Chapter 4 Open-Channel Flow

4-1 Introduction

An open channel is a watercourse that allows part of the flow to be exposed to the atmosphere. This type of channel includes rivers, culverts, stormwater systems that flow by gravity, roadside ditches, and roadway gutters. Open-channel flow design criteria are used in the following areas of transportation design:

- River stabilization (Section 4-6)
- Partially full flow pipes
- Roadside ditches (Section 4-3)
- Bridge design
- Downstream analysis

Proper design requires that open channels have sufficient hydraulic capacity to convey the flow of the design storm. In the case of earth-lined channels or river channels, bank protection is also required if the shear stress is high enough to cause erosion or scouring.

This chapter provides guidance for designing systems with open-channel flow, including determining design velocity (Section 4-2) and critical depth (Section 4-4), designing roadside ditches (Section 4-3) and backwater analysis for river flow (Section 4-5).

River stabilization (Section 4-6) may be necessary for highly erosive, high-energy rivers, to help the river dissipate some of its energy and stabilize the river banks and channel bottom. The success of the rock structures or rock bank protection is dependent on the ability of the rock to withstand the forces of the river; therefore, it is important to properly size the rocks used. The methodology for sizing rocks used in river stabilization is described in HEC-22.

The flow capacity of a culvert is often dependent on the channel up- and downstream from that culvert. For example, the tailwater level is often controlled by the hydraulic capacity of the channel downstream of the culvert. Knowing the flow capacity of the downstream channel, open-channel flow equations can be applied to a typical channel cross section to adequately determine the depth of flow in the downstream channel. This depth can then be used in the analysis of the culvert hydraulic capacity.

Biofiltration swales are shallow, grass-lined, open channels that clean stormwater runoff before it reaches a receiving body. The PEO should route stormwater through biofiltration swales or other approved stormwater BMPs as required in the *Highway Runoff Manual*.

A downstream analysis identifies and evaluates the impacts a project will have on the hydraulic conveyance system downstream of the project site. See Section 1-3.7.

Measurement of flow in channels can be difficult because of the nonuniform channel dimensions and variations in velocities across the channel. Weirs allow water to be routed through the structure of known dimension, permitting flow rates to be measured as a function of depth of flow through the structure.

4-2 Determining Channel Velocities

In open-channel flow, the volume of flow and the rate at which flow travels are useful in designing the channel. For the purposes of the *Hydraulics Manual*, the determination of the flow rate in the channel, also known as discharge, is based on the continuity of flow equation or Equation 4-1. This equation states that the discharge (Q) is equivalent to the product of the channel velocity (V) and the area of flow (A).

$$Q = V A \tag{4-1}$$

Where:

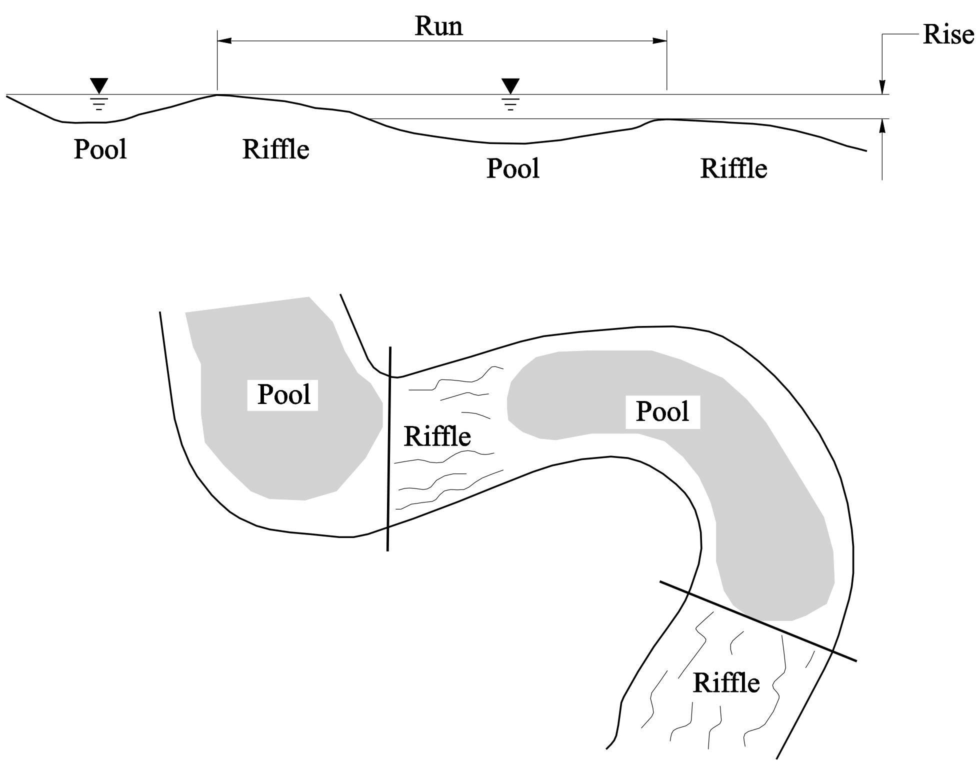
Q = discharge, cfs
V = velocity, ft/s
A = flow area, ft^2

In some situations, the flow area of a channel is known. If it is not, the flow area must be calculated. Computer programs and charts from HDS-4 are available for determining channel geometry or velocities.

4-2.1 *Field Slope Measurements*

By definition, slope is rise over run (or fall) per unit length along the channel centerline or thalweg. Slope is the vertical drop in the river channel divided by the horizontal distance measured along the thalweg of a specific reach. The vertical drop shall be measured from the water surface at the top-of-riffle (end of pool) to the next top-of-riffle to get an accurate representation of the slope in that reach (Figure 4-1).

Figure 4-1 Field Slope Measurement

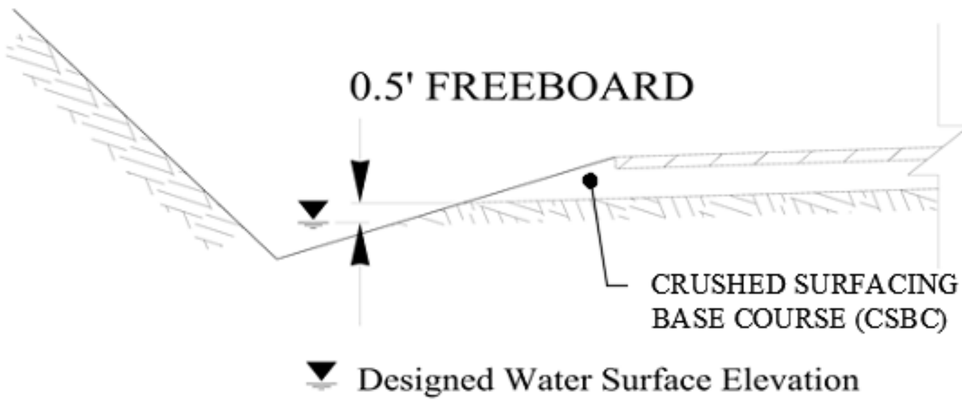


4-3 Roadside Ditch Design Criteria

Roadside ditches are generally located alongside uncurbed roadways with the primary purpose of conveying runoff away from the roadway. Ditches shall be designed to convey the 10-year recurrence interval with a 0.5-foot freeboard (from the ditch design water surface elevation to the bottom of the pavement subgrade or ditch spill) and a maximum side slope of 2H:1V (Figure 4-2). The preferred cross section of a ditch is trapezoidal; however, a "V" ditch can also be used where ROW is limited or the design requirements can still be met. In those cases where the grade is flat, preventing adequate freeboard, the depth of channel should still be sufficient to remove the water without saturating the subgrade shoulder.

To maintain the integrity of the channel, ditches are usually lined. See HDS-4, HEC-15, or the *Standard Specifications* for more information. WSDOT's *Design Manual* also contains design guidance for both paved and grass-lined ditches.

Figure 4-2 Drainage Ditch Detail



Ditches should not be confused with biofiltration swales. In addition to collecting and conveying drainage, biofiltration swales also provide runoff treatment by filtering out sediment. (See the *Highway Runoff Manual* for design guidance for biofiltration swales.) Roadside ditches are to be designed so the integrity or geometry of the roadway is not compromised.

4-4 Critical Depth

Before finalizing a channel design, the PEO must verify that the normal depth of a channel is either greater than or less than the critical depth. Critical depth is the depth of water at critical flow, a very unstable condition where the flow is turbulent and a slight change in the specific energy—the sum of the flow depth and velocity head—could cause a significant rise or fall in the depth of flow. Critical flow is also the dividing point between the subcritical flow regime (tranquil flow), where normal depth is greater than critical depth, and the supercritical flow regime (rapid flow), where normal depth is less than critical depth.

Critical flow tends to occur when passing through an excessive contraction, either vertical or horizontal, before the water is discharged into an area where the flow is not restricted. A characteristic of critical depth flow is often a series of surface undulations over a very short stretch of channel. The PEO should be aware of the following areas where critical flow could occur: culverts, bridges, and near the brink of an overfall.

A discussion of specific energy is beyond the scope of the *Hydraulics Manual*. The PEO should refer to HDS-5 or HEC-14, for further information.

4-5 River Backwater Analysis

Natural river channels tend to be highly irregular in shape so an analysis using Manning's equation, while helpful for making an approximation, is not sufficiently accurate to determine a river water surface profile. The HQ Hydraulics Section is responsible for computing water surface profiles and has several computer programs to calculate the water surface profile of natural river channels. The computation of the water surface profile is called a backwater analysis. The purpose of this section is to state when a backwater analysis is necessary as well as to summarize the minimum design requirements for the analysis and provide the project office with a list of field information required for the HQ Hydraulics Section to perform an analysis. This section will be revised in a future update.

A backwater analysis is performed when designing a bridge that crosses a river designated as a FEMA regulatory floodplain. WSDOT is required by federal mandate to design these bridges to accommodate the 100-year storm event. It is desirable to maintain a 3-foot vertical clearance between the bottom of the bridge and the 100-year water surface elevation. The water surface elevations for the 100-year and 500-year water surface profiles shall be shown on the plans.

Backwater analysis can be useful in culvert design. Computing the water surface profile can help the PEO determine if the culvert is flowing under inlet or outlet control. The region must provide the following information to the HQ Hydraulics Section to complete a river backwater analysis.

1. A topographic surface of the project site with 1- or 2-foot contour intervals is required. The extent of the topographic mapping required is site-specific but shall include all areas within the 100-year floodplain. All bridge and unique attributes of the project area shall be identified.
2. The Manning's roughness coefficients must be established for all parts of the river within the project area. See Appendix 4A for guidance. The HQ Hydraulics Section will need photographs of the channel bed and streambank along the reach of interest to determine the appropriate channel roughness. Photographs are especially important in areas where ground cover changes.

To prevent subsequent difficulties in the backwater analysis, the HQ Hydraulics Section should be contacted to determine the necessary parameters. For additional information about backwater analyses, see FHWA's HDS-7.

4-6 River Stabilization

Because of the abundance of watercourses in Washington State, and the legacy of highway placement along and across their corridors, stabilization of part of the river cross section or alignment is often necessary to protection transportation investments. New roadways and other infrastructure must be placed to minimize interaction with or effects on waterbodies, avoiding them altogether if possible. This section discusses the options available for those cases where action must be taken and provides a subset of suggested techniques and associated technical references for those techniques. This is not a comprehensive guide, and as new techniques arise, all should be considered (in coordination with HQ Hydraulics Section) for their cost benefit in addressing interactions with water bodies.

4-6.1 *Streambank Protection*

Extensive guidance exists for numerous techniques for bank protection, from riprap to revegetation. Many techniques recommended in Pacific Northwest Rivers incorporate LWM. Some of the most pertinent guidance documents are listed below:

- HEC-23, Volumes 1 and 2
- Integrated Streambank Protection Guidelines (ISPG; WDFW 2002)
- Stream Restoration Design (National Engineering Handbook 654, NRCS 2007)
- Bank Stabilization Design Guidelines (Baird et al. 2015)
- WDFW's Stream Habitat Restoration Guidelines (April 2012 Draft)

The techniques are too numerous to discuss in detail in this document. Figure 4-3 lists the most common treatment types and the conditions for which they are most appropriate.

Figure 4-3 Common Treatment Types and Conditions

No Action	Flow-redirection Techniques	Structural Techniques	Biotechnical Techniques	Internal Bank-Drainage Techniques	Avulsion-prevention Techniques	Other Techniques
Allow Bank Erosion to Continue	Groins	Anchor Points	Woody Plantings	Subsurface Drainage Systems	Floodplain Roughness	Channel Modifications
Move structures at risk	Buried Groins	Roughness Trees	Herbaceous Cover	--	Floodplain Grade Control	Riparian Buffer Management
--	Barbs	Riprap	Soil Reinforcement	--	Floodplain Flow Spreader	Spanning Habitat Restoration
--	Engineered Logjams	Log Toes	Coir Logs	--	--	Off-Channel Spawning and Rearing Habitat
--	Drop Structures	Rock Toes	Bank Reshaping	--	--	--
--	Porous Weirs	Log Crib walls	--	--	--	--
--	--	Manufactured Retention Systems	--	--	--	--

Note:
-- = not applicable

Additionally, matrices 1, 2, and 3 in the ISPG provide qualitative ratings of each technique relative to the underlying cause of a problem is site-based (local conditions) or reach-based (watershed conditions).

4-6.2 *Riprap for Bank Stabilization*

Riprap bank protection is a layer of rock placed to stabilize the bank and inhibit lateral erosion. Riprap is deformable, compared to rigid channel linings such as concrete. Rigid channel linings are generally not recommended for the same reasons that flexible linings are recommended. If rigid linings are undermined, the entire rigid lining will be displaced increasing the chances of failure and leaving the bank unprotected. Riprap rock encased in grout is also an example of a rigid channel lining.

There are disadvantages to using riprap bank protection. Replacing streambank vegetation with riprap will create a relatively smooth surface, resulting in higher water velocities. This change will impact the channel downstream, and to some extent upstream, where the riprap ends, creating a higher potential for erosion. Because of impacts to the adjacent channel, the PEO should consider if using riprap for bank protection would solve the problem or create a new problem. In addition, Section 24-046 of Title 222 of the Washington Administrative Code (WAC 222-24-046) states that bioengineering techniques are preferred, that work area is to be minimized to the area needing protection, and that mitigation will be required whenever riprap is used. These aspects should be considered when determining if riprap is appropriate.

Riprap bank protection is primarily used on the outside of curved channels or along straight channels when the streambank serves as the roadway embankment. Riprap on the inside of the curve is only recommended when overbank flow reentering the channel may cause scour. On a straight channel, bank protection shall begin and end at a stable feature in the bank, if possible. Such features may be bedrock outcroppings or erosion-resistant materials, trees, vegetation, or other evidence of stability.

This section does not apply to an existing bridge or when historical evidence indicates that riprap will be needed around a new bridge. In those cases, the region should indicate this information on the Bridge Site Data Sheet (Form 235-001) and refer the riprap design to the HQ Hydraulics Section.

4-6.2.1 Riprap Sizing for Bank Protection

A design procedure for rock riprap channel linings was developed by the University of Minnesota as a part of a National Cooperative Highway Research Program (NCHRP) study under the sponsorship of the AASHTO. The design procedure presented in this section is based on this study and has been modified to incorporate riprap as defined in the *Standard Specifications*.

Once the PEO has completed the analysis in this section, the PEO should consider the certainty of the velocity value used to size riprap along with the importance of the facility. For additional guidance, PEOs can consult *NCHRP Report 568 - Riprap Design Criteria* and *Hydraulic Engineering Circular 23 - Bridge Scour and Stream Instability Countermeasures* (Lagasse et al. 2006).

Manning's formula or computer programs compute the hydraulic capacity of a riprap-lined channel. The appropriate n-values are shown in Figure 4-4.

Figure 4-4 Manning's Roughness Coefficients for Riprap (n)

Type of Rock Lining[1]		n (Small Channels)[2]	n (Large Channels)
Spalls	D_{50} = 0.5 ft	0.035	0.030
Light Loose Riprap	D_{50} = 1.1 ft	0.040	0.035
Heavy Loose Riprap	D_{50} = 2.2 ft	0.045	0.040

Notes:
[1]See the *Standard Specifications*.
[2]Small channels can be loosely defined as less than 1,500 cubic feet per second.

Using Manning's equation, the PEO can determine the slope, the depth of flow, and the side slopes of the channel required to carry the design flow. The PEO, using this information, can then determine the required minimum D_{50} stone size with Equation 4-2.

$$D_{50}=C_R\ d\ S_o \tag{4-2}$$

Where:

D_{50} = Particle size of gradation, ft, of which 50 percent by weight of the mixture is finer
C_R = Riprap coefficient (see Figure 4-5)
D = Depth of flow in channel, ft
S_o = Longitudinal slope of channel, ft/ft
B = Bottom width of trapezoidal channel, ft (see Figure 4-5)

Figure 4-5 **Riprap Coefficients**

Channel	Angular Rock 42° of Repose (0.25' < D_{50} < 3')			Rounded Rock 38° of Repose (0.25' < D_{50} < 0.75')		
Side Slopes	**B/d=1**	**B/d=2**	**B/d=4**	**B/d=1**	**B/d=2**	**B/d=4**
1.5H:1V	21	19	18	28	26	24
1.75H:1V	17	16	15	20	18	17
2H:1V	16	14	13	17	15	14
2.5H:1V	15	13	12	15	14	13
3H:1V	15	13	12	15	13	12
4H:1V	15	13	12.5	15	13	12.5
Flat Bottom	12.5	12.5	12.5	12.5	12.5	12.5

Note:
Angular rock should be used for new bank protection as it is better at interlocking and providing a stable slope. Rounded rock is unstable and is not recommended for new bank protection. The coefficients have only been provided to verify if native material is a sufficient size to resist erosion. Rounded rock use in new designs should be limited to the channel bed region and to provide streambed characteristics in a bottomless arch culvert.

a. Example 1 – Riprap Sizing for Bank Protection

A channel has a trapezoidal shape with side slopes of 2H:1V and a bottom width of 10 feet. It must carry a Q_{25} = 1,200 cfs and has a longitudinal slope of 0.004 ft/ft. Determine the normal depth and the type of riprap, if any, that is needed.

After estimating the velocity (Section 4-2) and guessing a roughness coefficient for riprap from Figure 4-4 (for this example, n = 0.035 was chosen for spalls), the normal depth was found to be d = 7.14 ft with a velocity of V = 6.92 ft/s.

Next, use Figure 4-5 to determine what type, if any, riprap is needed.

$$B/d = \frac{10ft}{7.14ft} = 1.4$$

Given a side slope of 2H:1V, and a calculated value of B/d = 1.4, C_R is noted to be between 16 and 14 in Figure 4-5 for angular rock. It is allowable to interpolate between B/d columns.

$$D_{50}=C_R\ d\ S_o$$

$$D_{50}=15(7.14ft)(0.004)=0.43ft$$

From Figure 4-4, "Spalls" would provide adequate protection for a D_{50} of 0.5 foot or less in this channel. If the present streambed has rock that exceeds the calculated D_{50}, then manmade protection is needed.

b. Example 2 – Riprap Sizing for Bank Protection

Repeat the process using a 1 percent slope, and the PEO finds:

$$D=5.75\ ft$$

$$V=9.72ft/s$$

$$B/d=10/5.75=1.74ft$$

$$C_R=14.5$$

$$D_{50}=14.5(5.75ft)(0.01)=0.83ft$$

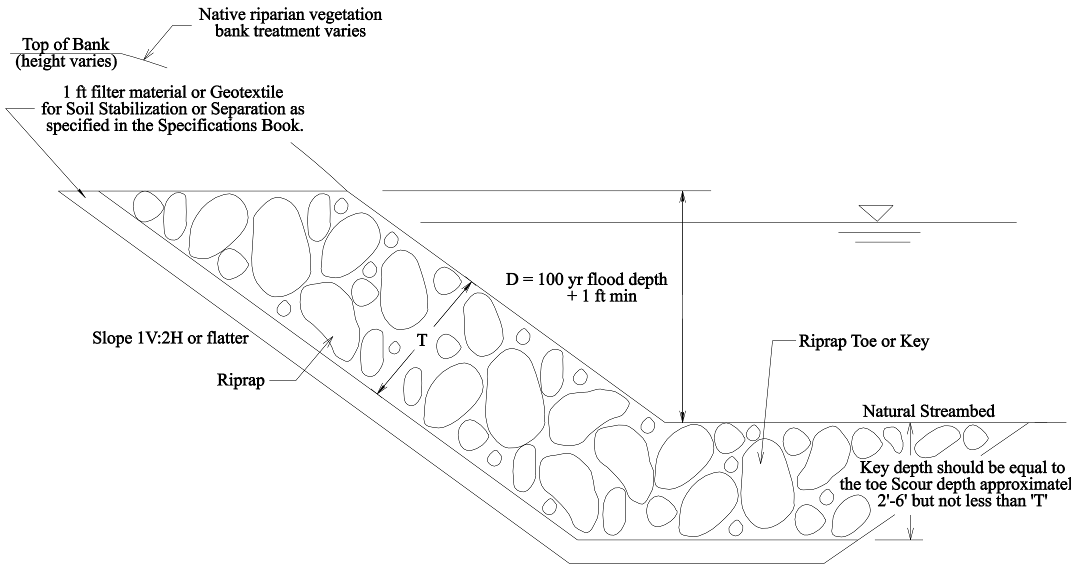
In this case, from Figure 4-4, light loose riprap would be appropriate. Since the roughness coefficient noted in Figure 4-4 for light loose riprap is n = 0.040, the PEO may recalculate the depth and velocity to get a more exact answer but this would only change the normal depth slightly and would not affect the choice of bank protection. In some cases, on very high velocity rivers or rivers that can transport large rocks downstream, even heavy loose riprap may not be adequate to control erosion and specially sized riprap may need to be specified in the contract. The HQ Hydraulics Section and the HQ Materials Laboratory are available for assistance in writing a complete specification for special riprap.

Once the size of riprap is determined, there are several methods in which riprap bank protection can be constructed. Two types of riprap placement, including dumped rock riprap and hand-placed riprap, are discussed in the following sections.

4-6.2.2 Placement of Riprap Bank Protection

Once the type of riprap has been selected from Figure 4-4, the next step is to determine the appropriate installation. Several factors affect the placement of riprap including: the type of filter material best suited for the project site, the thickness of riprap placement, and the depth to key riprap to prevent undermining. Figure 4-6 illustrates a typical cross section of a riprap bank protection installation.

Figure 4-6 Typical Cross Section of Riprap Bank Protection Installation



The filter material acts as a transition between the native soil and the riprap, preventing the piping of fines through the voids of the riprap structure and at the same time allowing relief of the hydrostatic pressure in the soil. There are two types of filters that are used: gravel (filter blanket) or fabric (geotextile). A filter blanket may consist of a 1-foot thick layer of material graded from sand to 6 inches of gravel, (placed in layers from fine to coarse out to the riprap). Filter materials are further described in the *Standard Specifications* and *Design Manual*. If the existing banks are similar to the filter material of sands and gravel, no filter layer may be needed.

The proper selection of a filter material is critical to the stability of the original bank material in that it aids in preventing scour or sloughing. Prior to selecting a filter material, the PEO should first consult with the Region Materials Engineer and the RHE to determine if there is a preference. In areas of highly erodible soil (fine, clay-like soils), the HQ Hydraulics Section should be consulted, and an additional layer of sand may be required. For additional guidance selecting the appropriate filter material, see *Hydraulic Engineering Circular No. 11*.

The thickness of riprap placed (shown as T in Figure 4-6) depends on which type of riprap was selected; quarry spalls, light loose riprap, or heavy loose riprap. Riprap thickness is 2 feet for light loose riprap, 3 feet for heavy loose riprap, and 1 foot for quarry spalls. Care should be taken during construction to ensure that the range of riprap sizes, within each group, is evenly distributed to keep the riprap stable. Riprap is usually extended to 1 foot above the 100-year flood depth of the water as shown in Figure 4-6. However, if severe wave action is anticipated, it should extend farther up the bank.

The PEO and construction inspectors must recognize the importance of a proper toe or key at the bottom of any riprap bank protection. The toe of the riprap is placed below the channel bed to a depth equaling the toe scour depth. If the estimated scour is minimal, the toe is placed at a depth equivalent to the thickness of the riprap and helps to prevent undermining. Without this key, the riprap has no foundation and the installation is certain to fail. Where a toe trench cannot be dug, the riprap shall terminate in a stone toe at the level of the streambed. A stone toe (a ridge of stone) placed along steep, eroding channel banks is one of the most reliable, cost-effective, bank stabilization structures available. The toe provides material, which will fall into a scour hole and prevent the riprap from being undermined. Added care should be taken on the outside of curves or sharp bends where scour is particularly severe. The toe of the bank protection may need to be placed deeper than in straight reaches.

4-6.3 *Channel Stabilization*

Channel stabilization, as opposed to bank stabilization, involves controlling and maintaining the channel cross section, alignment, and gradient, for some given length of the stream. There can be several reasons to stabilize a channel. At WSDOT, it is typically to protect transportation infrastructure such as a culvert or roadway embankment. Some channel stabilization may also be used for fish habitat or passage. The major types of channel stabilization are concrete or rock linings, weirs, dams, and grade-control structures. There are also fish passage features known as roughened channels; see Chapter 7 for more details.

Notably, channel stabilization is a significant modification to natural processes, and is not only technically challenging to design a maintenance-free, sustainable project, but also it is increasingly difficult to obtain the necessary environmental permits from the regulatory agencies. Therefore, such projects should be undertaken only when there are no other feasible options, only in consultation with HQ Hydraulics Section.

Figure 4-7 lists the major categories of channel stabilization techniques, the major materials involved, the risks, as well as references and manuals. Because this topic is so broad and because there is existing guidance, we refer designers to these references for details.

Figure 4-7 Channel Stabilization Techniques

Technique/ Structure	Objectives	Risks	Materials	References
Drop structures	Grade control	Outflanking, becoming fish passage barrier	Logs; concrete; sheet metal	WCDG; ISPG; HEC-23
Engineered Log Jams	Alignment control; avulsion control	Change in flow direction renders ineffective	Steel beams; wood piles; logs with/out rootwads	ISPG
Barbs, groins	Alignment control	Loss of riparian habitat; erosion of adjacent areas; incorrect spacing	Rock; rock with logs	ISPG; HEC-23
Log deflectors	Alignment control	Scour	Logs with rootwads; anchors or piles	ISPG, WCDG
Channel relocation	Alignment control	Design channel doesn't match equilibrium slope and/or shape, resulting in erosion or aggradation	Excavation of natural materials with possible additions of wood or rock	ISPG; National Engineering Handbook 654
Floodplain roughness/ grade control	Avulsion control	Insufficient roughness at bank-overtopping flows	Logs; plantings; seeding; rock	ISPG
Rock weirs	Grade Control	Mass failure; fish barrier	Rock; rock with logs	Rock Weir Design Guidance (BurRec); National Engineering Handbook 654

Notes:

HEC-23 = Hydraulic Engineering Circular No. 23 - Bridge Scour and Stream Instability Countermeasures Experience, Selection, and Design Guidance (Federal Highway Administration 2009)

ISPG = Integrated Streambank Protection Guidelines (Washington Department of Fish and Wildlife 2004)

WCDG = Water Crossing Design Guidelines (Washington Department of Fish and Wildlife 2013)

4-7 Appendices

Appendix 4A Manning's Roughness Coefficients (n)

Figure 4A-1 References for Manning's Roughness Coefficients

Category of Surface	Surfaces Included	Source
Open Channel and Pipe	Closed Conduits Pipes Pavement Gutter Manmade Channels	HEC 22
River, Stream, and Culvert Design for Aquatic Organism Passage	Rigid Channel Minor Streams Floodplains Major Streams Alluvial Beds Sand Beds Gravel Beds Cohesive Soils Composite Roughness Value	HDS 6 HEC 26 (when required for Aquatic Organism Passage) HEC 22 Chow V.T. 1959[1]
Channel Lining	Rigid Channel Unlined Channel Grass Gravel Riprap Gabion	HEC 15
Storm Sewer Conduit[2]	Concrete Pipe Metal Pipe Polyethylene Pipe PVC Pipe	HEC 22
Street and Gutter	Concrete Gutter Asphalt Concrete Pavement	HEC 22
Maintained Vegetation	Grass	HEC 15 Chow V.T. 1959[3]

Notes:
(1)See Figure 4A-2 on following page.
(2)For storm sewer pipes 24 inches or less in diameter, use n = 0.013.
(3)See Figure 4A-3 on following page.

Figure 4A-2 Manning's Roughness Coefficients for Stream Channels

Stream Channels	Manning's n
Minor streams (surface width at flood stage less than 100 feet):	
1. Fairly regular section:	
a. Some grass and weeds, little or no brush	0.030-0.035
b. Dense growth of weeds, depth of flow materially greater than weed height	0.035-0.05
c. Some weeds, light brush on banks	0.035-0.05
d. Some weeds, heavy brush on banks	0.05-0.07
e. Some weeds, dense willows on banks	0.06-0.08
f. For trees within channel, with branches submerged at high stage, increase all above values by 0.01-0.02	
2. Irregular sections, with pools, slight channel meander; increase values given in 1a-e above 0.01-0.02	
3. Mountain streams, no vegetation in channel, banks usually steep, trees and brush along banks submerged at high stage:	
a. Bottom of gravel, cobbles, and few boulders	0.04-0.05
b. Bottom of cobbles, with large boulders	0.05-0.07
Floodplains (adjacent to natural streams):	
1. Pasture, no brush:	
a. Short grass	0.030-0.035
b. High grass	0.035-0.05
2. Cultivated areas:	
a. No crop	0.03-0.04
b. Mature row crops	0.035-0.045
c. Mature field crops	0.04-0.05
3. Heavy weeds, scattered brush	0.05-0.07
4. Light brush and trees:	
a. Winter	0.05-0.06
b. Summer	0.06-0.08
5. Medium to dense brush:	
a. Winter	0.07-0.11
b. Summer	0.10-0.16
6. Dense willows, summer, not bent over by current	0.15-0.20
7. Cleared land with tree stumps, 100 to 150 per acre:	
a. No sprouts	0.04-0.05
b. With heavy growth of sprouts	0.06-0.08
8. Heavy stand of timber, a few down trees, little under-growth:	
a. Flood depth below branches	0.10-0.12
b. Flood depth reaches branches	0.12-0.16

Major streams (surface width at flood stage more than 100 feet): Roughness coefficient is usually less than for minor streams of similar description on account of less effective resistance offered by irregular banks or vegetation on banks. Values of n may be somewhat reduced. Follow recommendation in publication cited if possible. The value of n for larger streams of most regular section, with no boulders or brush, may be in the range of 0.028-0.033.

Figure 4A-3 Manning's Roughness Coefficients for Highway Channels and Swales with Maintained Vegetation

Surface	Manning's n	
	Manning's n at Depth of flow <0.7 feet	Manning's n Depth of flow 0.7-1.5 feet
Bermudagrass, Kentucky bluegrass, buffalo grass:		
Mowed to 2 inches	0.07-0.045	0.05-0.035
Length 4 to 6 inches	0.09-0.05	0.06-0.04
Good stand, any grass:		
Length about 12 inches	0.18-0.09	0.12-0.07
Length about 24 inches	0.30-0.15	0.20-0.10
Fair stand, any grass:		
Length about 12 inches	0.14-0.08	0.10-0.06
Length about 24 inches	0.25-0.13	0.17-0.09

Note:
Values shown are for velocities of 2 and 6 feet per second.