Appendix B. Recommended Guidance for Culverts and Outfalls

The following information is intended to provide guidance in designing stormwater outfalls and surface water culverts in a way that provides multiple benefits to watersheds, not just conveyance. Each site is unique and a number of additional requirements may also apply. The format is written similar to that of the facility design criteria found in Section 2.3.4 for ease of readability, but none of the design information is a requirement of the Stormwater Management Manual. It includes the following sections:

B.1. Culverts and other water crossing structures

Culverts and other water crossing structures allow water to flow under a road or other constructed obstructions along drainageways. Proper sizing, placement, and design of culverts and other water crossing structures can reduce impacts to conveyance, water quality and watershed processes. Improperly sized or poorly placed culverts can change hydraulic conditions that alter or interrupt the transport of woody debris and sediments, and can change groundwater/surface water interactions. Poorly designed culverts and bridges can induce major channel and bank erosion that threatens to undermine roadways, or impede flood flow conveyance, that in turn causes flooding and failure of roadways.

Poorly designed road crossings can prevent fish from migrating to spawning and rearing habitats. Over time, this can result in degradation of the biological productivity of the stream system and a net reduction in ecological benefits. Culverts can also restrict or block wildlife passage.

Drainageway conveyance, including natural or manmade channels, is protected through drainage reserves (see Section 1.3.4 and Section 2.3.4.20). Drainage reserves are no build areas that require approval from BES for any encroachments. Culverts and other water crossing structures constitute a channel encroachment. Crossings over open channels should be designed to maintain continuity of flows upstream and downstream of the crossing or culvert, minimize negative effects on watershed processes and ecological functions.

Summary of Analysis and Design Methods

This section provides a brief description of hydrologic analysis and design methodologies for open-bottom and natural-bed box culverts. Detailed design requirements and procedures are not included here, but can be found in reference documents listed below and cited in this section.

- Hydrologic analysis requirements for culverts in the public right-of-way or otherwise owned by the City of Portland are provided in chapter six of the Portland Sewer and Drainage Facilities Design Manual (BES 2007).
- Culvert design requirements and procedures are detailed in Chapter 8, Appendix A and Appendix J of the Portland Sewer and Drainage Facilities Design Manual (BES 2007).
- Culvert design guidance for fish passage is provided in the Oregon Department of Fish and Wildlife Fish Passage Criteria (ODFW 2004) and related statutes, the Oregon Road/Stream Crossing Restoration Guide

(ODFW 1999), and the Washington Department of Fish and Wildlife Design of Road Culverts for Fish Passage (WDFW 2003).

- Permits from the US Army Corps of Engineers and the Oregon Division of State Lands may be required.

Additional Design Information

Culverts constructed under Public Works Permits that would be owned or managed by the City of Portland must meet the requirements of the BES Sewer and Drainage Facilities Design Manual and the technical standards of the City of Portland Standard Construction Specifications.

Before a water-crossing structure or culvert may be placed within a drainageway that provides fish passage or other wildlife benefits, Oregon Department of Fish and Wildlife (ODFW) consultation and approval may be required. ODFW often refers to water crossing design guidelines published by the Washington Department of Fish and Wildlife. Additional requirements may be imposed by state and federal requirements.

A bridge, rather than a culvert, may be required if any of the following apply:

- The active channel is greater than 20 feet wide.
- A roadway width requires a culvert longer than 150 feet.
- Endangered Species Act (ESA) listed fish or other wildlife as identified by the Oregon Department of Fish and Wildlife are present.
- The channel gradient is greater than 6%.
- Woody debris movement occurs frequently.
- There is active channel movement.
- Large animals (e.g.,coyote or deer) need wildlife passage.
- A culvert could not achieve hydraulic or hydrologic requirements.

Bridge design would need to consider a variety of items, including, but not limited to, bankfull width, flood plain utilization ratio, stream type, bridge performance, and channel meander migration. Bridge design requirements are not included in the Stormwater Management Manual and should meet state and local building, structural, and transportation requirements.

Design Information

Culverts and other water crossing structures should be designed to safely pass stormwater from the 25-year storm for build-out conditions in the upstream drainage basin without surcharging the inlet by maintaining continuity of flows upstream and downstream. For streams with a Federal Emergency Management Agency designated floodplain, culverts and other water crossing structures should be designed to convey the 100-year flow. Proposed channel crossing structures will require formal engineering calculations and designs. Channels are complex systems that provide critical habitat and convey water, sediment, and woody debris. Crossings have significant impacts on the proper functioning of channels by changing the way water and sediment are conveyed. Culverts should be designed to maintain the geomorphic function of natural channels, protect habitat, provide fish passage, protect water quality and convey flood flows.

Three standard approaches to culvert design are listed below (no-slope, stream simulation, and hydraulic). See Figure B-1 for a summary of criteria to help guide designers toward an appropriate channel crossing structure at the concept and planning stages. Additional analysis will be necessary to determine the correct structure for site conditions.

Figure B-1. Culvert Design Approach Guidance

Design Approach	Channel Width (bankfull width)	Channel Slope	Channel Stability	Culvert Length	Floodplain Utilization Ratio
No-slope culverts	Less than 10 feet	<3%	Stable	<75 ft	<3
Stream Simulation	Less than 15 feet	Any	Moderate or Stable	Require additional analysis for length-width ratio >10	<3
Hydraulic	Additional engineering methods exist for more complicated situations.				

Floodplain utilization rate is defined the flood prone width divided by the bankfull width. Table summarized from Barnard, R. J., J. Johnson, P. Brooks, K. M. Bates, B. Heiner, J. P. Klavas, D.C. Ponder, P.D. Smith, and P. D. Powers (2013), Water Crossings Design Guidelines, Washington Department of Fish and Wildlife, Olympia, Washington.

Open Bottom or Natural Culverts (No-Slope and Stream Simulation)

Culverts designed with an open-bottom or natural-bed are designed to mimic the substrate and flow conditions in the natural streambed above and below the culvert. To accomplish this, the culvert alignment, culvert bed grade, and channel bed material should generally be as similar as possible to the adjacent natural streambed. The culvert size is based on geomorphic features and fish passage, sediment transport continuity and flow conveyance are assumed to be achieved by mimicking the natural channel.

Design Approaches

There are two standard design approaches for open-bottom and natural-bed culverts: no-slope and stream simulation. Both design approaches are described below:

No-Slope Culvert Design Approach

The criteria below apply to the No-Slope design (See Figure B-2)

1. The culvert is set at a nearly flat gradient, no more than plus or minus 0.5 percent.

2. The width of the bed inside the culvert (not the culvert span) is greater than or equal to the prevailing bankfull width of the stream in the reach where the culvert is located. The culvert should not constrict the bankfull flow and is expected to maintain streambed material similar to that found in the adjacent channel.

Figure B-2. No-slope schematic diagram showing the four principle components of the design.

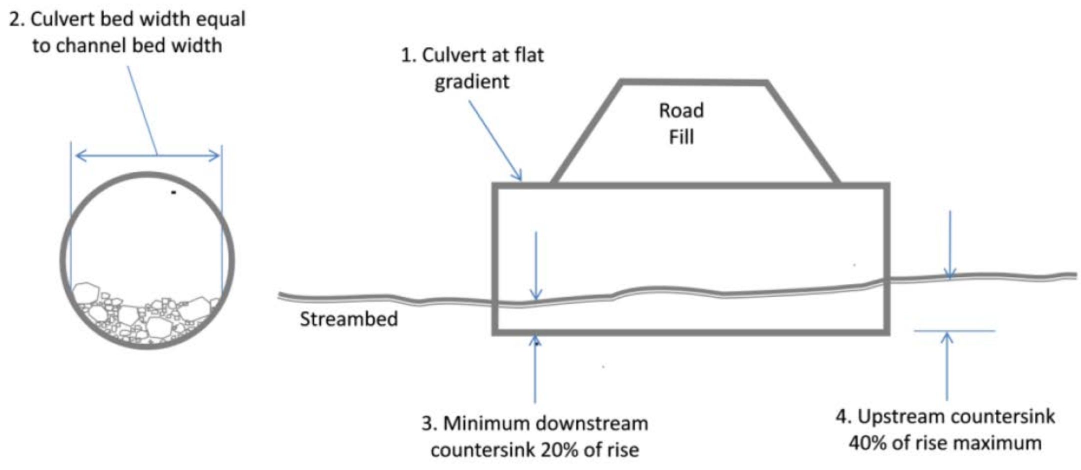

Illustration from Barnard, R. J., J. Johnson, P. Brooks, K. M. Bates, B. Heiner, J. P. Klavas, D.C. Ponder, P.D. Smith, and P. D. Powers (2013), Water Crossings Design Guidelines, Washington Department of Fish and Wildlife, Olympia, Washington.

In addition, a no-slope culvert should meet the following design criteria:

- A bed should be placed in the culvert that is composed of material similar to or an improvement of the bed of the adjacent stream.
- Adequate clearance between the culvert bed and crown should be provided to pass expected debris and high flows during flooding events.

Stream Simulation Design Approach

The culvert shape, dimensions, slope and bed roughness should be designed to provide flood conveyance capacity and fish passage and not result in any further degradation of water quality.

Design Guidance

1. Moderately confined channels.
2. Bankfull width less than 15 feet.
3. Equilibrium stream slope (stable channel).
4. Culvert bed slope should not be greater than 1.25 times the upstream channel's slope
5. Additional analysis for culverts with a length-to-width ratio greater than 10.

Both no-slope and stream simulation designed culverts should take into account the following design criteria:

Horizontal Alignment

Culvert alignment should be established to make the culvert as short as possible while minimizing the skew of the culvert relative to the existing stream channel alignment. Skew between the upstream channel orientation and the culvert inlet increases inlet contraction resulting in turbulence at high flows and a reduction of flood conveyance capacity and sediment transport. In-channel deposition and bank scour often occur upstream of culverts with excess skew. When the culvert is skewed relative to the downstream channel alignment, there is an increased risk of bank erosion near the culvert outlet. When conditions make the ideal alignment impractical, the designer should consider relocation of a portion of the channel or small angle bends with bank stabilization.

Culvert Length

The culvert length should be minimized to reduce channel disturbance. This consideration should be balanced with the need to minimize the skew of the culvert alignment relative to the stream channel as described above.

The maximum culvert length that can provide conveyance capacity, stream power continuity, subcritical flow regime, and fish passage (if required) for any given channel is dependent on stream hydrology and geomorphology (e.g., slope, sediment transport conditions). Culvert length can be minimized by adding headwalls to each end of the culvert, by narrowing the road or by steepening the fill embankments.

Culvert Size

The width of the active stream channel is the stream width that occurs annually at ordinary high water. This width can be determined by measuring the stream's cross-sectional distance between the ordinary high water line (OHWL) on both banks of the stream, or estimated by physical features such as the following:

- A topographic break from vertical bank to flat floodplain.
- A topographic break from steep slope to gentle slope.
- A change in vegetation type.
- A textural change of depositional sediment.
- The elevation below which no fine debris (needles, leaves, cones, seeds) persists.
- A textural change of matrix material between cobbles or rocks.

To the maximum extent practicable, the culvert span should be 1.2 times the active channel plus two feet. At least three typical cross section widths should be used for an average.

The minimum culvert bed width should be calculated as 1.2 times the active stream channel width plus two feet. A span of at least 6 feet is typically necessary to enable channel bed construction within a culvert. For construction and maintenance of the culvert, a minimum effective rise (from the culvert bed to the height of the culvert crown) of 4 feet is recommended. This should allow for the passage of wood and sediment and favor other natural fluvial processes.

Flood Conveyance Design (Hydraulic Analysis)

Demonstrating flood conveyance capacity and performing scour analysis for flood flows is usually required when using hydraulic analysis. This type of analysis must be performed by a registered professional engineer. Acceptable design approaches include:

- Federal Highway Administration Hydraulic Design of Highway Culverts (FHWA 2012)

- Analysis with a hydraulic model such as HEC-RAS

This analysis should provide water surface profiles, energy grade line, bed shear, and velocities through the structure for the applicable design flows.

Culverts should be sized to:

- Convey 25-year design storm flow
- Not cause an increase of more than 1-ft in the 100-year flood elevation under full build-out conditions as per Portland City Code Title 24.50.060
- Culverts in designated floodways should meet the conveyance criteria outlined in Title 24.50

Design Storm

Typically, culverts should be designed to convey the 25-year storm flow through a roadway fill without surcharging the inlet (i.e., water depth shall not exceed the inside height of the culvert crown). If regular high water conveyance is predicted, culverts may need to be designed to convey the 100-year storm flow. If the risk associated with culvert failure is high, a more conservative standard may be required.

In addition, if the culvert is not oversized to convey the 100-year peak flow, a route should be established to safely convey any flow exceeding the 25-year storm without damage to property, endangering human life or public health, or causing significant environmental impact.

Culvert Bed Slope

Culvert bed slope should be set as close as possible to the natural channel gradient extending upstream and downstream of the culvert. For new installations, this is the slope of the existing channel. For replacement culverts, this is the slope of the channel upstream and downstream of the roadway crossing (beyond the extents of any channel scour or bed aggradation created by the culvert that is being replaced). Calculated slope should approximate the average slope of the adjacent streambed from 10 channel widths upstream and downstream of where the new culvert should be placed.

Installing the culvert bed at a slope significantly lower (flatter) than the natural gradient may result in a reduction of stream power and resultant sediment aggradation that reduces conveyance capacity and hinders other natural functions. Installing the culvert bed at a slope significantly higher (steeper) than the natural gradient may induce instability of the culvert bed material during higher flows. The ratio of the culvert bed slope to the natural channel slope should not exceed 1.25.

The culvert pipe/structure itself may be installed flat or on a slope, depending upon the culvert length and bed slope. For box culverts, the slope of the culvert should be minimized to decrease shear stress between the culvert bottom and the bed material. The depth of channel bed material can vary through the length of a bottomless/open-bottom culvert that is laid flat to create the desired bed slope through the culvert. This typically requires a taller culvert pipe/structure so that the hydraulic opening on the upstream side meets the design criteria. Longer culverts should include some slope in order to maintain embedded depths and inlet capacity.

Culvert Bed Material

A bed should be placed in the culvert that is composed of material similar to or an improvement of the bed of the adjacent stream. The use of grout or any other substrate-binding bed material together is not recommended.

During construction, the small rock, large rock, and fines should be mixed before placing. The final bed surface should be washed gently with water to allow the fines to work into interstitial spaces and provide a good seal, and to demonstrate that this seal has occurred.

Bed material should be sized based on a sieve analysis of the adjacent natural stream channel. The bed material distribution should be well-graded, non-porous and have approximately 5 to 10% fines. Larger material may be used in moderation to assist in grade retention and to provide resting areas for migratory fish. It is not appropriate to compare sediment size estimates with channel reaches that are controlled by large wood, deeply incised, or not in equilibrium.

Vegetated channels should be designed to match expected natural conditions as determined by the reference reach approach. The design should maintain stability and prevent erosion. Analysis using accepted engineering methods should be used including the stable channel design approach included in the Sewer and Drainage Facility Design Manual or other approach.

Scour Analysis and embedded depth

Hydraulic analysis should be performed to ensure structural integrity at high-flows. Scour analysis should be performed to ensure that bed material remains within the culvert during flood flows. The designer may need to include some large oversized key boulders that should remain in place during the 100-year flow and stabilize the bed. The design should take scour analysis into account when determining the bed material design and proposed embedded depth of countersunk culverts and footings.

Baseflow Channel

The minimum cross-sectional dimensions for the baseflow channel 1 foot wide x 6 inches deep) are based on confining the summer baseflow. The baseflow channel helps to maintain stream power on the bottom leg of the hydrograph, hence transporting the fine-grained materials through the culvert. In addition, the baseflow channel confines low flows and helps to maintain sufficient depths for fish passage during low flow periods.

Woody Debris Transport

Adequate clearance between the culvert bed and crown should be provided to pass expected debris during flooding events. Culverts shall be designed to provide some transport of woody debris. The size of material to pass through a culvert should be selected based on woody material present in the system (considering root-wad diameter for larger pieces) and culvert size constraints. The water depth required to pass (i.e., float the material) should be calculated and accommodated. The culvert rise can be designed so that sufficient water depth and freeboard occurs during a storm in which the material would be mobile.

If it is not feasible to design for wood passage, and frequent accumulations of wood can reasonably be expected in the channel system upstream, the culvert may be vulnerable to blockage with wood mobilized in higher flow events. In these situations, consideration should be given to installing wood trapping measures in the upstream channel. For example, one or more engineered logjams could be installed in the channel upstream of the culvert to trap wood at a targeted location. If the culvert is not sized to effectively convey woody debris, long-term maintenance may be required to periodically remove collected debris in the channel upstream of the culvert and place it downstream of the culvert.

When frequent transport of large woody debris should be provided, a bridge should be considered. While there is no easy way to quantitatively evaluate the frequency of wood transport, considerations should be made for the downstream transport of woody debris when woody debris accumulations are observed in the channel, there is history of culvert plugging in the system, and/or there is a potential for recruitment of wood from a well-vegetated riparian corridor.

Inlet/Outlet Treatment

If the culvert width is less than the upstream or downstream channel width or the skew of the culvert inlet or outlet relative to the stream alignment is significant (not recommended, but sometimes may be necessary), structural protection of the inlet and/or outlet may be necessary. Depending on the size of the channel and the peak flow rates that the culvert should convey, this protection can range from concrete wingwalls to rock armoring or woody debris embedded in a tapered section of the channel bank approaching the upstream culvert entrance. If the channel is actively meandering, large wing walls and/or upstream bank stabilization is strongly recommended, regardless of culvert width.

Grade Control

If the stream channel bed is aggrading (rising) or degrading (incising), grade control structures may be needed up or downstream of the channel crossing. Such instability is indicated by evidence of historical fluctuations in channel bed elevation (e.g., headcuts, channel avulsion, gravel-splay deposits in floodplain). If instability is observed downstream of the road crossing, grade control should be installed below the culvert to prevent the upstream migration of headcuts that could undermine the structure and damage the roadway. If instability is observed upstream of the road crossing, grade control can help to stabilize the reach. Grade control structures can also be used to adjust the gradient of the adjacent channel. Grade control structures should also meet all applicable fish passage requirements.

Hydraulic Design

Under certain circumstances, a closed-bottom culvert sized using only hydraulic analysis may be allowed. Culverts designed under this approach should provide passage of the 25-year flow with no surcharge (additional clearance may be required in larger systems or when debris passage is required). Natural bed material is not required but should demonstrate flow conveyance and should be designed to prevent upstream deposition or downstream scour. This may not be allowed in any locations requiring fish passage and may be used in instances to protect against landslide hazards or along roadside ditches, for example.

Structural Design

Culverts, bridges and all water crossing structures require engineering design and analysis to ensure they are providing adequate structural strength. Structural designs should take into account the strength of underlying soils, soil cover, traffic loads and other design considerations. Typical culvert materials include: metal pipe (arch pipe or closed pipe), pre-cast concrete and cast-in-place concrete. Selection of the optimal material for a particular site is typically based on cost, site accessibility and construction planning, and structural strength.

Minimum Cover Requirements

Cover requirements vary depending on the culvert material selected:

- All culverts made of metal require soil cover between the top of the culvert barrel and the overlying ground surface or roadway pavement section. The depth of cover over the culvert will vary depending upon the weight of traffic loads or other land use that can be expected atop the culvert.
- Culverts made of reinforced concrete (cast-in-place or pre-cast) can be designed to directly support required traffic loads.

Foundation

The type of foundation necessary depends on the structure selected. A geotechnical engineer should be consulted to determine the adequacy of the underlying soil to support the weight of the structure, adjacent backfill, and the overlying roadway or other overlying land use. The geotechnical engineer's recommendations should be followed to achieve sufficient structural support for long-term success and prevent differential settlement.

Construction Considerations

Construction of open bottom and natural-bed box culverts requires fairly intrusive excavation and local modification of channel conditions at each end of the culvert. There are many considerations that should be addressed for timely completion of construction and prevention of adverse environmental impacts during construction. Prior to construction, in-water work permits should be obtained from multiple state and federal regulatory agencies, including but not limited to, the US Army Corps of Engineers, ODFW, and DSL.

The time and duration of culvert construction should be carefully considered to minimize stream sedimentation, flow interruption, and disturbance of fish during sensitive periods. Generally, construction should be performed during low flow conditions in mid to late summer. For guidance on when in-water construction is allowable in the project area, consult ODFW's *Guidelines for Timing of In-Water Work to Protect Fish and Wildlife Resources*.

Vegetation removal and brush work should minimize impacts to birds and wildlife, specifically nesting birds, to comply with the Migratory Bird Treaty Act.

Disturbance of the bed and banks should be limited to that necessary to place the structure, embankment protection, and any required channel modification associated with the installation. This should expedite completion of construction and minimize potential for adverse water quality impacts. Project activities should be kept within the regulated work areas only. Equipment should not be allowed to enter any waters of the State or U.S., or the regulated work area except as allowed in permits issued for the project. All disturbed areas associated with culvert or other water crossing structure construction should be replanted with native vegetation to help stabilize soils and slopes; this includes construction access roads, equipment landing pads, and other areas upland of the bed and banks. Untreated areas within the project's work area may trigger upslope erosion and subsequent in-water impacts.

Heavy machinery that produces excessive ground compaction may not be allowed within the drainage reserve during construction. Low ground-pressure vehicles (such as spider hoes or those approved under Environmental Zoning or Greenway Code allowances) may be allowed if the applicant can show adequate soil and vegetation protection during construction and restoration.

B.2 Outfalls

Outfalls are a stormwater conveyance feature that discharge from a stormwater management facility to a stormwater-only system, such as a drainageway, creek, stream or river. Outfalls should be designed and constructed to provide flow conveyance and should minimize impacts to stream channels and watersheds. Outfall design and construction should prevent and reduce erosive conditions and protect the stability of shorelines, channels, and ravine slopes.

Additional Design Information

Outfalls owned or managed by the City of Portland must meet the requirements of the BES Sewer and Drainage Facilities Manual and the technical standards of the City of Portland Standard Construction Specifications.

If the conveyance channel in which the outfall is used has fish passage or other wildlife requirements, Oregon Department of Fish and Wildlife (ODFW) consultation and approval may be required. Additional requirements may be imposed by state and federal agencies.

Outfalls subject to Portland City Code Title 33 requirements (33.430 Environmental Zones) must meet the standards for stormwater outfalls of City Code Section 33.430.180 or be approved through environmental review.

The following outfall design criteria are for outfalls smaller than 36 inches in width. Three types of outfalls are addressed below in prioritized order:

- Open channel outfalls: stormwater is discharged via an open channel (such as a ditch) to a stream, drainageway, or another open channel. Open channel outfalls are good options for sites with existing ditches or channels.
- Upland dispersion: stormwater is spread out over an area outside of the riparian zone and higher in elevation than the receiving stream, drainageway, or open channel. Sometimes referred to as level spreading. Upland dispersion is a good option for sites where stormwater currently infiltrates.
- Piped outfalls: stormwater is discharged from a piped conduit (typically concrete, metal or plastic) to a stream, drainageway or open channel. A piped outfall is often used at the terminus of a storm sewer piped network or to convey water down slope.

Design Information

Outfall design and selection is dependent upon local conveyance and energy dissipation requirements. The size of the outfall is determined based on Oregon plumbing code requirements and the design storm size (typically, the 25-year design storm). Configuration and placement of the outfall should be designed based on site conditions, such as site slopes, drainage basin size, fish passage status, soil erodibility, receiving channel conditions, slope stability, and existing vegetation. Drainageways may have steep slopes or banks and may have unstable landforms (i.e. slump). Geotechnical investigation to determine the stability of the stream or river bank, as reviewed and approved by BES or BDS, may be required prior to approval.

The outfall should be oriented at no less than a 30 degree angle from a perpendicular alignment with the receiving channel; with the confluence of flow oriented in the downstream direction.

Outfalls should be located above the downstream mean low water level. Endwalls or flared end sections may be required for exposed outfall pipes greater than 12 inches in diameter. Publicly accessible outfalls greater than 18 inches in diameter should include grated protection.

Erosion and Scour Control

The outfall and the construction area should be designed, constructed and maintained to reduce erosion. Erosion can result when the dispersed flow passes over sparsely vegetated ground or bare soil and when the shear stress of the flowing water exceeds the shear stress at which the soil lining the outfall channel or receiving waterway is stable (the critical shear stress). If the construction of an outfall results in bare soil, long-term erosion control should be provided through vegetation coverage and best management practices as required by the Erosion Control and Sedimentation Manual (Administrative Rule ENB-4.10). Such practices may include a natural-fiber erosion control blanket (such as jute, coir, or excelsior) to provide soil stabilization while the vegetation matures and native vegetation becomes established. Thick vegetation cover is critical to effective dispersion and infiltration of stormwater.

Protection from erosion can be provided by several techniques. A few of these techniques are listed below.

- rock lining (large riprap or smaller quarry spalls, or streambed boulders;

- geotextile fabric lining;
- low-rise check dams spanning the outfall channel;
- plantings on the channel banks; and/or
- woody structures installed in the drainageway channel bank.

The design should also minimize flow velocities and dissipate energy at the outfall to the extent possible, thereby decreasing the potential for erosion and scour in the flow path to the adjacent stream, drainageway, or open channel. In general, stormwater conveyance systems should be designed to reduce flow velocity throughout the length of the network, not just at the outfall. Erosion control techniques such as rock, should not impede fish passage within the receiving water.

Outfall Discharge Protection and Energy Dissipation

Protection of outfalls at the point of discharge to a drainageway, stream or other waterway is important to protect channel bank stability and reduce erosion. Depending on the flow velocity and existing site conditions, a variety of natural materials can be used to disperse energy and prevent erosion. While rock is a traditionally used material, the use of large woody debris is preferred if feasible. Large woody debris (larger than 12" diameter) from long-lived species such as Western redcedar or sitka spruce is preferred. Large wood can be engineered to deflect flow and dissipate energy as effectively as large rock, and provides additional habitat benefits to aquatic and terrestrial ecosystem processes. Logs may be stacked to form outfall wing walls or to shore up banks on either side of an outfall's confluence with a shoreline. It may also be used to build structural beds on stream banks or slopes where native riparian vegetation should be planted post-construction. Incorporating large wood into outfall designs may also contribute to project impact mitigation, particularly if the project takes place in an area bearing ESA-listed fish or wildlife.

The use of large, rounded boulders at the outfall outlet may be useful to deflect debris moving downstream away from the outfall. With the use of the proper size and gradation, rocks provide energy dissipation as well as protection against soil erosion. All rock protection areas should be interplanted with willow stakes or other appropriate riparian vegetation to increase slope stability, reduce erosion, provide shading and other habitat functions, and improve aesthetics. See Figure B-3 for information on using rock for outfall protection.

Figure B-3. Rock Protection at Outfalls

Outfall Diameter	Discharge Velocity at Design Flow	Average Stone Size	Depth	Width	Length	Height
2 inch		1 inch	2 inch	12 inch	24 inch	
4 inch		2 inch	4 inch	24 inch	36 inch	
6 inch		4 inch	6 inch	36 inch	48 inch	
>6 inch	0-5 feet per second	Riprap	2 x max stone size	Diameter + 6 feet	As calculated	Crown + 1 foot
	6-10 feet per second	Riprap	2 x max stone size	Greater of (diameter + 6 feet) or (3x diameter)	As calculated	Crown + 1 foot

Riprap size shall be calculated as ds = 0.25* (V/g)(6” minimum), where ds= rip rap size, V = average velocity (ft/s) and g=32.2 ft/s^s.

High velocity flows have significant kinetic energy, which can cause extensive erosion and scour at an outfall and/or receiving waterway. When flow velocity is high at an outfall, the energy should be dissipated and erosion protection should be in place to protect against scour. The design of an energy dissipation device is unique to the site; both the engineer designing the system and the reviewer of the design should consider that the device may not match the specifications above. However, as long as it can be proven to both dissipate energy and protect against erosion and scour, it can be considered acceptable.

Energy dissipation techniques include:

- rock outfalls with vegetation incorporated;
- pipe tee diffusion structures; and
- non-rock dissipaters that are shaped with soils, vegetation, berms, and woody debris are encouraged.

Energy dissipation structures (stilling basins, drop pools, hydraulic jump basins, baffled aprons, bucket aprons should be engineered) may be required where velocities are greater than 5 feet per second.

Open Channel Outfalls

To use an open channel outfall, the following conditions should be met:

- The soils through which the outfall channel is constructed should be stabilized through approved erosion control measures and may require an official geotechnical report.
- The longitudinal slope (in the direction of flow) of the outfall channel should be less than 20 percent.
- Side slopes shall be a maximum of 3:1. Steeper side slopes may be allowed for channels with rock protection.
- Freeboard should allow at least 6 inches for the 25-year flow.
- The open channel should not pose safety risks at design flow depth.
- Fish passage should be prohibited into any stormwater quality facility through an open channel outfall.

Channel Depth and Width

The primary concerns where an open channel outfall merges with a wider and deeper channel are prevention of erosion at the confluence of the outfall channel and the receiving channel, and stabilization of the outfall channel. The bottom (invert) of the open channel outfall should be at the same elevation as the bottom of the receiving channel, to avoid spilling of water down the bank of the receiving channel that can cause erosion of the bank or bed of the receiving channel. There should be 6 to 12 inches of freeboard depth above the design storm water surface elevation in an open drainage channel.

Angle of Discharge at Confluence with Drainageway Channel

The open channel outfall should be oriented at no less than a 30-degree angle from a perpendicular alignment with the receiving channel, with the confluence of flow oriented in the downstream direction.

Plantings

Native vegetation should be incorporated into the design of an open channel outfall. In most cases involving planting, the use of an erosion control blanket over the bare soil is recommended until the vegetation is fully established. Vegetation should be fully established at 90% cover within one year of planting. Reference the Portland Plant List for appropriate vegetation. See Title 11 Tree Code for tree requirements relating to development situations.

Grade and Erosion Control

To minimize erosion and scour, the outfall should be designed to be at the same elevation as the bottom of the open channel and the bottom of the receiving waterway. Where the outfall channel slope drops steeply to meet the receiving drainageway channel, one or more grade control structures (larger than typical check dams) may be required to create a step-pool sequence within the open channel outfall. Steep (greater than 20 percent slope) elevation drops of greater than 1 foot should be avoided through use of properly designed and installed grade controls, particularly if upstream fish passage is a consideration. Outfalls on grades over 20% may be required to pipe down slope to the receiving waterway. Appropriate grade control measures depend upon the outfall channel, the receiving waterway, and the site characteristics.

If the receiving drainageway channel is deeply incised near the outfall, grade control structures may be needed within the drainageway channel for a reasonable distance downstream of the outfall point to prevent the outfall discharges from worsening the incision problem. If a project site appears to need grade control structures for channel stability, a stream restoration design professional should be consulted early in the project design.

If check dams are used to slow velocities in the open channel outfall, a minimum of three check dams are recommended. They should be made of wood or rock, and should be keyed into the open channel bed and banks to prevent the dam from being displaced or bypassed during high flows. Where rock is used, the rock should be placed by hand or mechanically, rather than dumped from a truck. Check dams are a good choice for steep outfall channels if channel lining is impracticable. Check dams are not usually necessary in low-gradient (less than 1 percent channel slope) reaches.

Upland Dispersion

Dispersion of concentrated stormwater flows is often a good choice for discharges to long slopes, ravines, riparian areas, and other natural areas where erosion could readily occur otherwise. Where soil conditions are appropriate, this method enables stormwater to be used to support habitat functions while also adding stormwater attenuation benefits through uptake by vegetation, decreased flow velocities, and allowing infiltration. Effective dispersion occurs when concentrated flows are converted to sheet flow. The primary concerns for effective dispersion design are stable slopes, a suitably-sized vegetated flowpath downslope of the dispersal location, prevention of erosion caused by the dispersed flow, and selection of plantings that are suited to the hydrologic regime that should be created by the flow dispersion.

To use upland dispersion, the following conditions should be met:

- Stormwater discharges are considered low flow (100-year flow less than 2 cfs).
- The slope(s) onto which the runoff will be dispersed should be stable.
- The slope(s) onto which runoff will be dispersed should have a gradient of 20 percent or less. Otherwise, evaluation by a geotechnical engineer or qualified geologist and approval by the City of Portland Bureau of Development Services may be required.
- There should be no existing concentrated surface discharge (channels or ditches) on the site.
- No drinking water wells, septic systems, or springs used for drinking water may lie within 100 feet of the proposed dispersion site.
- A vegetated flow path of at least 50 feet should be accommodated from the proposed dispersion location to the nearest property line, structure, environmental zone, or steep slope (greater than 40 percent).

Vegetated Area Requirements

Native plants are required in any temporary disturbance areas in drainage reserves. For plant recommendations, see the Portland Plant List. Choose plants appropriate for the native plant community type as described in the Portland Plant List. Vegetation should be planted in quantities per Figure B-4 and should reach 90 percent vegetation cover within one year. See Title 11 Tree Code for tree requirements relating to development situations and City Code Title 33, the for vegetation requirements related to applicable environmental zoning. For public natural areas with approved master plans or management plans, vegetation requirements may vary.

Figure B-4. Vegetation density for restoration of outfall temporary disturbance areas

Number of Plants	Vegetation Type	Per square feet	Size	Spacing density (on center)
2	Trees	100	6’ min height or 1 ½” caliper	Per plan
10	Shrubs	100	1 gallon	Per plan
70	Herbaceous plants	100	4” pots	12”
240	Herbaceous plants	100	Plugs	6”

Sizing and siting guidance

A flow dispersal trench can be used to provide upland dispersion, where direct discharge from a storm drain or culvert infiltrates or percolates through a wide gravel-filled trench before it spreads out and continues onto existing soil and vegetation. The design criteria for a single flow dispersal trench include:

- Discharge points with up to 0.2 cfs discharge for the peak 100-year flow may use rock pads or dispersion trenches to disperse flows.
- Piped discharge points with between 0.2 and 0.5 cfs discharge for the 100-year peak flow should use only dispersion trenches to disperse flows.
- Dispersion trenches should be a minimum of 2 feet wide by 2 feet deep in section, 50 feet in length; filled with ¾ - 1½ inch washed drain rock; and provided with a level notched grade board.
- Manifolds may be used to split flows up to 2 cfs discharge for the 100-year peak flow between four trenches (maximum).
- Multiple dispersion trenches should have a minimum spacing of 50 feet.
- If the 100-year peak flow at the outfall is greater than 2 cfs, dispersion is not an option for the site.

Piped Outfall

On slopes over 20%, it may be difficult to route stormwater through an open channel or disperse upland without causing severe erosion. In such situations, it may be appropriate to use a piped outfall system. To use a piped outfall, the following conditions should be met:

- The soil, slope, or space requirements of an open channel or upland dispersion outfall cannot be met.
- Hand trenching should be provided where runoff will pass over erodible soils where slopes have a gradient of 15 percent or steeper.
- For slopes steeper than 40 percent, the pipe should be installed on the ground surface to minimize disturbance of what could be an unstable slope.

Construction Considerations

Every outfall project is unique and brings with it specific considerations and requirements necessary to protect watershed function and public health and safety. Please note that these guidelines describe only some of the available construction techniques and that others may be appropriate in certain situations.

Construction in and adjacent to streams that provide habitat for fish should adhere to prescribed periods for in-water work, as defined in the Oregon Department of Fish and Wildlife Guidelines for Timing of In-Water Work to Protect Fish and Wildlife Resources. Vegetation removal and brush work should minimize impacts to birds and wildlife, specifically nesting birds, to comply with the U.S. Fish and Wildlife Service's regulatory Migratory Bird Treaty Act.

Heavy equipment and machinery should be kept out of the receiving waterway and off of the banks. Project activities should be kept within the regulated work areas only. Channel beds and banks are typically in a delicate state of equilibrium and can easily be damaged by the action and forces of large earth-moving machinery. Equipment operations within the waterway can cause the release of sediment and disrupt the natural layering and armoring of particles on the channel bed. Out of the waterway, excessive compaction of native soils can slow or limit the propagation of beneficial vegetation, or increase the erosive nature of hillslopes and create conditions conducive to sediment runoff into the conveyance channel. Low ground-pressure vehicles (such as spider hoes or those approved under Environmental Zoning or Greenway Code allowances) may be allowed if the applicant can show adequate soil and vegetation protection during construction and restoration.

For open channel outfalls, the new channel excavation should be completed and stabilized before making the connection to the receiving drainageway. This should minimize the amount of time that disturbance occurs in the receiving drainageway while also enabling the downstream end of the excavated area to serve as a temporary sediment trap for downstream water quality protection. A plug of native soil or other approved equivalent should be retained between the outfall channel excavation and the receiving drainageway until the connection is ready to be made. If runoff or other discharge will occur in the area where a new energy dissipater or open channel outfall is to be constructed, flow bypass or other forms of dewatering should be accomplished to enable construction in relatively dry conditions.

B.3. Reference Material

Culvert Design

Portland Sewer and Drainage Facilities Design Manual (2007 w 2011 Errata)
http://www.portlandoregon.gov/bes/article/360710

Oregon Department of Transportation, Hydraulics Manual (2014)
http://www.oregon.gov/ODOT/HWY/GEOENVIRONMENTAL/pages/hyd_manual_info.aspx#Hydraulics_Manual

Federal Highway Administration, Hydraulic Design of Highway Culverts (2012)
http://www.fhwa.dot.gov/engineering/hydraulics/pubs/12026/hif12026.pdf

United States Department of Agriculture, Forest Service; Stream Simulation Design for Culverts (2015)
http://www.stream.fs.fed.us/fishxing/aop_pdfs.html

United States Army Corps of Engineers, Conduits, Culverts and Pipes (1998)
http://www.publications.usace.army.mil/Portals/76/Publications/EngineerManuals/EM_1110-2-2902.pdf

Washington Department of Fish and Wildlife, Implementation and Effectiveness Monitoring of Hydraulic Structures (2015)
http://wdfw.wa.gov/publications/01746/wdfw01746.pdf

Washington Department of Fish and Wildlife, Water Crossing Design Guidelines (2013)
http://wdfw.wa.gov/publications/01501/wdfw01501.pdf

Washington Department of Fish and Wildlife, Stream Habitat Restoration Guidelines (2012)
http://wdfw.wa.gov/publications/01374/wdfw01374.pdf

Stream Simulation Design for Culverts
http://www.stream.fs.fed.us/fishxing/aop_pdfs.html

Fish Passage Design

National Oceanic and Atmospheric Administration, Guidelines for Salmonid Passage at Stream Crossings (2001)
http://www.westcoast.fisheries.noaa.gov/publications/hydropower/fish_passage_at_stream_crossings_guidance.pdf

National Oceanic and Atmospheric Administration, Comparing Fish Passage Opportunities (2014)
http://h2odesigns.com/wp-content/uploads/2014/12/NMFS_FishPassageWindowFinalReport_2014.pdf

Oregon Requirements for Fish Passage

Oregon Administrative Rules, Chapter 635-412-0005, Fish Passage:
http://arcweb.sos.state.or.us/pages/rules/oars_600/oar_635/635_412.html

Oregon Department of Fish and Wildlife, Fish Passage Website
http://www.dfw.state.or.us/fish/passage/

Oregon Department of Fish and Wildlife, Fish Passage Criteria (2004)
http://www.dfw.state.or.us/agency/commission/minutes/05/Nov/F_4_ODFW%20Fish%20Passage%20Criteria%20-%202004.pdf

Other Resources

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Montgomery, D. R. and J. M. Buffington (1998). Channel Processes, Classification and Response. River Ecology and Management. N. a. Bilby. New York, Springer.

Pleus, A. E., and D. Schuett-Hames, et al. (1998). Method manual for the reference point survey, Prepared for the Washington State Department of Natural Resources under the Timber, Fish, and Wildlife Agreement.

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