Department of Fish and Wildlife

**DESIGN GUIDELINES APPROVED FOR USE IN DESIGNING WATER CROSSINGS OVER FISH-BEARING WATERS IN WASHINGTON STATE**

# FHWA Hydraulic Engineering Circular 26

# Culvert Design For Aquatic Organism Passage[1]

*Notes for appropriate use to comply with WAC 220-660-190*

November 9, 2015

HEC 26 was written for a national audience and can be applied in states where the protection for fishlife is different from that found in Washington. However, these accompanying notes should provide sufficient additional guidance to allow the designer to comply with Washington State Hydraulic Code rules WAC 220-660-190, Water Crossings, and WAC 220-660-200, Fish Passage Improvement Structures.

## Chapter 1: INTRODUCTION

*Section 1.3 – Design Procedure Applicability*

(1) In areas under the jurisdiction of the Washington State Hydraulic Code (RCW 99.55/WAC 220-660), applicability of this document is subject to compliance with applicable portions of these notes.

(2) In Washington State, culverts that are made passable through the use of baffles, grade controls (log or rock structures fully spanning the channel) or roughened channels are considered Fish Passage Improvement Structures and are permitted under WAC 220-660-200.

## Chapter 2: CULVERTS AS PASSAGE BARRIER

*Section 2.2 – Barrier Mechanisms*

In addition to barrier conditions created by a single culvert, there are cumulative effects associated with multiple culverts along a migration path, especially when those culverts are close together. In these instances, hydraulic criteria (velocity, depth, energy dissipation)

[1] FHWA (2010) **Culvert Design For Aquatic Organism Passage.** Hydraulic Engineering Circular (HEC) 26. Federal Highway Administration – National Highway Institute. Washington DC.

that would allow for passage through a single culvert may not be adequate. Another consideration is that anadromous fish have limited energy reserves available to migrate and spawn; energy expended negotiating successive partial barriers (or even culverts that nominally meet hydraulic criteria) may limit the ability of spawners to reach otherwise accessible spawning areas, or even limit spawning success within accessible areas.

*Section 2.2.5 – Barrier Mechanisms: Excessive Turbulence*

Additional discussion of and guidance for turbulence and energy dissipation is provided in the Water Crossing Design Guidelines (WCDG)[2] (pp. 124-134).

*Section 2.2.6 – Barrier Mechanisms: Culvert Length*

In the case of multiple culverts in series, the effective barrier length may include the lengths of all culverts and intervening stream reaches, particularly if there are no adequate resting areas (e.g pools with sufficient depth and cover).

## Chapter 5: PASSAGE HYDROLOGY

*Section 5.2.1 – Design Hydrology: Flood Peak, $Q_p$*

(1) All water crossings in Washington must "retain upstream and downstream connection in order to maintain expected channel processes. These processes include the movement and distribution of wood and sediment and shifting channel patterns," (WAC 220-660-190(2)). The sizing of a culvert cannot be based solely on the flood conveyance.

(2) For fish passage improvement structures (e.g. grade controls, roughened channels) used to provide fish passage at or adjacent to a culvert, WAC 220-660-200 requires that the structure (or bed material, for roughened channels) must withstand the "maximum expected flow" (no recurrence interval specified). For culverts using the hydraulic design method, the rules require that the structure "must include consideration of flood capacity for current conditions and future changes likely to occur in the stream channel." Additional discussion and guidance is provided in the WCDG (pp 108-110).

*Section 5.2.2 – Design Hydrology: High and Low Passage Flows*

(1) Only when a water crossing is permitted under WAC 220-660-200 can a fish passage be based solely on a velocity criterion. When permitted under WAC 220-660-190(3)(a), "(t)he water crossing design must provide unimpeded passage for all species of adult and juvenile fishes. Passage is assumed when there are no barriers due to behavioral

[2] Barnard RJ, Johnson J, Brooks P, Bates KM, Heiner B, Klavas JP, Ponder DC, Smith PD, Powers PD. 2013. **Water Crossings Design Guidelines**. Washington Department of Fish and Wildlife: Olympia, Washington.

impediments, excessive water slope, drop or velocity, shallow flow, lack of surface flow, uncharacteristically coarse bed material, and other related conditions."

(2) For culvert designs utilizing fish passage improvement structures, such structures may not cause "significant migratory delays", as determined by WDFW. Compensatory mitigation may be required if a structure cannot pass all fish species present at all mobile life stages. For the purpose of meeting hydraulic design requirements, low fish passage design flow is defined as the two-year, seven-day low flow discharge for the subject basin, or, where that information or necessary flow data are unavailable, the depth of the proposed culvert when no water is flowing. For the purpose of meeting velocity requirements in roughened channels and hydraulic design culverts, the high fish design flow is specified, but not defined. Additional discussion and guidance is provided in the WCDG (pp. 108-111).

## Chapter 6: STREAM GEOMORPHOLOGY

*Section 6.1.2 – Channel Characteristics: Gradient*

Culvert designs which use substantially over-sized sediment to maintain a gradient within the culvert in excess of 1.25 times the prevailing natural upstream gradient are not considered stream simulation culverts.

*Section 6.1.4 – Channel Characteristics: Key Roughness Elements*

Care should be taken to limit use of certain types of roughness elements (oversized substrate, boulders, stone sills) in lower gradient reaches (typically < 4%), where they may serve to limit natural pool formation.

*Section 6.2.1 – Channel Transformations: Channel Evolution*
*Section 6.2.2 – Channel Transformations: Channel Incision, Headcuts, and Aggradation*

(1) Incised channels in urban areas usually represent a geomorphic response to changes in hydrology, sediment load, and constraints on channel geometry (e.g. straightening, bank hardening) imposed by urban land development and infrastructure. While "recovery" to a pre-development channel condition may be difficult or impossible, the expected trajectory to a new, more ecologically functional equilibrium condition is generally predictable (see channel evolution models by Schumm, et al[3] and Cluer and Thorne (2013).[4] Where a reasonable potential for achieving this condition exists, channel designs for water crossing structures are encouraged to accommodate, or at least not

[3] Schumm SA, Harvey MD, and Watson CC. 1984. *Incised Channels: Morphology, Dynamics,and Control*. Water Resources Publications: Littleton, CO.

[4] Cluer B, and C Thorne. 2013. *A Stream Evolution Model Integrating Habitat and Ecosystem Benefits*. River Research and Applications. (2013). Wileyonlinelibrary.com. DOI: 10.1002/rra.2631.

preclude, expected channel changes. Additional discussion and guidance is provided in WCDG (pp. 144-146).

(2) Excessive and/or persistent aggradation often reflects the position of the site in the watershed (e.g. at or below grade breaks or alluvial fans) or changes in hydrology and/or sediment supply attributable to natural or land use factors. Even if not currently apparent, the risk of aggradation over the life of the culvert may be ascertained by a geomorphic reach assessment. In some instances, lower degrees of aggradation may be accommodated by increasing the height (to account for increased bed elevation) and width (to account for increased width/lateral migration of the channel) of the structure. In more severe cases, replacement with a bridge, elevation of the road grade, or relocation of the crossing may be required to avoid chronic in-channel maintenance issues.

*Section 6.3.1 – Stream Classification: Montgomery and Buffington*

This classification system is particularly useful for higher gradient (> 0.001) channels above the larger alluvial valleys in Western Washington. This system is both form- and process-based, and will provide the designer with a relatively easy and generally reliable basis for determining type of channel to be simulated in many geomorphic settings, as well as the expected reach-scale response to variations in wood, water, and sediment supply.

*Section 6.3.2 – Stream Classification: Rosgen*

This classification system was developed using channels in the Rocky Mountains and Intermountain West, and may be best applied east of the Cascade Range.

## CHAPTER 7 -DESIGN PROCEDURE

*During the development of HEC 26, WDFW and other resource protection agencies were critical of a design method that relied primarily on bed stability and velocity. While there is much discussion in previous chapters about channel geomorphology, the design sequence shown in Figure 7.1 still does not refer back to natural channel conditions in a comprehensive way. We encourage those using these guidelines to view the culvert in the context of the adjacent channel and ensure that the design conforms to the requirements in WAC 220-660-190(2) and (3).*

*Section 7.3 – Step 3. Check for Dynamic Equilibrium.*

In watersheds degraded by human activity (e.g. urbanization, forest or agricultural practices), channel characteristics (width, depth, bed material, slope) at the site reflect land use-imposed changes in hydrology and sediment supply/transport. In these instances, a determination must be made regarding whether to design a crossing which maintains the current degraded channel, or provide for a channel that may be expected to occur if the adjacent reach(es) are allowed and/or have the potential to achieve some new equilibrium state.

*Section 7.4 – Step 4. Analyze and Mitigate Channel Instability*

The Integrated Streambank Protection Guidelines[5] are recommended for use in Washington State.

*Section 7.5 – Step 5. Align and Size Culvert for $Q_P$*

(1) See note (1) for Section 5.2.1 above. It is generally assumed that a culvert small enough to flow full cannot maintain stream-like conditions, as required by WAC 220-660-190(2). Culverts which flow full, nearly full, or develop inlet control conditions at $Q_{100}$ or less, should be increased in size, unless the water surface elevation was created by a downstream backwater condition that recedes gradually enough to preclude excessive scour.

(2) Floodplain relief culverts should be used with caution; if they connect directly to or create fish bearing streams in the floodplain, they will be required to meet applicable regulations for water crossing structures.

*Section 7.5.2 – Step 5. Align and Size Culvert for $Q_P$: Length*

Culverts designed for fish passage (even stream simulation culverts) generally don't fully simulate all the features that provide the degree of energy dissipation and hydraulic diversity found in natural channels. These features include bed roughness, profile variation (e.g. pools and riffles/steps), planform variation (lateral migration) and hydraulic interaction with natural stream banks. In shorter culverts, this generally is acceptable, to the extent that it is unlikely to result in adverse conditions (e.g. reduced passability due to excessive turbulence, velocity, or lack of resting areas, increased bed scour) to the stream bed or for fish. As culvert length increases, there is an increased likelihood that excess kinetic energy may build to the point that these adverse conditions would occur. For long culverts (defined in the WCDG as longer than ten times the structure with), it is recommended that this be addressed in design. Further discussion and guidance is provided in WCDG pp. 40 – 41.

*Section 7.5.3 – Step 5. Align and Size Culvert for $Q_P$: Embedment*

In the case of rapidly incising channels, deeper embedments than those referred to here are recommended. A dense, well-graded bed material will eliminate subsurface flow, the major concern cited for shallower embedment.

*Section 7.5.4 – Step 5. Align and Size Culvert for $Q_P$: Bed Gradation*

WDFW has found that for a culvert to be considered "stream simulation" the median bed material size must be +/- 20% of the median particle size ($D_{50}$) found in a reference reach of the same stream.

[5] WA State Aquatic Habitat Guidelines Committee. 2003. *Integrated Streambank Protection Guidelines*. Available at: http://wdfw.wa.gov/publications/00046/.

*Section 7.5.6 – Step 5. Align and Size Culvert for $Q_P$: Debris*

The passage of debris and sediment is required by WAC 220-660-190(2). Stream simulation and no-slope culverts do not have specific provisions for required vertical clearance to pass debris. In general, these culverts should pass expected debris in most circumstances. Additional discussion and guidance is provided in WCDG (pp. 15, 26).

*Section 7.6.1 – Step 6: Permissible Shear Stress*

The values developed in Table 7.1 were developed for use in roadside ditches with relatively uniform material gradations and angular bed material. The minimum value provided (F* = 0.047) is larger than what may apply for well-graded beds of rounded material typically used for simulated streambeds. See Buffington and Montgomery (1997)[6] for more information.

*Section 7.6.1.3 - Step 6: Permissible Shear Stress/Applied Shear Stress*

It should be emphasized that the applied shear stress calculation uses the maximum channel depth, and not the hydraulic radius (which is more representative of the mean flow depth). Shear stress calculations generated from HECRAS and other hydraulic models are usually based on hydraulic radius.

*Section 7.7 - Step 7. Check Channel Bed Mobility at $Q_H$*

Given that $Q_H$ is usually substantially less than a bankfull or channel-forming discharge, general mobility of the culvert and channel bed is not expected or necessarily desired at this discharge. For alluvial channels that are not sediment supply-limited, relative mobility should be evaluated at the bankfull discharge (typically a 2-year to 5-year peak flow event). In general, mobility relative to the upstream channel reach is more important, since this is the local source of the sediment to the culvert bed. In this case, it is extremely important that the upstream reference reach be above the influence of the culvert and at the approximately the same gradient (within 25%), to insure that the channel bed was formed under expected natural conditions.

*Section 7.8 - Step 8. Check Culvert Bed Mobility at $Q_H$: Pressure Flow*

Culvert designs resulting in pressure flow at any point up to the peak design discharge are undersized and need to be enlarged to accommodate this discharge, expected debris, sediment and natural channel patterns (WAC 220-660-190(2)).

*Section 7.9 - Step 9. Design Stable Bed for $Q_P$*

(1) In many instances, a geomorphic reach assessment can identify whether the channel upstream of the culvert is supply- or transport-limited, based on readily identifiable geomorphic features and watershed characteristics. See WCDG pp. 73-82 more information and guidance.

(2) The minimum native streambed material layer thickness should generally be no less than the predicted total scour for the culvert, including expected channel regrade.

[6] Buffington JM and DR Montgomery. 1997. *A systematic analysis of eight decades of incipient motion studies, with special reference to gravel-bedded rivers*. Water Resources Research Vol. 33 No. 8, pp. 1993-2029.

Exposure of an oversized sublayer due to channel incision may cause the culvert to be considered a passage barrier.

*(3)* WDFW strongly discourages the use of sills, and encourages the correct sizing of culvert fill materials. See WCDG pp.68-69 for more information.

*Section 7.9.2 - Step 9. Design Stable Bed for $Q_P$: Design Equations*

The approach shown here is for design of riprap. Use of this material should only occur well below the top of the culvert bed (see note 2 under Section 7.9 above). Beds constructed of this material at or near the surface will generally be considered roughened channels (see WAC 220-660-200 and WCDG pp. 122-137).

*Section 7.10 - Step 10. Check Culvert Velocity at $Q_H$*

Culverts complying with the provisions in WAC 220-660-190 (6) are presumed to be passable and provide for expected channel processes.

*Section 7.11 - Step 11. Check Culvert Water Depth at $Q_L$*

Culverts complying with the provisions in WAC 220-660-190(6) are presumed to be passable and provide for expected channel processes. An exception would be where there is excessive infiltration into the culvert bed, due to an overly uniform or open bed gradation, or inadequate construction control during placement. This situation would require corrective action (see Section 8.4.1 Sealing Voids) to restore surface flows that emulate the adjacent channel reaches.