# Appendix A.4 Design Guidance for Culverts and Outfalls<sup>1</sup>

# **Open Bottom Culverts and Outfalls**

The inclusion of the detailed information regarding the design and construction of stormwater outfalls in the SWMM, is a focused effort by the City of Portland to provide options for stormwater management that are functional and minimize impacts to watersheds. The guidance documents are intended to provide guidance to designing stormwater outfalls and culverts. The guidance documents are also intended to provide flexibility to the engineer for designing a system, and to the reviewer examining the designed system. Staff recognizes the uniqueness of each site and potential stormwater management system.

Natural, open channel systems are formed and maintained by key watershed processes including flood flows, base flows, the erosion, transport and accumulation of sediments and woody debris, and the interaction of surface water and groundwater. When these processes are in equilibrium, they support a broad range of biological and ecological functions, including: fish spawning, rearing and migration; wildlife passage; habitat connectivity; and other ecological attributes that contribute to high biological productivity. In addition to ecological benefits, natural, open channel streams provide additional beneficial functions such as flood attenuation and water quality treatment.

# **Open Bottom / Natural-Bed Box Culverts Description**

Culverts and bridges at road crossings and other constructed obstructions along these channels can disrupt watershed processes by altering or interrupting the transport of woody debris and sediments, and changing groundwater/surface water interactions. Poorly designed or failing road crossings can also block fish passage, preventing 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 the ecological benefits it produces. Culverts can also restrict or block wildlife passage. In worst case situations, poorly designed culverts and bridges can induce major channel and bank erosion that threatens to undermine the roadway, and/or impede flood flow conveyance that in turn causes flooding of the roadway.

<sup>&</sup>lt;sup>1</sup> The information included in this section is from a guidance document compiled by Herrera Environmental Consultants for the City of Portland *Concept Designs and Technical Guidance –Stormwater Outfalls* (April 2007) has been edited by City staff to eliminate duplicative information that is already contained in the SWMM, the SDFDM, and other references.

Ideally, road crossings over open channels should be designed to minimize the negative effects on watershed processes and ecological functions while adequately conveying flood flows downstream. To the extent possible, culverts beneath roadways should be designed to provide the following functions of a natural, open channel stream:

- Stream bed material transport,
- Woody debris transport,
- Natural flood attenuation,
- Biological productivity,
- Water quality benefits,
- Fish migration.
- Wildlife passage (other than fish),
- Surface water/ground water hydraulic connectivity.

These functions can be largely maintained by simulating a natural channel bed through the bottom of a culvert. Stream simulation methodology (ODFW 2004, WDFW 2003) can be used to design an open-bottom or natural-bed box culvert. An open-bottom culvert typically consists of a pipe arch or bottomless concrete structure (typically called a three-sided box) supported on footings, spanning a streambed for the entire length of the roadway crossing. Alternatively, a box-shaped culvert structure can be placed in a deeper excavation and partially filled with substrate materials to simulate a natural streambed. Typical culvert configurations are shown in **Exhibit SW-530**. If properly designed, these types of culverts can mimic the substrate and flow conditions in the natural channel upstream and downstream of the culvert, thereby reducing the impacts of the road crossing structure on natural channel functions. While these culverts typically cannot reproduce all conditions of a natural streambed (e.g., floodplains, undercut banks, etc.) it can vastly reduce the impacts relative to traditional round, small diameter culvert installations.

## Applicability

The selection factors for open-bottom and natural-bed box culverts are listed in **Exhibit A.4-1**. As indicated in in **Exhibit A.4-1**, open-bottom and natural-bed box culverts are recommended for a variety of scenarios.

When native migratory fish are currently present or were historically present in the system, the culvert must provide fish passage pursuant to Oregon Department of Fish and Wildlife (ODFW) requirements. Current state law and ODFW fish passage criteria require consideration of fish passage requirements prior to installation or replacement of culverts in waters where native migratory fish are currently or were historically present.

In most cases, fish passage should be accommodated with the culvert design. The process for satisfying fish passage requirements includes native migratory fish determination, defining the fish passage criteria, and obtaining plan approval from all of the required federal, state, and local agencies.

Wildlife passage is also an important consideration for culvert design. Culvert width can be increased to contain an artificial ledge inside the culvert on one or both sides to enable connectivity for terrestrial species.

For specific guidance on additional measures that can be incorporated into culvert or bridge design to maximize wildlife passage, the wildlife crossings toolkit has various resources: <a href="http://www.wildlifecrossings.info/beta2.htm">www.wildlifecrossings.info/beta2.htm</a>. For project-specific information, contact Oregon Department of Fish and Wildlife: <a href="http://www.dfw.state.or.us">www.dfw.state.or.us</a>.

## Bridges

Many of the concerns related to culverts at road crossings can be alleviated by constructing a bridge rather than a culvert. Bridges are the most appropriate choice to maintain the integrity of many of Portland's urban stream systems, particularly those systems with wide active channels (greater than 20 feet).

Bridges do not have the dimensional limitations of culverts and can be large enough that the structure does not significantly affect the flood hydraulic profile. A bridge, rather than a culvert crossing, should be considered when:

- The active channel width is greater than 20 feet.
- The channel gradient is greater than 6 percent.
- Movement of large woody debris occurs frequently.
- There is a high risk associated with flooding.
- The channel is actively meandering.
- There are large animals such as coyote or deer present and there is limited local wildlife passage.
- It is difficult to achieve hydraulic objectives (i.e., flood flow capacity, stream power continuity, subcritical flow regime, debris flows, and fish passage depth and velocity criteria, if applicable).

#### **Exhibit A.4-1:** Selection considerations for open bottom and box culverts

	Open Bottom or Box Culvert							
Selection Factors	Required by ODFW	Recommended	Consider Bridge	Additional or Alternate Measures	Natural Stream Function of Culvert			
Fish Passage								
Native migratory fish currently or historically present (Unless waiver or exemption obtained from ODFW)	Х				Provide fish passage and habitat			
Wildlife Passage (non migratory fish)								
Resident fish, amphibians, small animals present		Х			Provide wildlife passage and habitat			
Large animals (coyote, deer) present with limited upland passage			Х					
Downstream Fish Presence	Downstream Fish Presence							
Tributary to fish-bearing stream		Х			Maintain biological productivity (invertebrate habitat) and water quality functions			
Woody Debris Transport	I		1	Γ				
Woody debris in channel, high potential for recruitment (well vegetated riparian corridor)		Х	Х	Consider upstream trapping with engineered log jam or collection and relocation of large wood to prevent blockage	Provide woody debris transport, lowering likelihood of culvert blockage			
Hydrologic Conditions		•						
High variability in flow, "flashy" flow regime (typical for highly developed, urban, snowmelt and rain on snow systems)		Х		Sufficient embedded depth to allow for vertical fluctuations in bed elevation	Enable sediment transport through culvert during episodes of bed scour and deposition (typical of flashy systems)			
Flooding Concerns								
Flooding could endanger human health and safety, result in extensive property damage, or impact the environment significantly		Х	Х		Reduce likelihood of inlet blockage with debris or aggraded sediment that could result in capacity reduction and flooding. Channel provides natural flood control.			
Channel Gradient	i	<b>.</b>		+	1			
Gradient greater than 6% and vulnerable to debris flow (headwaters include channels >20%)		Х	Х		Provide some capacity for debris flow			
Up- and down-stream gradients differ or culvert bed slope differs from channel gradient		Х	Х	Sufficient embedded depth to allow for vertical fluctuations in bed elevation/consider grade control structures	Allow for some vertical fluctuations in bed elevation due to grade change			
Channel Width								
Channel width greater than 20 feet			Х					

	Open Bottom or Box Culvert					
Selection Factors	Required by ODFW	Recommended	Consider Bridge	Additional or Alternate Measures	Natural Stream Function of Culvert	
Channel Stability	·					
Vertically aggrading or incising- evidence of historical fluctuations in channel bed elevation (e.g., headcuts, near-vertical channel banks, channel avulsion, gravel-splay deposits in floodplain)		х		Grade control structures recommended	Provides sediment transport / Allows for some vertical fluctuations in bed elevation	
Actively meandering		Х	Х	Large wing walls or upstream bank stabilization	Provides sediment transport / Allows for more horizontal fluctuations in channel alignment than traditional round culverts	
Confined channel-if confined due to historical incision		X		Grade control structures recommended	Provides sediment transport / Allows for some vertical fluctuations in bed elevation	
High sediment flux		Х		Sufficient embedded depth to allow for vertical fluctuations in bed elevation	Provides sediment transport / Allows for some vertical fluctuations in bed elevation	
Maintenance		· · · ·				
Maintenance required		X		Consider grates in road bed to provide access for sediment removal	Larger culvert easier to access to remove debris and accumulated sediment	

#### 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 City of Portland public drainage system are provided in chapter six of the Portland Sewer and Drainage Facilities Design Manual (BES 2006).
- 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 2006).
- 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.

## **Design Storm**

Typically, culverts must be designed to convey the 25-year storm flow (SDFDM Appendix J page 13 says 100 year) through a roadway fill without surcharging the inlet (i.e., water depth shall not exceed the inside height of the culvert crown). 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 must 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.

## Hydrologic Analysis

The peak flow values used for culvert design should be estimated using single-event hydrologic methods. The Rational Method is recommended for culverts conveying runoff from a drainage basin less than 50 acres in size. Modeling peak flows based using the HEC-HMS (U.S. Army Corps of Engineers Hydrologic Engineering Center - Hydrologic Modeling System) or EPA SWMM (U.S. Environmental Protection Agency Stormwater Management Model) program, or a comparable alternative, is recommended for culverts conveying runoff from a drainage basin equal to or greater than 50 acres in size. The selected hydrologic analysis method for culverts conveying flow from these larger drainage areas requires approval from the City of Portland. Drainage area characteristics (e.g., area, land use, ground surface cover characteristics, time of concentration, runoff coefficients, runoff curve numbers, and infiltration rates) must be estimated to represent the future build-out condition as defined in the Comprehensive Plan.

Rainfall depths and an Intensity-Duration-Frequency Curve have been developed for the City of Portland. These are provided in the Portland Sewer and Drainage Facilities Design Manual.

## **Design Procedures**

The culvert shape, dimensions, slope and bed roughness must be designed to provide flood conveyance capacity. To maintain natural stream function, it is also

recommended that stream power (described below) is preserved through the culvert and that a subcritical flow regime (described below) is maintained. These three goals (conveyance capacity, stream power continuity, and subcritical flow regime) can be achieved by performing iterations using the following equations. The conditions during a 100-year event should also be evaluated.

### Conveyance Capacity for Design Storm

The culvert shape, dimensions, slope and bed roughness should be designed to convey the peak design flow at build-out land use conditions in the upstream drainage area. Manning's Equation can be used to evaluate open channel flow (when the pipe is not surcharged) through the culvert barrel. Using English measurement units, the equation is as follows:

Q=1.49/n (A\*
$$R^{2/3}$$
\* $S^{1/2}$ )

Where, Q = flow rate (cubic feet per second)

n = roughness coefficient (dimensionless)

A = flow cross section area (square feet)

R = hydraulic radius = flow cross section area / wetted perimeter (feet)

S = friction slope (feet/foot)

note: for uniform flow, S equals the slope of the channel bed.

Chapter 8 of the Portland Sewer and Drainage Facilities Design Manual (BES 2006) provides a discussion about the application of this equation for calculating capacity and velocity for pipes and channels.

For calculations using Manning's Equation, a Manning's roughness value ("n") of 0.013 must be used for the culvert regardless of culvert material type. BES has selected this constant value, while recognizing that it can vary as a function of pipe material, flow depth and pipe size. Approval must be obtained to use an alternative roughness factor. A typical roughness value for streambed gravel is 0.03.

When assuming open-channel flow, it is important to confirm that the tailwater (water surface elevation at the downstream end of the culvert) is not significantly greater than the culvert invert due to downstream controls. If tailwater conditions prevail at the downstream end of the culvert, the analysis must address "outlet control." Methods of analysis for culverts flowing under outlet control can be found in the Federal Highway Administration publication entitled Hydraulic Design of Highway Culverts (FHWA 2001a) as well as in many other hydraulic engineering publications.

### Sediment Transport Capacity

Sediment transport capacity is directly related to stream power (Simons and Sentürk 1992). Stream power is not a quantitative measure unto itself (i.e., there is not an optimal range of stream power values that can be applied between watersheds).

Rather, it can be used as a relative measure of sediment transport capacity between adjacent stream and culvert reaches. Thus, the power of adjacent reaches can be compared to identify areas which may exhibit sediment aggradation in the channel (a reach with a low stream power value relative to the adjacent upstream reach) or channel bed degradation (a reach with a high stream power relative to the adjacent upstream reach). Stream power ( $\Omega$ ) can be calculated according to Simons and Sentürk (1992) as follows:

$$\Omega = v^* \tau_o = v^* \gamma^* R^* S_b$$

Where, v = velocity (feet per second)

 $\tau_{o}$  = shear stress (shear force per unit wetted area, in pounds per square foot)  $\gamma$  = specific weight of water (62.4 pounds per cubic foot at a water temperature of 50°F)

R = hydraulic radius = flow cross section area / wetted perimeter (feet)  $S_b$  = channel bed slope (feet/foot).

The stream power for the upstream reach, within the culvert barrel, and for the downstream reach can be compared at low and high flows (e.g., 2- and 25-year events) to assess the ability of the culvert to move sediment through the system.

#### Flow Regime

It should be confirmed that a subcritical flow regime is maintained through the culvert (i.e., the Froude number (F) is less than unity).

$$F=v/(g^*y_h)^{1/2}$$

Where, v = velocity (feet per second)

g = acceleration due to gravity  $(32.2 \text{ ft/s}^2)$ 

 $y_h$  = hydraulic depth.

#### Fish Passage Criteria

When fish passage is required, additional criteria, such as maximum velocity and minimum depths during fish passage flows must be met. Fish passage criteria vary as a function of fish species, age, and the time of migration among other factors. These requirements are detailed in Oregon Department of Fish and Wildlife guidance.

#### Surcharged Flow

Headwater depth under higher flow conditions (100-year peak flow) should be evaluated. Nomographs for culvert conveyance under inlet and outlet control conditions are provided in the Washington State Department of Transportation Highway Runoff Manual (WSDOT 2006).

### **Culvert Design Considerations**

Considerations for the design of open-bottom and natural-bed box culverts are discussed below. For detailed design discussions refer to Oregon and Washington Department of Fish and Wildlife guidance documents (ODFW 1999, 2004; WDFW 2003).

In general, stream simulation culverts 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.

## 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 are 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 culvert span, rise and slope will be determined iteratively to meet capacity, stream power and Froude number requirements. Additional considerations regarding culvert span and rise are provided below.

The culvert span should be no less than the active channel width. According to ODFW (2004), 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.

To more closely simulate stream functions, it has been suggested that the minimum culvert bed width be calculated as 1.2 times the active stream channel plus two feet (WDFW 2003).

Usually a span of at least 6 feet is 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.

# **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).

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. It has been suggested that the ratio of the culvert bed slope to the natural channel slope should not exceed 1.25 (WDFW 2003).

It is recommended that the culvert design process include a comparison of stream power in the culvert barrel to the up-and downstream reaches of the stream to confirm continuity in sediment transport capacity. 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/openbottom 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 will require some slope in order to maintain embedded depths and inlet capacity.

# **Culvert Bed Material**

For Stream Simulation culverts, ODFW recommends the following mix of fill/bed material to provide the best streambed function:

- 30 percent fines (dirt or silt; this allows the new bed to "seal" and water to remain in the channel rather than flow sub-surface).
- 30 percent small rock (½ to 6 inch diameter).
- 30 percent large rock (6 inch D<sub>100</sub> diameter).
- 10 percent "shadow" rock (D<sub>150</sub> to D<sub>200</sub>; these simulate undercut banks, large wood, and boulders and should remain in place during flood events).

D<sub>100</sub> rock is the size (diameter) of the largest rock found naturally in the stream. D<sub>150</sub> to D<sub>200</sub> rock is 50 to 100 percent larger than the largest rock found naturally in the stream. Shadow rock should protrude 30 to 50 percent above the final streambed elevation. 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.

Another approach is to select the bed material size based on the adjacent natural stream channel (WDFW 2003). In the "reference reach approach" the maximum particle size and appropriate distribution can be determined by examining reaches directly upstream from the culvert. If the culvert is designed to maintain stream power and subcritical flow, this material will move as the bed material in the adjacent channel, (so it will be replenished if it degrades). If the sediment transport capacity in the culvert will be higher, the size of the native channel substrate materials should be increased by a factor of safety to ensure bed stability.

## **Embedded Depth**

The minimum embedded depth (depth of the bed material in the bottom of the culvert) is 12 inches, or 20 percent of the culvert rise, whichever is greater. The bottom of a box culvert or round arch culvert must be buried at sufficient depth in the channel bed to prevent exposure by scour. Scour calculations are therefore an important component of the design analysis, particularly if the culvert will constrict the flow of the upstream channel cross-section. Methods of scour analysis applicable to culvert installations can be found in FHWA (2006, 2001b, 2001c).

# **Baseflow Channel**

The recommended 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

Culverts can be designed to provide some transport of woody debris. The size of material to pass through a culvert can 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) can be calculated. 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 must 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 will be necessary. Depending on the size of the channel and the peak flow rates that the culvert will 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.

# Grade Control

If the stream channel bed is aggrading (rising) or degrading (incising), grade control structures are recommended. 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 should be used to re-grade an adjacent channel to a steeper gradient.

If fish passage requirements are applicable, the grade control structures must meet ODFW elevation drop criteria.

# Materials

There are several options for open-bottom and natural-bed box culvert material. Selection of the optimal material for a particular site is typically based on cost, considerations for onsite assembly as relates to desired construction duration, and site accessibility for material delivery. Material options for most applications include the following:

- Pre-cast concrete,
- Cast-in-place concrete,

Metal arch pipe.

Cast-in-place concrete is the most expensive of these options, and results in the most construction impacts. However, it allows for a structure that conforms to the exact project and site constraints. Metal arch pipe is least expensive and due to its lighter weight, typically less complex construction than concrete. However, in certain soil and moisture conditions, metal pipe can be subject to corrosion, limiting its design life. For a detailed discussion of corrosion, including soil pH and resistivity values that may warrant protective coatings, see Section 5.7 of the Oregon Department of Transportation Hydraulics Manual (ODOT 2006). The ODOT Hydraulics Manual also provides information on the design life of different pipe materials (design lives summarized in Table 5-3 are applicable, provided that the requirements from Section 5.4 are met for the pipe material).

#### **Minimum Cover Requirements**

Open bottom 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 may vary depending upon the weight of traffic loads or other land use that can be expected atop the culvert. Typically a minimum 2 feet of soil or crushed rock cover is needed above the culvert barrel to protect the culvert from deformation under heavy traffic loading. If a three-sided concrete box is proposed for the open bottom culvert, the top slab of the structure may be specified with a thickness that can greatly reduce or eliminate soil cover requirements. A structural engineer should be consulted for site-specific recommendations for cover depth when an open bottom culvert is planned.

Natural-bed box culverts are usually made of reinforced concrete, including a thick top slab, or elliptical metal pipe arches. As with open bottom culverts made of reinforced concrete, the top slabs on reinforced concrete boxes can be specified to a thickness that is capable of supporting heavy traffic loads. In some light traffic areas the top of the concrete box culvert can serve as the roadway driving surface. Cover depth over a natural-bed box culvert can typically be minimal if desired by specifying a stronger culvert material. The designer should evaluate the tradeoff of a taller and stronger box structure (at greater material cost) that requires less cover versus a lesser structure height (at lower material cost) covered with onsite soil from the culvert excavation.

### **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. As such, there are many considerations that must be addressed for timely completion of construction and prevention of adverse environmental impacts during construction.

### **Erosion Control**

Temporary erosion control measures should be implemented during construction to minimize erosion and prevent sediment from impacting site runoff. Permanent stabilization measures should be implemented to protect stream water quality and rehabilitate vegetation in the stream corridor. Details on appropriate erosion and sediment control measures are provided in the Erosion Control Manual (City of Portland, 2008).

# Replanting

ODFW recommends that all disturbed areas be protected from erosion within 7 calendar days of completion of the project using vegetation or other means, and that the stream banks should be re-vegetated within 1 year with native or other approved woody plant species.

## **Stream Dewatering/Diversions**

Culvert and related channel improvements should be constructed "in the dry" whenever possible to prevent or minimize water quality impacts on streams and biological communities. Construction in relatively dry site conditions typically enables faster completion of the construction work, avoids potential conflicts with sensitive fish species that may be present in the stream at the time of construction, and minimizes potential for mobilization of soil and sediments into the stream.

## **Bed Material Placement**

Culvert fill material can be loaded into the pipe from either end using hand equipment for smaller projects, and with a small Bobcat® style front-end loader, a small bulldozer, a gravel conveyor belt or a rail-mounted cart for larger projects where hand placement is not practical. Alternatively, the bed material can be pushed into the culvert with a log or stiff board manipulated by an excavator (WDFW 2004). For culverts that are assembled in the field (in the excavation) in sections, stream bed material can be placed from the top before installing the top section of the culvert. Care should be taken in the method in which the bed material is placed. According to WDFW (2004):

In order to achieve stream simulation, fill materials must be arranged to mimic channel conditions. Avoid grid patterns or flat, paved beds made of the largest rocks. A low-flow channel and secondary high-flow bench on either side should be created in the culvert. A step-pool profile generally occurs in the 3 to 10 percent slope range. The spacing of steps is somewhat variable, but one to four channel widths with a maximum 0.8-foot drop between successive crests is recommended. This type of channel ensures that stream energy is dissipated in pool turbulence, creating better fish passage and more stable channels. Segregating a portion of the coarsest fraction into bands can encourage this pattern. Do not exceed 0.8 feet of drop between successive steps. The steepest channels (greater than 10 percent grade) are cascades with large roughness elements protruding into the channel. The same material comprises the whole depth of fill. Stratification, such as placing spawning gravel over a boulder fill in a steep channel, is not appropriate.

If the culvert bed material will be laid on a relatively steep slope or subjected to high velocity flows that could mobilize the channel bed material, baffles or other sill materials will be needed at intervals through the culvert length to hold the smaller bed materials in place. Sometimes it is sufficient to place boulder clusters within the culvert to prevent significant mobilization of bed material while not compromising high flow conveyance capacity. The designer should refer to ODFW (1999) and WDFW (2003) for details on options and design guidance for bed material retention.

## Schedule

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. If fish are present, construction must not coincide with fish migrations, spawning, and egg incubation periods. If in-water excavation is anticipated, timing must conform to state guidelines.

# Foundation

If a box culvert structure is used, the only foundation typically required is crushed rock bedding material beneath the structure to create a smooth, even surface upon which the structure is laid. However, a geotechnical engineer should always 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. Site-specific techniques may be needed in some instances to provide a stable foundation for a box culvert. The geotechnical engineer's recommendations should be followed to achieve sufficient structural support for long-term success. A civil engineer also needs to be consulted to look at proposed and future loadings on the culvert as well as the basin dynamics.

If an open bottom culvert structure is used, the culvert will need to be laid on a foundation to prevent differential settlement over time that could compromise culvert functions and/or cause damage to the overlying roadway. Parallel foundation support is needed for each side of the culvert through the length of the culvert. Again, a geotechnical engineer should be consulted to determine the most appropriate foundation design for site-specific conditions. The basic options for open bottom culvert foundations include the following:

- Footing pads
- Continuous spread footings
- Pilings.

# Minimizing Disturbance of Streambed and Banks

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 will expedite completion of construction and minimize potential for adverse water quality impacts. All disturbed areas associated with culvert construction should be replanted with native vegetation to help stabilize soils and slopes.

## Outfalls

#### **Outfall Description**

This section provides guidance for designing and constructing drainage system outfalls to open channels or upland areas in such a manner as to prevent and reduce erosive conditions to protect the stability of shorelines, channel grades, ravine slopes, and channel banks. Three types of outfalls are addressed below. These are described in a preferred sequence for use; the first priority is for an open channel outfall, the second priority is for upland dispersion, and the third priority is for a piped outfall.

- **Open channel outfalls** The location where stormwater is discharged via an open channel (typically a ditch) to a stream, drainage way, or another open channel. The longitudinal slope (in the direction of flow) of the outfall channel must be less than 20 percent.
- Upland Dispersion A method used to spread out concentrated discharge of stormwater over an area outside the riparian zone and higher in elevation than the receiving stream, drainageway, or open channel. Where soil conditions are appropriate, this method enables stormwater to be used to support habitat functions while also adding attenuation benefits through uptake by vegetation, decreased flow velocities, and allowing infiltration. Upland dispersion is recommended only for low flows (100-year flow less than 2 cfs) and where site conditions are appropriate. Level spreading is another term that may be used for upland dispersion.
- Piped outfalls The location where stormwater is discharged from a piped conduit (typically made of concrete, metal, or plastic) to a stream, drainageway, or open channel, as indicated above. This is often the end or terminus of a storm sewer pipe network.

#### Applicability

This section can be used as guidance for outfalls that are smaller than 36 inches in diameter/width. Abiding by the guidelines listed does not preclude submittal of additional engineering information when required by the City of Portland or other jurisdictions. See the City of Portland 2006 Sewer and Drainage Facilities Design Manual (SDFDM), Chapters 6 and 8 and Appendices A and J, for more detailed design information.

This section is *not* intended to cover outfalls governed by the City's municipal NPDES permit (National Pollutant Discharge Elimination System permit for separate storm sewer systems) with the Oregon Department of Environmental Quality (i.e., the larger municipal storm drain outfalls discharging to receiving water bodies throughout the City).

### **Open Channel Outfalls**

Open channel outfalls are good options for sites with existing concentrated surface discharge (ditches or channels). For use of an open channel outfall to be acceptable, the following conditions must be met:

- The soils through which the outfall channel is constructed must be stable.
- The longitudinal slope (in the direction of flow) of the outfall channel must be less than 20 percent.
- Adequate space must be available to meet the design criteria for an open channel, such as side slopes and freeboard, as described in Section 8.5.1 of the 2006 SDFDM.
- The open channel will not pose safety risks at design flow depth.

#### **Upland Dispersion**

Dispersion of stormwater flows is often a good choice for sites with limited development where stormwater currently infiltrates, particularly if there are steep slopes, ravines, riparian areas, and/or other natural areas downstream where erosion could readily occur if stormwater is concentrated in an open channel outfall. For upland dispersion to be feasible, the following conditions must be met:

- The slope(s) onto which the runoff will be dispersed must be stable.
- The slope(s) onto which runoff will be dispersed must have a gradient of 20 percent or less.
- There must 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 must be accommodated from the proposed dispersion location to the nearest property line,

structure, environmental zone, or steep slope (greater than 40 percent).

 It is imperative to determine and document potential downstream effects and conflicts associated prior to permitting and construction.

#### **Piped Outfalls**

Piped outfalls should be used if 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 in a slope area that is higher than 20 feet with a gradient of 15 percent or steeper.
- For slopes steeper than 40 percent, it is recommended that the pipe be installed on the ground surface to minimize disturbance to what could be an unstable slope.

#### Outfall Design

Before initiating the design process, it is imperative that an assessment of the site be made to determine its existing characteristics, such as the type and condition of soil, vegetation, and habitat. Many outfalls have failed or otherwise caused significant environmental damage, such as major erosion, because the outfall design did not fully consider potential adverse consequences.

In most settings, the impacts of outfall design should be considered with the design storm event in mind. Under design event conditions, discharge velocities are greatest and have the most potential to damage slopes and receiving waterways. However, in settings where fish passage is an issue, low flow periods may require special consideration.

All outfalls should be designed to accommodate the peak flow during the pertinent recurrence interval design storm specified in SWMM **Chapter 1** and Section 6.4 of the SDFDM. 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.

## **Open Channel Outfalls**

Open channel outfalls may be appropriate for sites with concentrated surface discharge under undeveloped conditions, as long as the slope, soil stability and space requirements indicated in the *Applicability* section of this document can be met.

#### Hydrologic Analysis and Hydraulic Design

- Design Storm Recurrence Interval: 25 years (see Section 6.4.1 of the SDFDM)
- As set forth in Section 8.5.3 of the SDFDM, there are separate velocity limitations identified for specific channel lining materials and for the vegetation within the channel. See the SDFDM for listed values. Please note, rock outfalls with native tree stakes is another type of vegetative channel lining that can accommodate slope up to 10% and a maximum velocity of 4 fps.

#### **Channel Depth and Width**

The primary concerns where an open channel outfall merges with a wider and deeper channel is 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. As recommended in the SDFDM, there should be 6 to 12 inches of freeboard depth above the design storm water surface elevation in an open drainage channel.

#### **Erosion and Scour Control**

The outfall and receiving waterway must be protected against erosion and scour. Erosion and scour can result 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). The maximum shear stress in the channel at any particular flow depth should be used as a basis for design to ensure the design is conservative. Maximum shear stress can be calculated as follows:

 $\tau_d = \gamma d S$ 

$\tau_d$ = maximum shear stress, lb/ft <sup>2</sup>
$\gamma$ = unit weight of water, 62.4 lb/ft <sup>3</sup>

d = depth of flow, ft S = average channel slope, ft/ft For more information on shear stress refer to Section 8.5.5 of the SDFDM. Protection from erosion can be provided by these techniques:

- > rock lining (large riprap or smaller quarry spalls, or streambed boulders),
- > geotextile fabric lining (PDOT 2007, Section 00350),
- > low-rise check dams spanning the outfall channel,
- > plantings on the channel banks, and/or
- > woody structures installed in the drainageway channel bank.

Each technique has specific design requirements listed in Chapter 8 of the SDFDM. As a rule of thumb, if check dams are used to slow velocities in the open channel outfall, a minimum of three check dams should be used with dam heights and spacing as indicated in the check dams **Exhibit SW-520**. They should be made of wood or rock, and must be keyed into the open channel bed and banks to prevent the dam from being displaced during high flows. Where rock is used, the rock must 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.

### 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 (see Exhibit SW-521).

## Plantings

Whenever possible, 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. For guidance on plantings, refer to Section 8.5.6 of the SDFDM and SWMM **Appendix F**.

# Grade Control

To minimize erosion and scour, the outfall should be designed to minimize the elevation difference between 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) are required to create a step-pool sequence within the open channel outfall. Short drops of less than a foot will not typically require grade control, unless the outfall channel bed material is highly erodible. But 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. Appropriate grade control measures depend upon the outfall channel, the receiving waterway, the site characteristics, and fish passage considerations.

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 fish passage considerations apply to the site, ODFW fish passage design criteria for the elevation drop across a grade control structure must be adhered to (WDFW 2004).

Options for grade control include log sills, plank sills, and boulder controls. Design guidelines may be obtained from Chapter 7 of the Washington Department of Fish and Wildlife document entitled Design of Road Culverts for Fish Passage (WDFW 2003).

#### **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. 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 will be created by the flow dispersion.

#### Vegetated Area Requirements

A vegetated flowpath of at least 50 feet, and preferably greater, should be maintained between the dispersal point and any property line, structure, steep slope (greater than 40 percent), or Environmental Zone.

### **Dispersion Model**

One method used to disperse concentrated stormwater flow in hilly terrain is through a flow dispersal trench (see Exhibit SW-524), 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. It is recommended that this method not be used where hill slopes are greater than 20 percent. The discharge point shall not be placed on or above slopes greater than 20 percent or above identified erosion hazard areas without evaluation by a geotechnical engineer or qualified geologist and approval by the City of Portland Bureau of Development Services. The guidance below pertains to sites that meet these slope considerations.

The following guidance for dispersion trench design is taken from the Washington State Department of Transportation Highway Runoff Manual (WSDOT 2006). 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 must use only dispersion trenches to disperse flows. Dispersion trenches must be a minimum of 2 feet wide by 2 feet deep in section, 50 feet in length; filled with  $\frac{3}{4}$  - 1½ inch washed drain rock; and provided with a level notched grade board (see **Exhibit SW-160**). 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 must 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.

#### **Erosion Control**

Both the areas where stormwater enters and is dispersed must be protected against erosion. Erosion can result when the dispersed flow passes over sparsely vegetated ground or bare soil. If the dispersion area must be planted to provide the desired vegetation cover, a natural-fiber erosion control blanket (such as jute, coir, or excelsior) is recommended to provide soil stabilization while the vegetation matures, see City of Portland 2008 Erosion Control Manual. Native vegetation should be incorporated into an upland dispersion area, if not already present. Thick vegetation cover is critical to effective dispersion and infiltration of stormwater.

#### **Piped Outfalls**

On very steep or sensitive slopes, it may be difficult or impossible 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 (see **Exhibit SW-522**). All outfalls shall be located above the downstream mean low water level. Where the outfall may impact the receiving stream, especially fish bearing streams, consultation and approval by an ODFW authority may be required. The angle of discharge at the confluence with a drainageway channel is discussed later in this section.

### **Energy Dissipation**

High velocity flows have significant kinetic energy, which can cause extensive erosion and scour at an outfall and/or receiving waterway. Every attempt should be made to decrease this kinetic energy throughout the conveyance network. However, when flow velocity is high at an outfall, the energy must be dissipated and erosion protection must be in place to protect against scour. This applies to all outfall scenarios regardless of outfall type. 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 these specifications. However, as long as it can be proven to both dissipate energy and protect against erosion and scour, it can be considered acceptable.

#### Techniques available:

- Rock outfalls with vegetation incorporated;
- Pipe Tee diffusion structures (see Exhibit A.4-2);
- 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) are required where velocities are greater than 20 feet per second.



Exhibit A.4-2: Pipe Tee Diffuser

\*These shall be designed by a professional engineer using published references such as Hydraulic Design of Energy Dissipaters for Culverts and Channels (U.S. Department of Transportation, Federal Highway Administration) and other references. The construction plan submittal shall identify the design reference.

In general, rock protection of outfalls is most common. With the use of the proper size and gradation, rocks provide energy dissipation as well as protection against soil erosion. Depending on the flow velocity and existing site conditions, loose rocks such as riprap or quarry spalls can be used. **Exhibit A.4-3** has information on rock sizing based on outfall diameter and velocities. **Exhibit SW-523** and **Exhibit A.4-4** show two options for outfall energy dissipaters made of rock. All rock protection areas shall be inter-planted with willow stakes or other approved plantings, every two feet on center, to increase stability, reduce erosion, provide shading, and improve aesthetics.

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 (same as described for open channel outfalls, see **Exhibit SW-521**).

Outfalls shall be located above the downstream mean low water level, except as approved by the City. Concrete endwalls will be required for all exposed outfall pipes greater than 12 inches in diameter (see Exhibit SW-524). Publicly accessible outfalls greater than 18 inches in diameter shall include grated protection in accordance with Exhibit SW-525.

Outfalls to drainageways and rivers are often located in Environmental Zones. Environmental Review may be required pursuant to City Code Title 33.

Drainageways and rivers 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 for approval.



Exhibit A.4-3: On-Site Storm Outfall

	Discharge Velocity						
Outfall Diameter	at Design Flow	Туре	Depth	Width	Length	Height	
2 inch		Average stone size 1 inch	2 inch	12 inch	24 inch		
4 inch		Average stone size 2 inch	4 inch	24 inch	36 inch		
6 inch		Average stone size 4 inch	6 inch	36 inch	48 inch		
>6 inch	0 – 5 fps	Riprap <sup>a</sup>	2 x max. stone size	Diameter + 6 feet	As calculated <sup>b</sup>	Crown + 1 foot	
	6 - 10 fps	Riprap <sup>a</sup>	2 x max. stone size	Greater of: (diameter + 6 feet) or (3 x diameter)	As calculated <sup>b</sup>	Crown + 1 foot	
	11 - 20 fps	Gabion or riprap <sup>a</sup>	2 x max. stone size	Greater of: (diameter + 6 feet) or (4 x diameter)	As calculated <sup>b</sup>	Crown + 1 foot	
	Over 20 fps		Engineered energy dissipater required				
<ul> <li>Riprap size shall be determined using the following formulae and the <i>City of Portland Standard Construction Specifications</i> (PDOT 2007), Section 00390.11 Riprap.</li> <li>Riprap size ds=0.25*Do*Fo (6" minimum).</li> <li>Depth=2*ds (1 foot minimum).</li> </ul>							

#### **Construction Techniques for Both Open Channel and Piped Outfalls**

To the extent possible, heavy equipment and machinery should be kept out of the receiving waterway and off the banks. 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.

For open channel outfalls, it is required that the new channel excavation be completed and stabilized to the extent practicable before making the connection to the receiving drainageway. This will 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 should be retained between the outfall channel excavation and the receiving drainageway until the connection is ready to be made.

Construction in and adjacent to streams that provide habitat for fish must adhere to prescribed periods for in-water work, as defined in the Oregon Guidelines for Timing of In-Water Work to Protect Fish and Wildlife Resources (ODFW 2000). As defined currently, the preferred in-water work period for Willamette River tributaries within city limits is July 1 to October 15. Project applicants should check the in-water work dates prior to proceeding with in-water work.

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 must be accomplished to enable construction in relatively dry conditions.