likewise, a dam or undersized culvert lower in the system may cause a sediment supply issue affecting the gradient.

Upstream hillslope and/or channel instability or watersheds that have large areas of disturbed land can create a potential for large sediment pulses or aggradation at the crossing. A structure should be designed to accommodate any expected excessive sediment input to avoid becoming a maintenance problem in the future.
The specialty report shall note whether or not aggradation, degradation, or headcutting is a risk in the future and how the design will accommodate these risks.

7-2.5.3  **Floodplain Flow Paths**

Determine whether there is a mapped floodplain for the water body that the highway is crossing or an adjacent water body (i.e., the crossing may be in the mapped floodplain of a larger river). Also describe whether any floodplains exist and how the flows move through these floodplains.

Anticipated changes to floodplains as a result of any structure change or grading shall also be discussed, even if it is not required for a permit. The HQ Hydraulics Section will determine whether or not the changes to the floodplain are significant. If the changes are deemed significant, then the PEO will need to communicate those changes to the local jurisdiction. In some instances, this may require a FEMA map revision.

7-2.5.4  **Channel Migration**

A description of any past channel migration and potential future channel migration shall be documented in the specialty report. LiDAR and past aerial photographs should be utilized to determine where the channel has been in the past, if available.

7-2.5.5  **Existing Large Woody Material and Channel Complexity Features**

LWM within the reference reach and near the crossing shall be documented, as well as the potential for future LWM recruitment. The channel type (Montgomery and Buffington 1993) and any key features such as LWM, boulders, and bedrock outcrops that are creating channel complexity or influencing channel alignment shall be noted as well as the capability of the system to move wood if future conditions provided a stream buffer that could recruit LWM.

7-2.5.6  **Sediment**

Sediment size determination in the reference reach is typically done through either Wolman pebble counts (or other method as approved by the HQ Hydraulics Section shown to produce similar results) or grab samples, depending on the size of the streambed material. If a grab sample is used, the sample size needs to be large enough to produce accurate results. Guidance on sample size can be found in scientific literature.

The sediment sampled should be within the reference reach. Note any large, naturally occurring material that is on-site and include the notation within the design documentation. In some cases, large, unnatural material or large deposits not transported by the current flow regime may be shaping the current stream conditions including elements from previous or upstream streambank stabilization and scour protection efforts. While it may not be accurate to include this angular rock or other streambank stabilizing material in the pebble counts, making note of it may be useful for understanding the reach conditions and what the stream is capable of mobilizing.

Understanding the sediment supply in the system is critical to being able to determine the correct size material to be placed back into the stream. If a system is sediment starved, it may be necessary to provide material that is coarser than the adjacent reaches to avoid channel incision. If a system has a healthy sediment supply, it may make sense to place material that is mobile and matches the sediment in the adjacent reach.
7-2.6 **Hydrology**

If the hydrology at a site is estimated incorrectly, this can lead to underestimating or overestimating the required size for the structure’s span, incorrect scour elevations and depth estimates, incorrect channel shape, and incorrect LWM sizing and anchoring requirements.

Additional information about hydrology can be found in Chapter 2. Justification for the chosen methodology being the most appropriate is required for all projects, including if the USGS regression equation is used. In many instances, the USGS regression equation may be the best available information, but this shall be confirmed through modeling, site conditions, maintenance history, and engineering judgment. The standard error for the USGS regression equation is quite high in some areas and it may be necessary to adjust the flows based on these standard errors. Other methodologies, such as the basin transfer method or HSPF may be more appropriate. In urban areas, hydrology models that include future build out conditions may be available for use.

7-3 **Hydraulic Analysis**

Model outputs are required as part of the specialty report and must be used to verify that the minimum proposed structure size meets the appropriate WACs, WDFW's 2013 WCDG, and this chapter. WSDOT requires the use of SRH-2D unless otherwise approved by the HQ Hydraulics Section. Additional guidance will be provided in future revisions to the Hydraulics Manual.

7-3.1 **Manning’s n**

Special care shall be taken to determine Manning’s n. In addition to the typical charts and tables available for Manning’s selection, there are several equations that are valid for gravel bed systems that predict a Manning’s n value. The selection process used for determining what the Manning’s values are for the system shall be documented in the specialty report. Additional information on Manning’s n can also be found in Chapter 4 and Appendix 4A.

7-3.2 **Boundary Conditions**

Boundary Conditions should be set for normal depth unless other information is known. In cases where there is tidal or flood influence from another water body, both a normal depth condition and a backwater condition shall be analyzed. For freeboard, the backwater condition is conservative and for scour the normal depth condition is conservative. The boundary conditions used for each scenario and the reasoning for them shall be documented in the specialty report.

7-4 **Design**

All WSDOT crossings for fish bearing waters must meet WAC 220-660, at a minimum. In WRIAs 1 through 23, the design must also meet the requirements of the 2013 Federal Court Injunction for Fish Passage.

The process that is required for WSDOT design projects is described in the sections that follow and summarized in Appendix 7A. These sections only cover the Bridge Design and Stream Simulation Design methods; other methods may be appropriate but must be approved by the HQ Hydraulics Section prior to use.
The design flow for WSDOT projects is the 100-year, unless it is determined on approval by the HQ Hydraulics Section that another lower event would cause a more extreme case than the 100-year. For example, if the project is within the floodplain and the entire area is flooded, then a different storm event or boundary condition may be more appropriate (i.e., 10-year backwater on larger water body for backwater with the 100-year storm on the smaller water body).

All the supporting calculations/information for the design process below shall be included in the specialty report.

7-4.1 Constraints

Constraints are infrastructure or land ownership issues that interfere with natural stream processes and need to be identified as soon as possible. Constraints can be both man-made and natural and, when encountered, should be discussed with stakeholders early in the design process to prevent project delays in the future if not all parties agree on whether a constraint exists or may be resolvable within the scope of a project. There may be design constraints other than those covered in this section.

7-4.1.1 Infrastructure

Infrastructure can include adjacent culverts/bridges, pipelines, buildings, water intakes/diversions, groundwater wells, and roadways as well as other infrastructure types not listed here. Infrastructure that is a design constraint can be owned by WSDOT or by other parties.

7-4.1.2 Environmental Impacts

Environmental impacts should be considered when completing a stream design. If meeting the design methodology causes a large environmental footprint (i.e., if a roadway that needs to be raised next to a wetland or stream grading would need to be extended for a great distance), discussions with WDFW and the Tribes should occur to determine what the best design is to move forward and whether mitigation may be used in lieu of meeting requirements/recommendations.

7-4.1.3 Grade Separation

Many culverts have been in place for a long time and the stream has adapted around them. Culverts may have been historically placed at a grade break in the channel that is dissimilar to the upstream and downstream reach. If there is a large grade separation between the upstream reach and the downstream reach, it may be necessary to allow for a natural channel regrade, producing a steeper reach with an overcoarsened channel. As much information as possible should be obtained about historical conditions and the cause of the grade break and discussions with WDFW and the Tribes should occur to determine the best solution for the project.

7-4.1.4 Cultural Resources

Impacts to cultural resources should be considered when completing a stream design. If meeting the requirements and recommendations for the project would have an impact on cultural resources, WDFW and the Tribes should be consulted to determine the way to proceed.
7-4.2 **Channel Alignment**

Typically, it is favorable to keep the alignment in its current location unless the investigations done during the data gathering phase show that it should be relocated. Another reason to realign the crossing would be to eliminate the crossing all together if the channel realignment is done.

It is not always possible to cross a roadway at an ideal angle or avoid sharp bends leading into or out of a structure. The total length of covered stream should be considered and the maximum angle of a bridge structure to centerline of a roadway per the Bridge Design Manual, if a bridge structure is used. While the HQ Hydraulics Section does not typically recommend a structure type or layout, it is important for the Stream Designer to know what this constraint is and keep it in mind while designing the layout to make an efficient crossing. As a result of the crossing angle, if armoring is determined necessary, see Section 7-4.10.

Channel sinuosity and curve radii must match what would be expected in the reference reach, and a channel must not be artificially lengthened by increasing sinuosity beyond what would be expected to decrease slope. Meanders extended unnaturally to obtain length will not be stable. Conversely, channel sinuosity must not be unreasonably reduced or eliminated in the interest of shortening the structure span.

If a channel needs to be realigned, it must be done so in a way that does not increase the slope significantly or create an erosion risk. In the case of slope, WSDOT uses the stream simulation recommendation from WDFW's 2013 WCDG of a slope no steeper than 125 percent of the upstream reach (or downstream if it is deemed that the downstream reach is more appropriate). In systems where the slope is low gradient (i.e., less than 1 percent), exceeding the slope limit while still meeting this criterion may be permissible but must be approved by the HQ Hydraulics Section. If it is not practicable to meet the slope constraint, approval by the HQ Hydraulics Section is required.

If allowing for natural regrade is determined undesirable, the Stream Designer must evaluate the long-term degradation, scour, potential equilibrium slopes, and whether a larger structure will be required as a result of the channel regrade. Lateral migration during the process of the regrade should be considered and appropriate countermeasures must be implemented to protect banks from destabilization as a result of construction. Refer to Chapter 4 for additional guidance.

If regrade is determined not to be desirable, the reach must be designed to be stable. This may cause the project to be permitted as a fish passage improvement structure (see Section 7-5.2) and require long-term maintenance and monitoring. The streambed material decision tree found in Appendix 7A may help the Stream Designer determine whether or not to allow for channel regrade.
7-4.3 **Channel Cross Section**

The channel cross section should mimic that of the reference reach, while keeping construction methodologies in mind. If a system is highly modified (i.e., an agricultural ditch) and the grading for structure replacement is minimal, it may be appropriate to match the adjacent reach instead. For highly modified systems, contact the HQ Hydraulics Section for assistance.

Cross section lengths should be rounded to the nearest tenth of a foot. Slope should be rounded to the nearest 0.5:1. Example plans and plan requirements can be found in WSDOT’s *Plans Preparation Manual*. An example cross section is illustrated in Figure 7-2.

**Figure 7-2** Final Design Cross Section

![Channel Cross Section Diagram](image)

Flows within the channel cross section must mimic those in the reference reach. For example, if the active channel is overtopped at less than a 2-year event, the channel should behave the same through the design reach.

7-4.4 **Hydraulic Opening**

For the purposes of this chapter, the minimum structure width recommended by the specialty report is defined as the minimum hydraulic opening. This is needed to make a distinction between what is required to meet WAC and this chapter versus what may be installed at project completion. The minimum span of a structure shall be the hydraulic opening; however, the actual structure width determination is made by Region or the Bridge and Structures Office unless there is a hydraulic reason to place upper limitations on size. Any required scour protection shall not encroach within the hydraulic opening unless it is placed below the total scour elevation.

For preliminary plans, prior to the structure type being known, it is recommended that 2:1 cut slopes with a note that “grading limits to be based on final structure size, type and location” are shown unless it is known that the structure will be buried. This lets the reviewers know that the structure type is undetermined while showing the potential impact areas. Cross sections should clearly depict where the minimum opening is, as shown in Figure 7-3.
7-4.4 Hydraulic Opening

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Figure 7-3 Minimum Hydraulic Opening

There are three methods for determining the minimum hydraulic opening: stream simulation, confined bridge, and unconfined bridge. However, the process used for confined bridge is the same as stream simulation. All methods are dependent on the floodplain utilization ratio (FUR), which determines how confined a stream is. The minimum hydraulic opening is determined from Equation 7-1 (2013 WCDG, Equation 3.2), unless otherwise approved by the HQ Hydraulics Section.

\[ W_{HYO} = 1.2 \times W_{bf} + 2 \text{ feet} \]  

(7-1)

Where

- \( W_{HYO} \): Width of hydraulic opening
- \( W_{bf} \): BFW

The minimum width of the hydraulic opening is to be taken vertically through the entire structure. If a round or arch structure is used, additional width/height may be necessary to maintain the opening through the anticipated scour/required freeboard.

The design flood for temporary bridges that will be in water for one season or less shall use the 25-year flow event for the design flood. For temporary bridges that will be in water for more than one season, the 100-year flow shall be used for the design flood.

7-4.4.1 Floodplain Utilization Ratio

The FUR needs to be calculated using existing conditions. The FUR is the width of the floodplain relative to the main channel. To determine the FUR for WSDOT designs, compare the 100-year water surface width from the model output to either the available BFW information or, if BFW is not available, the 2-year top width. To determine what the FUR is through the upstream reach, it is recommended that the existing structure be removed from the model.

A FUR larger than 3.0 is considered an unconfined system, while a FUR less than 3.0 is considered confined. If the system is unconfined, the unconfined bridge design method applies. If the system is confined, either the confined bridge design method or the stream simulation design method applies. More explanation of the FUR can be found in the 2013 WCDG. For areas that are tidally influenced, see Section 7-4.4.5.
7-4.4.2 Unconfined Systems

An unconfined system has a FUR of greater than 3.0. In these situations, the velocity ratio, which is defined as the velocity at the thalweg of the main channel through the structure divided by the velocity of the main channel immediately upstream of the structure if the roadway fill were to be removed entirely, is used to determine structure size. The velocity ratio shall be close to 1, which means that the ratio when rounded to the nearest tenth shall be 1.1 or less at the 100-year event. In some low velocity cases, a ratio of more than 1.1 may be allowable if the increase in velocity ratio does not result in bed coarsening, increased scour, significantly increased backwater, or negative biological/geomorphological effects. The HQ Hydraulics Section must approve in these instances.

If an existing structure is being replaced by a new structure, a velocity ratio of more than 1.1 may be acceptable. In this case, the existing structure should not have evidence of significant erosion, scour, or other performance issues. The HQ Hydraulics Section must approve in these instances.

For preliminary design, the Stream Designer is to assume vertical walls for the edge of structure while determining the minimum hydraulic opening in the hydraulic model. Once the final structure size has been determined by others, the model shall be updated to reflect the updated structure. Additional width may be required in instances where lateral migration is a concern.

7-4.4.3 Confined Systems

For confined systems, the BFW plus a factor of safety is recommended. In the case of WSDOT crossings, minimum structure width shall not be less than what is given by Equation 7-1 unless otherwise approved by the HQ Hydraulics Section. In many cases, this width is appropriate. In some cases, a wider structure may be more appropriate.

Additional width is required if the following apply:

- The structure is creating an excessive backwater.
- The velocities through the structure differ greatly from the adjacent reach.
- Aggradation is expected.
- Lateral migration is expected throughout the system.
- The Stream Designer has reason to believe additional width is needed.

7-4.4.4 Tidally Influenced Systems

For tidally influenced systems follow at a minimum Appendix D from the 2013 WCDG. Additional guidance will be provided in future revisions to the Hydraulics Manual.

7-4.4.5 Climate Resilience

WSDOT uses climate science and tools to evaluate the influence climate change has on projects throughout the state of Washington. This is done through the use of the best available science and working with the Climate Impacts Group and stakeholders’ groups. Contact HQ Hydraulics for guidance on incorporating climate resiliency on projects. Additional guidance will be provided in future revisions to the Hydraulics Manual.

Climate resilience should also include the future risk of forest fire. If the watershed is located in an area that has a high potential for future forest fires, additional structure width and height may be warranted to accommodate this risk.
7-4.5 Freeboard

A structure that does not have adequate freeboard can require repeat maintenance activities and a more robust structure and could have an increased scour depth.

A minimum of 3 feet of freeboard above the 100-year water surface elevation is required on all structures greater than 20 feet and on all bridge structures unless otherwise approved by the HQ Hydraulics Section for reasons discussed below. The Stream Designer shall also confirm local ordinance requirements are met and any necessary permit conditions are satisfied.

The freeboard required on all buried structures unless otherwise approved by the HQ Hydraulics Section are listed in Figure 7-4.

Figure 7-4  Freeboard Requirements on Buried Structures

<table>
<thead>
<tr>
<th>Structure Bankfull Width</th>
<th>Required Freeboard</th>
</tr>
</thead>
<tbody>
<tr>
<td>Less than 8-foot bankfull width</td>
<td>1-foot above 100-year flow event</td>
</tr>
<tr>
<td>8- to 15-foot bankfull width</td>
<td>2 feet above 100-year flow event</td>
</tr>
<tr>
<td>Greater than 15-foot bankfull width</td>
<td>3 feet above 100-year flow event (bridge)</td>
</tr>
</tbody>
</table>

In areas that are tidally influenced, the impacts of 2 feet of sea level rise shall be considered for the project.

The required minimum freeboard shall be maintained across the entire minimum hydraulic opening, as shown in Figures 7-5 and 7-6. Additional consideration should be given to maximize freeboard for increased internal clearance for access and/or animal crossings, constructability, fill height, etc. If aggradation is expected to occur, additional freeboard shall be given above the 100-year equal to the anticipated aggradation.

Figure 7-5  Freeboard Requirements on Box Structures/Vertical Abutments
The design flood for temporary bridges that will be in water for one season or less shall use the 25-year flow event for the design flood. For temporary bridges that will be in water for more than one season, the 100-year flow shall be used for the design flood. The freeboard required for temporary bridges shall be 1 foot above the design flood water surface elevation, at a minimum. Debris loading shall be evaluated for the system and the freeboard increased if additional clearance for debris is necessary.

7-4.6 **Buried Structures**

Buried structures for WSDOT projects can follow either the bridge design or stream simulation design criteria. If a buried structure is used, a few additional criteria apply.

If a structure length is more than 10 times its width, then the structure width shall be increased by 30 percent to allow the channel to meander, per the WCDG.

The WCDG and WAC require that all stream simulation culverts be countersunk a minimum of 30 percent and a maximum of 50 percent, but not less than 2 feet overall. Alternative depths of culvert fill may be acceptable with engineering justification that considers channel degradation, aggradation, and total scour. Scour analyses are typically considered acceptable engineering justification.

Buried structures shall be countersunk a minimum of 2 feet below total scour at the design flood, regardless of span width. If this requirement cannot be met, approval from the HQ Hydraulics Section is required. It is understood that four-sided structures are created in whole foot increments, so if the countersink is slightly below 2 feet, contact the HQ Hydraulics Section to verify if additional depth is required.

In some cases, constructability is easier if the structure is placed flat or the Stream Designer may recommend the structure be placed at a different slope than the streambed. Buried structures may be placed at a different slope than the prevailing stream gradient so long as the minimum freeboard is met throughout the structure, the minimum required countersink is met throughout the structure, and justification is provided and approved by the HQ Hydraulics Section. In some cases, this may require a slightly taller structure. The reasoning for placing the culvert at a different slope shall be described in the specialty report.
7-4.7 Sediment

WAC dictates allowable sediment sizes in a fish bearing stream. Stream simulation design aims to mimic natural conditions to the extent possible, but sometimes stream conditions have been altered, reaches have been sediment starved, or adjacent infrastructure (constraints) do not allow for bed mobility into adjacent reaches.

Apply the stream simulation requirement of a $D_{50}$ that is within 20 percent of the reference reach unless constraints prevent this. A Streambed Material Decision Tree to further assist stream designers in determining which methodology to use for streambed sediment sizing in these special cases, is shown in Appendix 7A.

For sediment sizing, WSDOT uses the Modified Critical Shear Stress Approach, as described in Appendix E from the 2008 U.S. Forest Service (USFS) Guidelines for all systems under 4 percent and the Unit-Discharge Bed Design as described by the 2013 WCDG for systems greater than 4 percent. A system is considered stable if the $D_{84}$ is stable at the design flow event.

7-4.7.1 No Constraints

As previously described, apply the stream simulation requirement of a $D_{50}$ that is within 20 percent of the reference reach unless prevented by constraints. Most systems fall into this scenario. The design process for sediment sizing under these conditions is to match the reference reach material to the extent possible using the materials available from WSDOT’s Standard Specifications.

Stability of the bed mix shall still be evaluated and documented in the report.

7-4.7.2 Constraints

If there are constraints in the systems, as described in Section 7-1, that could have an impact on the stream design, the risk of the stream not being stable will need to be evaluated.

In some cases, a bed design based on the pebble count from the existing reference reach will meet the requirements for stability. The existing pebble count will need to first be evaluated for stability, using the appropriate methodology from Section 7-4.7. If the $D_{84}$ is not stable at the design flood, then a risk assessment will need to be conducted to determine the next steps. The HQ Hydraulics Section and RHE shall be a part of the risk assessment process.

7-4.7.2.1 Risk Assessment

To complete a risk assessment for the site, the constraints must be identified and what the potential impact to those constraints would be if natural processes were to occur. If the constraints are private or public infrastructure not owned by WSDOT, the owners of the infrastructure should be consulted. The Streambed Material Decision Tree in Appendix 7A can be helpful in determining the level of risk; however, the ultimate decision on constraints and risks to constraints is made by the project team.

If it is determined that the project is high risk and cannot be allowed to regrade, a roughened channel must be constructed. A roughened channel is designed to be completely non-deformable up to the design discharge. If a roughened channel is built, any habitat features must be installed at the time of construction, as they are unlikely to form themselves. A roughened channel will likely have additional permit requirements (and possibly long-term commitments) associated with it.
If a project is considered medium risk, an alternative analysis needs to be conducted. The Stream Designer needs to describe the constraint, describe the impact of meeting the requirements for sediment size, identify and evaluate any alternatives, and describe the preferred alternative. When describing the preferred alternative, the Stream Designer must also describe how the preferred alternative reduces the risk to an acceptable level and what potential impact to fish life this alternative may have. In cases where coarser sediment is necessary on a medium-risk project, an overcoarsened channel with habitat complexity features may be constructed. This channel is subject to agreements between WSDOT and permitting agencies. An overcoarsened channel has a $D_{84}$, which is stable at the Design Flood.

If a project is determined to be low risk, then the bed material should match the pebble count in the reference reach and the process described in Section 7-4.7.1 applies.

### 7-4.7.3 Coarse Bands

Coarse bands are bands of material that are coarser than the overall bed design material. They are meant to keep the stream centered in the culvert, should be partially deformable, and are not intended to be grade control. As a result of project monitoring and repair, it was determined that the use of a fine band of material upstream of a coarse band can help seal the streambed mix. Fine bands consisting of Streambed Fine Sediment, a natural or manufactured sand, meeting the grading requirements in Figure 7-7 shall be placed upstream of all coarse bands.

#### Figure 7-7 Fine Band Grading

<table>
<thead>
<tr>
<th>Sieve Size</th>
<th>Percent Passing</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. 4</td>
<td>99 – 100</td>
</tr>
<tr>
<td>No. 10</td>
<td>46 – 86</td>
</tr>
<tr>
<td>No. 40</td>
<td>26 – 40</td>
</tr>
<tr>
<td>No. 200</td>
<td>10 – 20</td>
</tr>
</tbody>
</table>

The typical profile shape that WSDOT uses for Coarse and Fine Bands can be seen in Figure 7-8. More information on coarse bands, including spacing, can be found in the 2013 WCDG.

#### Figure 7-8 Coarse Band Profile Shape

Coarse bands are required within all structures that are four sided and that have a stream slope of 2 percent or less. Coarse bands are recommended within all structures that have a stream slope between 2 and 4 percent. Coarse bands are typically sized for the $D_{84}$ to be stable at the 100-year flow event and shall not have material that is larger than twice the $D_{100}$ of the design bed mix.
It may be necessary to have bands or clusters of coarser material beneath/inside of structures to help promote channel cross shape stability and channel complexity that are outside of what is recommended above. In these cases, the Stream Designer must use engineering judgement to determine what this will look like. See Section 7-4.10 for channel complexity. A Fine band may be required to be placed along side of the Coarse band to aide in streambed flow after construction. Contact the HQ Hydraulics Section for additional guidance on the use of Fine bands.

7-4.8 **Total Scour**

All structures shall be designed for total scour, as defined by HEC-18, regardless of structure span. All four-sided buried structures shall be countersunk a minimum of 2 feet below the total scour depth at the design flood and shall be countersunk deep enough for the bottom to not become exposed during the check flood. Foundation depth for three-sided buried structures/traditional bridge structures with abutments and piers shall be determined by the bridge and geotechnical office. Methodology used for determining total scour shall follow the methods described in HEC-18.

The design flood for temporary bridges that will be in water for one season or less shall use the 25-year flow event. For temporary bridges that will be in water for more than one season, the 100-year flow shall be used for the design flood.

7-4.9 **Lateral Migration**

All structures shall be designed to account for the lateral migration expected over the life of the structure. The Stream Designer shall document in the specialty report whether there is a high or low risk of the stream migrating to each pier and/or abutment and whether any preventative countermeasures or increase in structure size are recommended. In some cases, countermeasures may only be required if the structural element in question is not designed below the full depth of scour; this should be noted if it is the case and requires approval from the HQ Hydraulics Section, HQ Bridge Section, and HQ Geotechnical Section. If preventative countermeasures are necessary for embankment protection, this also is required to be described in the report.

7-4.10 **Channel Complexity**

Chapter 10 covers the requirements for channel complexity when LWM is used.

7-4.10.1 **Outside of Structure**

Channel complexity within the channel is most often accomplished by LWM and/or boulder clusters, depending on what is appropriate for the system.

If used in the system, boulder clusters should be sized large enough to remain stable, be placed in a way that they promote localized scour/pool development, do not create a low flow barrier risk, and engage in the active channel. Additional guidance will be provided in future revisions to the *Hydraulics Manual*. In addition to being stable during flow events, consideration should be given for the stream's location and whether vandalism could be an issue. If the location is in an area where there may be human activity, larger, heavier boulders may help keep the structures in place.
7-4.10.2 Inside/Under Structures

Mimicking bank structure inside of a structure or under a bridge is difficult when plants typically cannot grow, and the streambed material is designed to match that in adjacent reaches, which is often not stable at higher flow events. The lack of root structure at the edge of the bankfull channel and the instability of the material being placed can create a situation where the channel shape deteriorates over time. Aggradation inside of the structure can also cause the channel to lose its shape over time.

WSDOT has used coarse bands/coarse band barbs, boulder clusters, boulder cluster barbs, and lateral coarse bands. If boulders are used, the same recommendations as outside of the structure apply. Additional guidance will be provided in future revisions to the *Hydraulics Manual*.

7-4.10.3 Construction Recommendations

A channel takes a few large flows to have habitat elements form. In cases where a fish barrier is replaced, if these habitat elements are not formed during construction, the first migration of fish may be left with a long, straight channel that makes passage difficult. Leaving scour pools at the LWM and other complexity elements at locations where a pool would naturally form is recommended. A low flow pilot channel is also recommended to be installed that connects the habitat complexity elements immediately after construction.

7-4.11 Preventative Countermeasures

Preventative countermeasures are not always avoidable, whether it is to protect the structure itself or to protect a roadway adjacent to a water body. When a preventative countermeasure is necessary, the specialty report shall document the risk and rationale for the protection, any current evidence of erosion, and the countermeasure design. The ISPG, HEC-23, and Chapter 10 provide additional guidance on the implementation of countermeasures. The least amount of bank protection necessary to withstand the design flood is what should be installed and, if possible, buried away from the stream edge. For new structures, preventative countermeasures shall not encroach within the minimum hydraulic opening unless they are located below the total scour depth.

It is sometimes possible in low energy systems to provide the necessary protection through the use of planting and soil stabilization countermeasures.

7-4.12 Landscaping/Planting

There is guidance for planting near streams located in WSDOT’s *Roadside Manual* Chapter 830, that the landscape architect will follow for all projects located near streams. It is also beneficial for the Stream Designer to review this chapter. The Stream Designer shall collaborate with the landscape architect and provide input on the need for bank stabilization countermeasures, habitat complexity, and any planting that needs to be done prior to the first storm event of the year. Typically, the planting windows for WSDOT projects that do not install irrigation are October 1 to March 1 west of the Cascade Crest and October 1 to November 15 east of the Cascade Crest, per the WSDOT *Standard Specifications for Road, Bridge, and Municipal Construction*. If planting needs to occur before the end of these windows for stability reasons, the contract will need to be updated to reflect the timeline.
**7-4.13 Determining Crossing Design Methodology for Documentation**

The three most used design methodologies by WSDOT from WDFW’s 2013 WCDG are the Unconfined Bridge Methodology, Confined Bridge Methodology, and Stream Simulation Methodology. For all unconfined systems, the design methodology shall be described as unconfined bridge. For all confined systems over 20 feet, those expecting 1 foot or more of channel regrade, or slopes that are outside of the slope ratio, the methodology shall be described as confined bridge unless otherwise approved by the HQ Hydraulics Section. For all structures under 20 feet that do not fall into the categories described for unconfined bridge or confined bridge, the design methodology shall be stream simulation unless otherwise approved. If a different methodology was approved by the HQ Hydraulics Section, the design process shall be documented as the process that was approved. See Section 7-5 for some other available methods.

**7-5 Other Design Methods**

It is recognized that not all stream crossings will be able to meet stream simulation or either bridge design methodologies. As described in Section 7-4, there are other available design methodologies that can be accepted on a case-by-case basis with the approval of the HQ Hydraulics Section. This section will briefly describe some of the other methodology available.

Some of these design methodologies may need to include project objectives with performance measures, inspection schedules, maintenance triggers, and a contingency plan should the project fail to meet performance measures with permitting applications.

**7-5.1 No-Slope Design**

No-slope design recommendations can be found in the 2013 WCDG and the WAC. The no-slope designs are typically performed on BFWs of less than 10 feet, low gradients (less than 3 percent), and short culvert lengths (less than 75 feet). This design methodology is not preferred because it has a higher risk of becoming a barrier in the future, does not give the stream much room for natural processes, and has a lower capacity than stream simulation culverts and bridges.

**7-5.2 Fish Improvement Structures**

Fish improvement structures are any structures that facilitate the passage of fish either through or around the fish barrier that do not necessarily mimic natural channel processes. Structures such as roughened channels, roughened rock ramps, structure retrofit designs, and hydraulic culvert designs are examples of fish improvement structures. Fish improvement structures are only allowed by prior approval from the HQ Hydraulics Section. Additional information about roughened channels, roughened rock ramps, and structural retrofits are included below. Other fish improvement structures exist but are not covered here.

A fish improvement structure may be necessary to facilitate fish passage through an existing structure, allow for a transition between a newly constructed fish-passable structure and an upstream fishway, or as a means of grade control when deemed necessary. All fish improvement structures must meet WAC 220-660-200.

**7-5.2.1 Roughened Channel Design Methodology**

A roughened channel is a constructed channel with a streambed material and configuration designed to be non-deformable up to the design discharge. A roughened channel can help dissipate energy from an adjacent fishway into a newly constructed channel or may be necessary to prevent a channel from degrading over time.
7-5.2.2  Roughened Rock Ramp Design Methodology

Roughened rock ramps are similar to roughened channels except a roughened rock ramp uses large boulders to dissipate energy.

7-5.2.3  Structure Retrofit Design Methodology

An existing structure that currently does not provide fish passage can be authorized to remain in place until the end of its useful life by retrofitting the culvert to make it fish passable. It must be demonstrated that the culvert will comply with WAC 220-660-200(11). It is unlikely that a structure retrofits will be allowed within Water Resource Inventory Areas 1 through 23 due to the culvert injunction.

7-6  Temporary Stream Diversions

Temporary stream diversions shall be designed following the methodology described in Chapter 3 using the flow rates determined by this section. All other temporary culvert designs should follow the requirements of Chapter 3. Under most circumstances, the design and configuration of temporary culverts for streams is left to the Contractor to determine. This allows for the contractor to be able to create the most efficient work plan for their construction method. If the PEO wishes to design the temporary culverts, the reason shall be discussed with the HQ Hydraulics Section, and approval will be required.

For Design-Build Projects, the design and flow rate are determined by the Design-Builder based on the requirements of project permits.

For Design-Bid-Build projects on fish bearing streams, the HQ Hydraulics Section calculates the flow rates necessary for temporary culverts and that value is part of the special provisions. A conceptual level plan is typically required for permits, but no plans for the temporary culvert system should be put into the final plan set and should not be documented in the specialty report, unless otherwise approved.

Temporary culverts for streams shall be designed for the following storm events:

- **Single Season:** For a temporary culvert expected to be in place for a single fish window, the design flow rate shall be, at a minimum, equal to the expected 50 percent exceedance flow rate during the window the temporary culvert is in place with a contingency plan that shall be in place in two hours or less to bring the system to meet the expected 10 percent exceedance flow rate during the window the temporary culvert is in place. Determining the expected flow rates during the window the temporary culvert is in place can be done through Stream Gage Data (if available) or through an MGSFlood Seasonal Flow analysis (western Washington only). The flows can also be measured in the previous fish window years to get a base flow followed by an analysis for a 2-year storm based on rainfall for that fish window. If there is no data to calculate the flows during the construction window, then the expected 2-year flow rate shall be used for the design flow (contingency not necessary in this case) unless the PEO can justify a different flow if approved by the HQ Hydraulics Section.

- **Multiple Season:** The flow rate used for a temporary stream bypass expected to remain in place through a winter is to be the 10-year flow event as determined by the same hydrologic methodologies as for the 2-year event.

The design flood for temporary structures over water bodies shall be determined on a case-by-case basis by the HQ Hydraulics Section.
7-7 Monitoring

In September 2015, as part of the U.S. v. WA culvert injunction, state agencies and Tribal nations agreed upon and finalized a set of Monitoring Implementation Guidelines. Those guidelines are the basis of WSDOT’s current fish passage monitoring plan. Some elements of the monitoring plan apply to all statewide fish passage projects, not just those within the case area. Some projects have monitoring requirements as part of a state or federal permit. The monitoring plan, based on the agreed upon guidelines, provides protocols that can be applied to those special monitoring requirements and will ensure a consistent and efficient process.

There are three basic types of monitoring inspections:

**Post-Construction Compliance Inspection** - WSDOT evaluates all fish passage projects to ensure they are constructed as designed and permitted. Sites are also evaluated for their ability to pass fish using WDFW barrier assessment methods.

**Overwinter Inspection** - WSDOT inspects sites corrected under the injunction after the first full winter to evaluate the impact of high seasonal flows on fish passage at the new structure.

**Long-Term Evaluations** - Sites corrected under the injunction are evaluated 5 and 10 years after construction to determine if they still provide fish passage and to determine if the structures still conform to the fish passage standards under which they were constructed.

The results of the monitoring effort are summarized each year in the Fish Passage Annual Report, which can be found on the WSDOT Fish Passage Website (www.wsdot.wa.gov/Projects/FishPassage/default.htm). WSDOT uses the information from the monitoring efforts to work with WDFW and Tribes to improve upon the design and construction processes and will update this chapter as needed to reflect current practices and best available science.

7-8 Additional Resources

The Stream Designer may find the following manuals helpful for additional information:

- HEC-17: Highways in the River Environment - Floodplains, Extreme Events, Risk, and Resilience
- HEC-18: Evaluating Scour at Bridges
- HEC-20: Stream Stability at Highway Structures Fourth Edition
- HEC-25: Highways in the Coastal Environment, Volumes 1 and 2
- 2013 WDFW WCDG
- 2008 USFS Manual Stream Simulation: An Ecological Approach to Providing Passage for Aquatic Organisms at Road-Stream Crossing
- WDFW ISPG

7-9 Appendices

**Appendix 7A**  Streambed Material Decision Tree

**Appendix 7B**  Design Methodology Requirements for Bridges and Stream Simulation Culverts
Appendix 7A  Streambed Material Decision Tree

Streambed Material Decision Tree

OCTOBER 2016

**Select representative sites that:**
- are away from recent or chronic sediment sources
- are in riffles
- avoid pools
- outside of the influence of man-made or natural structures such as LWM, eroding banks

**Constraints on channel regrading (including but not limited to):**
- upstream/downstream infrastructure: culverts/bridges, pipelines, etc.
- water intakes/diversions
- groundwater wells
- upstream/downstream wetlands/habitat
- non-WSDOT property
- roadway geometry

**DEFINITIONS**

Criticality: the combination of probability of an effect to a structure, and the level of impact that the effect would have; see example chart on back.

*Designed streambed mix:* sediment size distribution that uses pebble counts from the reference reach for the D50 and D84, and an even, designed distribution of sizes for finer classes (USFS, 2008)

*Design reference reach:* a reach of stream, preferably within the same watershed, that is relatively stable

*Overcoarsened Channel:* a constructed channel with a median particle size that is greater than 20% larger than the median particle size of the design reference reach; it is deformable at discharges below the 100-year discharge.

*Project reach:* the segment of stream in which the fish passage is located

*Reference reach:* A stable segment of stream with consistent slope, geometry, planform, and sediment load that represents, to the best available knowledge, background condition of the project reach. (Rosgen, D.H., 1989)

*Roughened Channel:* a constructed channel with streambed material and configuration designed to be non-deformable up to the design discharge

*Stable stream:* A stream, over time (in the present climate), that transports the flows and sediment produced by its watershed in such a manner that the dimension, pattern and profile are maintained without either aggrading, nor degrading (Rosgen, 1996)

This document is intended to guide fish passage restoration design in cases where there are site constraints that are either too costly to resolve, or would take too long to resolve. In these cases, the regraded reach may be steeper than the initially identified reference reach. The reach assessment is an essential part of the process, but this document’s scope is limited to the decisions that affect the design of streambed materials which may be larger than what would normally be indicated by stream simulation-based design.
Table 1. Criticality Matrix. Risk is the probability of an effect on a constraint. Impact is the level of effect that damage to the constraint would have.

<table>
<thead>
<tr>
<th>Risk</th>
<th>Unlikely</th>
<th>Moderate</th>
<th>Likely</th>
<th>Very likely</th>
</tr>
</thead>
<tbody>
<tr>
<td>Impact</td>
<td>Minor</td>
<td>Moderate</td>
<td>Major</td>
<td>Extreme</td>
</tr>
<tr>
<td></td>
<td>Low</td>
<td>Low</td>
<td>Medium</td>
<td>Medium</td>
</tr>
<tr>
<td></td>
<td>Low</td>
<td>Medium</td>
<td>Medium</td>
<td>High</td>
</tr>
<tr>
<td></td>
<td>Medium</td>
<td>Medium</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td></td>
<td>Medium</td>
<td>High</td>
<td>High</td>
<td>High</td>
</tr>
</tbody>
</table>

REFERENCES


Appendix 7B  Design Methodology Requirements for Bridges and Stream Simulation Culverts

BRIDGE AND LARGE BOTTOMLESS CULVERT DESIGN METHODOLOGY

<table>
<thead>
<tr>
<th>Source Crossing Element</th>
<th>Goals</th>
<th>Summary of relevant Washington Administrative Code (WAC)</th>
<th>Summary of relevant WDFW Water Crossing Guidelines</th>
<th>Supplemental Guidance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bankfull/Bank Widths</td>
<td>Determine accurate bankfull relationship to site conditions. Design team will reach agreement on the bankfull width that is necessary, most after data review.</td>
<td>None.</td>
<td>Page 223-245. Appendix C1: Provides recommended methods to determine bankfull width.</td>
<td>Bankfull is highly variable (channel/river bank) determined by hydraulic modeling. Source sheets or record compilation. See WSDOT Hydrologic Manual, Chapter 7 Fish Passage.</td>
</tr>
<tr>
<td>Channel Slope/Gradient</td>
<td>For culvert, the slope of the bed is the project reach width x 25% for the preceding slope of apron and downstream. The slope of the bed inside a stream simulation culvert must not exceed the slope of the upstream channel by more than twenty-five percent, reach width x 25% for the preceding slope of apron and downstream. If the channel is heavily degraded, the slope should be that of state that would fit within the geomorphologic context of the reach.</td>
<td>50.4.2, Appendix C4: Provides recommended methods to determine bankfull depth.</td>
<td>Page 77-72, 73-74. Follow AFGH and FMF Guidelines. Prevent or limit local scour and clogging of the stream substrate.</td>
<td>Slope ratio greater than 1.25 or more than 1.1 for soils other than silt loam, requires some additional analysis. Know the slope of the stream bed where the culvert would be located. Use the applicable regulatory requirements for additional analysis. See also WSDOT Hydrologic Manual, Chapter 4 Fish Passage.</td>
</tr>
<tr>
<td>Croossectors/Skirts</td>
<td>Culvert bottom or bridge foundation does not become exposed for life of structure and subsurface soil is similar to adjacent channel.</td>
<td>72.46.4(6)(b), (c).</td>
<td>WSDOT designs bridges for the 500-year runoff. See also WSDOT Hydrologic Manual, Chapter 7 Fish Passage.</td>
<td>WSDOT designs bridges for the 500-year runoff. See also WSDOT Hydrologic Manual, Chapter 7 Fish Passage.</td>
</tr>
<tr>
<td>Channel Geometry</td>
<td>Controlling of channel profile and cross section maintained throughout reach address resistance to erosion, large woody material, and meander frequency.</td>
<td>72.46.4(6)(b), (c).</td>
<td>See also WSDOT Hydrologic Manual, Chapter 7 Fish Passage.</td>
<td>See also WSDOT Hydrologic Manual, Chapter 7 Fish Passage.</td>
</tr>
<tr>
<td>Floodplain Continuity</td>
<td>Controlled structures along floodplains and habitats and allows for floodplain connectivity. All water crossings must maintain upstream and downstream connection in order to maintain expected channel processes. These processes include the movement and distribution of sediment and water channel patterns. An erosion control structure is placed to protect bankfull slope so that river hydraulics will be protected.</td>
<td>70.72-78, 79-80. Allow combined sheet flow and flow of water on the floodplains. The bridge/culvert design must comply with livestock management development within floodplains.</td>
<td>If the noted V2/V is less than 0.5, no additional justifications is needed. If V2/V is greater than 0.5, must explain how there is no significant effect. V2 = design velocity V1 = existing velocity.</td>
<td></td>
</tr>
<tr>
<td>Fretboards</td>
<td>Maintain structural integrity of the crossing for the duration of the design life.</td>
<td>72.4.4, 72.5. Culverts/hab fish ref. to be designed to an approved design to maintain structural integrity to the 100-year peak flood.</td>
<td>See also WSDOT Hydrologic Manual, Chapter 7 Fish Passage.</td>
<td>See also WSDOT Hydrologic Manual, Chapter 7 Fish Passage.</td>
</tr>
<tr>
<td>Substrate</td>
<td>Channel substrates reference reach. The water crossing design must provide unimpeded passage for all species of adult and juvenile fish. Passage is assumed where there are no barriers due to behavioral, extraneous water steps, excessive water velocity, shallow flow, low flow, uneven surfaces, unstratified fish habitat, and other material conditions.</td>
<td>64.4-52, 64.6. A reference reach approach to sizing sediment is performed. Substrates should be designed to address both inflow at high flows and be well graded to prevent loss of significant surface areas.</td>
<td>See also WSDOT Hydrologic Manual, Chapter 7 Fish Passage.</td>
<td>See also WSDOT Hydrologic Manual, Chapter 7 Fish Passage.</td>
</tr>
<tr>
<td>Structural Spans</td>
<td>Crossing width (top) allow for geometric processes to occur including 100 year flood. Minimize the need for cross supports maintain structural integrity for the duration of the design life.</td>
<td>70.45-29.</td>
<td>See also WSDOT Hydrologic Manual, Chapter 7 Fish Passage.</td>
<td>See also WSDOT Hydrologic Manual, Chapter 7 Fish Passage.</td>
</tr>
<tr>
<td>Coarse Rocks</td>
<td>For culverts, fauna from structure and embankment gradient, to keep the thalweg of the culvert unobstructed intended to be good, curvatures, and to improve existing structure.</td>
<td>47-65.0. Riffle forms completely where WDFW can't be installed. Less important in deep streams.</td>
<td>Use for channel diameter less than 75%. Evaluate for slopes between 2% to 4%. Use material between the DFE and two times the DFE of the stream at the culvert.</td>
<td>See also WSDOT Hydrologic Manual, Chapter 7 Fish Passage.</td>
</tr>
<tr>
<td>Crossing Length</td>
<td>Minimum cross-channel channel and riparian impacts, increase width for long crossings, Structurally accommodate is should using a structural design, leading to the culvert right and the culvert left.</td>
<td>70.43-84.</td>
<td>See also WSDOT Hydrologic Manual, Chapter 7 Fish Passage.</td>
<td>See also WSDOT Hydrologic Manual, Chapter 7 Fish Passage.</td>
</tr>
<tr>
<td>Floodplain Utilization Ratio (FUR)</td>
<td>To determine if unaltered bridge design criteria are adequate for the bridge or burned structure.</td>
<td>Measure FUR outside the influence of any crossing structures.</td>
<td>See also WSDOT Hydrologic Manual, Chapter 7 Fish Passage.</td>
<td>See also WSDOT Hydrologic Manual, Chapter 7 Fish Passage.</td>
</tr>
<tr>
<td>Streambank Protection/ Stabilization</td>
<td>As proposed bank hardening must include the option, as well as other engineering methods as they become available. Any proposed bank hardening must include the option to install an armoring system, as a stay-by site option.</td>
<td>As proposed bank hardening must include the option to install an armoring system, as a stay-by site option.</td>
<td>See Integrated Streambank Protection Guidelines</td>
<td>See Integrated Streambank Protection Guidelines.</td>
</tr>
<tr>
<td>Hydrology</td>
<td>Correlated to watershed conditions and land use while avoiding over-eroded channels and maintaining an appropriate habitat for existing species.</td>
<td>301. Page 202-287. Appendix G2 Design Flows for Fish Passage</td>
<td>Address potential effects of extreme events (e.g., 50-year) use of flood studies.</td>
<td>Address potential effects of extreme events (e.g., 50-year) use of flood studies.</td>
</tr>
</tbody>
</table>
Stream Simulation Culvert Design Methodology

<table>
<thead>
<tr>
<th>Supplemental Guidance</th>
<th>Summary of relevant Washington Administrative Code (WAC)</th>
<th>Summary of relevant WDFW Water Crossing Guidelines</th>
<th>Design Methodology Requirements for Bridges and Stream Simulation Culverts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beeffall/Bed Width</td>
<td>Determine accurate beeffall widths relative to site conditions. Design team will reach agreement in the field whenever possible.</td>
<td>Beeffall is highly modified (urban/agricultural) determined by hydraulic modeling, reference reach or comparative analysis. See also WSDOT Hydraulics Manual, Chapter 7 Fish Passage.</td>
<td>Beeffall is highly modified (urban/agricultural) determined by hydraulic modeling, reference reach or comparative analysis. See also WSDOT Hydraulics Manual, Chapter 7 Fish Passage.</td>
</tr>
<tr>
<td>Culvert Gradient</td>
<td>The culvert is set at an inclination below total source and provides adequate flow area.</td>
<td>The culvert must be set at the prevailing stream gradient unless an alternative slope is approved by the department.</td>
<td>In cases where placing the culvert at the same gradient as the stream would cause construction issues, placing the culvert at a steeper angle may be acceptable.</td>
</tr>
<tr>
<td>Channel Slope/Gradient</td>
<td>The slope of the bed inside the culvert is within 20% of the slope of the upstream channel.</td>
<td>The slope of the bed inside a stream simulation culvert must not exceed the slope of the upstream channel by more than twenty-five percent.</td>
<td>Slope ratio greater than 1.25 or more than 10% of unregulated regime needs to be analyzed. In low gradient areas, provide compensation of designed gradient is outside slope ratio. See also WSDOT Hydraulics Manual, Chapter 7 Fish Passage.</td>
</tr>
<tr>
<td>Channel Geometry</td>
<td>Continuity of channel shape maintained throughout reach (channel complexity).</td>
<td>All water crossing must maintain upstream and downstream connection in order to maintain expected channel processes.</td>
<td>See WSDOT Hydraulics Manual, Chapter 7 Fish Passage.</td>
</tr>
<tr>
<td>Culvert/Source</td>
<td>Culvert bottom does not exceed exposed rock of structure and structure is similar to adjacent channel.</td>
<td>Must be countermarked a minimum of 30% and a maximum of 50% of the culvert, but not less than two feet. Alternative depths of culvert fill may be accepted with engineering justification.</td>
<td>WSDOT uses 300-year source depth plus 5 feet. See WSDOT Hydraulics Manual, Chapter 7 Fish Passage.</td>
</tr>
<tr>
<td>Cross Section</td>
<td>Adjacent channel shape is continuous through crossing.</td>
<td>If the channel is badly degraded, the cross section must be matched, expected stream measurements in order to limit main channel velocity and source to prevailing conditions.</td>
<td>See WSDOT Hydraulics Manual, Chapter 7 Fish Passage.</td>
</tr>
<tr>
<td>Floodplain Continuity</td>
<td>Constructed channel mimics adjacent channel hydraulic conditions.</td>
<td>Fish must be able to move freely at all times where fish are expected to move. All water crossings must maintain upstream and downstream channel processes. Floodplain connectivity may be approved if it can be shown that there are erosional impacts to fish life and habitat.</td>
<td>See WSDOT Hydraulics Manual, Chapter 7 Fish Passage.</td>
</tr>
<tr>
<td>Fishscreen</td>
<td>Crossing provides unimpeded passage of fish. 300 year food passes, LVM, and salmon.</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Substrate</td>
<td>Channel substrate mimics reference reach.</td>
<td>D50 should be between 75-90% of the D50 of the reference reach. The department may approve exceptions if the proposed alternative sediment is appropriate for the circumstances.</td>
<td>N/A</td>
</tr>
<tr>
<td>Culvert Size</td>
<td>Culvert opening should be wide enough to maintain sediment and stream flow continuity.</td>
<td>Width inside a culvert may be calculated by using any published stream simulation design methodology approved by the department, or may be determined on a case-by-case basis with an expected alternative plan that includes project objectives, inspection, maintenance, and contingency components.</td>
<td>N/A</td>
</tr>
<tr>
<td>Course Bounds</td>
<td>Help maintain and establish gradients for the flowpath of the culvert and not intended to be the final construction right of way that do not deform over time.</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Crossing Length</td>
<td>Minimum-defined length of channel and horizontal lengths. However the length and width of the channel, land, and cross-section should allow space to avoid abrupt bends leading to the culvert inlet and from the culvert outlet.</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Hydrologic Utilization Rate (FUR)</td>
<td>Determine if 3% is contained within FUR (1) or uncorrected (FUR &gt; 3).</td>
<td>For high floods and horizontal lengths, is calculated as the overlap of the 1% FUR and the 3% FUR that can be contained within the culvert.</td>
<td>N/A</td>
</tr>
<tr>
<td>Streambed Protection/ Stabilization</td>
<td>Mitigate preserving (use of riprap or concrete) and use bio-engineering techniques when appropriate.</td>
<td>Any proposed bank hardening must include:</td>
<td>N/A</td>
</tr>
<tr>
<td>Hydrologic/Design Flows</td>
<td>Develop design flows that accurately reflect water quality conditions, including future conditions.</td>
<td>N/A</td>
<td>N/A</td>
</tr>
</tbody>
</table>