4 Hydraulic Project Descriptions

4.1 General Descriptions

Riverine environments are those where flow is dominantly unidirectional, significant, and confined in a single channel or a set of intersecting channels.

Lacustrine environments are those freshwater bodies surrounded by land. Because impoundments behind dams have little significant flow, impoundments are included as a type of lacustrine environment.

Marine environments are those where physical processes are dominated by tides and/or waves and salinity is at least occasionally important. Marine environments include deltas and confined estuarine embayments (e.g., Willapa Bay, Commencement Bay).

These definitions mean that riverine environments may be tidally modulated, and marine environments may have varying salinity.

Hydraulic projects in the following categories are discussed in this chapter:

- Bank protection/stabilization (bulkheads, retaining walls, revetments, toe protection, beach nourishment, subsurface drainage, biotechnical bank protection, bank reshaping or regrading, soil reinforcement, coir and straw logs, integrated approaches)
- Shoreline modifications (groins, jetties, breakwaters)
- Overwater structures (docks, floats, piers, ramps, wharfs, pilings and non-structural pilings, and combined uses of these structures in marinas and terminals)
- Habitat modification (beaver dam removal, large woody debris manipulations, spawning substrate augmentation, riparian planting, wetland creation/restoration/enhancement, beach nourishment/contouring, reef creation, eelgrass planting/restoration/enhancement, in-channel and off-channel habitat modifications
- Channel modifications (dredging, gravel mining and bar scalping, sediment capping, channel creation and alignment)
- Water crossings (bridges, culverts, conduits)
- Fish passage (fish ladders, culverts, weirs, roughened channels, trap and haul)
- Fish screens (in-channel, off channel).
- Flow control structures (dams, weirs, dikes, levees, tide gates, intakes, outfalls).

4.2 Statutes and Rules Regulating Hydraulic Project Approval Permits

WDFW is charged by state law to preserve, protect, and perpetuate all fish and shellfish resources of the state. WDFW regulates construction that may affect fish and shellfish in accordance with the Hydraulic Code set forth in RCW 77.55. RCW 77.55.011(7) defines a hydraulic project as “the construction or performance of work that will use, divert, obstruct, or change the natural flow or bed of any of the salt or freshwaters of the state.”

The Hydraulic Code Rules establish “regulations for the construction of hydraulic projects or performance of other work that will use, divert, obstruct, or change the natural flow or bed of any of the salt or fresh waters of the state (WAC 220-110).” While WDFW exercises its authority by granting permits (known as hydraulic project approvals or HPA permits) prior to construction, in issuing the permit, it takes into account the likely ongoing effects of the project.

The following tables summarize the subsections of WAC 220-110 and of RCW 77.55 that may apply to various types of hydraulic projects. The tables are meant to be inclusive; some subsections are cited because they may be related to the HPA activity, even if the activity is not called out specifically in the citation.

Table 4-1: Freshwater hydraulic project provisions in Washington Administrative Code (WAC)

WAC – Freshwater Provisions		**White Paper Title (year)**									
WAC section number	WAC section title	bank protection (06)	water crossing structures (06)	overwater structures (06)	shoreline modifications (07)	fish passage structures (07)	marinas and terminals (07)	channel modifications (07)	habitat modifications (07)	fish screens (07)	flow control structures (07)
220-110-050	Bank protection	x	x	x	x	x	x	x	x	x	x
220-110-060	Construction of freshwater docks, piers, and floats and the driving or removal of piling		x	x			x				
220-110-070	Water crossing structures		x			x				x	x
220-110-080	Channel change/ realignment	x	x		x	x		x	x	x	x
220-110-100	Conduit crossing		x								x
220-110-120	Temporary bypass culvert, flume or channel	x	x		x	x		x	x	x	x
220-110-130	Dredging in freshwater areas	x	x		x	x	x	x	x	x	x
220-110-140	Gravel removal		x		x	x		x	x	x	x
220-110-150	Large woody material removal or repositioning	x			x	x	x	x	x	x	x
220-110-160	Felling and yarding of timber								x		
220-110-170	Outfall structures				x		x		x		x
220-110-180	Pond construction							x	x	x	x
220-110-190	Water diversions					x				x	x

WAC – Freshwater Provisions		**White Paper Title (year)**									
WAC section number	WAC section title	bank protection (06)	water crossing structures (06)	overwater structures (06)	shoreline modifications (07)	fish passage structures (07)	marinas and terminals (07)	channel modifications (07)	habitat modifications (07)	fish screens (07)	flow control structures (07)
220-110-200 through 220-110-209	Mineral prospecting[1]							x	x	x	
220-110-223	Freshwater lake bulkheads	x			x	x	x	x	x	x	x
220-110-224	Freshwater boat hoists, ramps, and launches	x		x	x	x	x	x	x		

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[1] The sections of WAC 220-110 pertaining to prospecting are currently under revision. As of April 2009, it is anticipated that the pertinent sections will become 220-110-200 through 220-110-206

Table 4-2: Saltwater hydraulic project provisions in Washington Administrative Code (WAC)

WAC – Saltwater Provisions		**White Paper Title (year)**									
WAC section number	WAC section title	bank protection (06)	water crossing structures (06)	overwater structures (06)	shoreline modifications (07)	fish passage structures (07)	marinas and terminals (07)	channel modifications (07)	habitat modifications (07)	fish screens (07)	flow control structures (07)
220-110-250	Saltwater habitats of special concern	x	x	x	x	x	x		x	x	x
220-110-270	Common saltwater technical provisions	x			x	x	x		x	x	x
220-110-271	Prohibited work times in saltwater areas	x	x	x	x	x	x		x	x	x
220-110-280	Bulkhead and bank protection in saltwater areas (nonsingle family residence)	x			x	x	x		x		x
220-110-285	Single-family residence bulkheads in saltwater areas	x			x	x			x		x
220-110-290	Saltwater boat ramps and launches	x			x	x	x		x		
220-110-300	Saltwater piers, pilings, docks, floats, rafts, ramps, boathouses, houseboats, and associated moorings	x		x	x	x	x		x		
220-110-310	Utility lines	x	x		x	x			x	x	x
220-110-320	Dredging in saltwater areas				x	x	x	x	x	x	x
220-110-330	Marinas in saltwater areas	x		x	x	x	x		x		x

Table 4-3: Aquatic plant control provisions in Washington Administrative Code (WAC)

WAC – Aquatic Plant Control Provisions		**White Paper Title (year)**									
WAC section number	WAC section title	bank protection (06)	water crossing structures (06)	overwater structures (06)	shoreline modifications (07)	fish passage structures (07)	marinas and terminals (07)	channel modifications (07)	habitat modifications (07)	fish screens (07)	flow control structures (07)
220-110-331	Aquatic plant removal and control technical provisions								x		
220-110-332	Hand removal or control								x		
220-110-333	Bottom barriers or screens								x		
220-110-334	Weed rolling								x		
220-110-335	Mechanical harvesting and cutting								x		
220-110-336	Rotovation							x	x		
220-110-337	Aquatic plant dredging							x	x		
220-110-338	Water level manipulation								x		x

In addition, the following sections are generally applicable to HPA permits:

220-110-020, Definitions
220-110-030, Procedures
220-110-032, Modification of technical provisions
220-110-035, Miscellaneous hydraulic projects – permit requirements and exemptions
220-110-040, Freshwater technical provisions
220-110-230, Saltwater technical provisions

Table 4-4: Revised Code of Washington (RCW) sections pertaining to hydraulic projects

RCW 77.55		**White Paper Title (year)**									
RCW section number	RCW section title	bank protection (06)	water crossing structures (06)	overwater structures (06)	shoreline modifications (07)	fish passage structures (07)	marinas and terminals (07)	channel modifications (07)	habitat modifications (07)	fish screens (07)	flow control structures (07)
77.55.011	Definitions	x	x	x	x	x	x	x	x	x	x
77.55.021	Permit	x	x	x	x	x	x	x	x	x	x
77.55.051	Spartina/purple loosestrife – removal or control							x	x		
77.55.081	Removal or control of aquatic noxious weeds – rules – pamphlet								x		
77.55.091	Small scale prospecting and mining - rules							X			
77.55.141	Marine beachfront protective bulkheads or rockwalls	X									
77.55.151	Marina or marine terminal			x			x				
77.55.161	Stormwater discharges										X
77.55.171	Watershed restoration projects - Permit processing								X		
77.55.181	Fish habitat enhancement project - Permit review and approval process	x	x		x	x		x	x		
77.55.191	Columbia River anadromous fish sanctuary - Restrictions									x	x

RCW 77.55		**White Paper Title (year)**									
RCW section number	RCW section title	bank protection (06)	water crossing structures (06)	overwater structures (06)	shoreline modifications (07)	fish passage structures (07)	marinas and terminals (07)	channel modifications (07)	habitat modifications (07)	fish screens (07)	flow control structures (07)
77.55.221	Flood damage repair and reduction activities - five year maintenance permit agreements	x	x					x	x		
77.55.231	Conditions imposed upon a permit - reasonably related to a projects	x	x	x	x	x	x	x	x	x	x
77.55.241	Off-site mitigation	x	x	x	x	x	x	x	x	x	x
77.55.261	Placement of woody debris as condition of permit	x	x	x	x	x	x	x	x	x	x
77.55.271	Sediment dredging or capping actions – dredging of existing channels and berthing areas – mitigation not required						x	x	x		
77.55.281	Fishways on certain agricultural drainage facilities					x					x

4.3 Federal regulations that may also apply.

Many activities that are permitted by the HPA program may also require a permit from the U.S. Army Corps of Engineers authorizing the placement of fill in waters of the United States (known as a Section 404 permit, referring to Section 404 of the federal Clean Water Act) or the placement of structures in navigable waters (known as a Section 10 permit, referring to Section 10 of the federal Rivers and Harbors Act).

In many cases, a Corps Nationwide Permit containing standard conditions applies. However, on September 26, 2006, the Corps proposed revision of the Nationwide Permit system; therefore, it is not practical for this analysis to make assumptions about future permit conditions that might be imposed by the Corps for projects authorized under the Nationwide Permit system.

All projects authorized under Corps permits are subject to additional conditions, some of which may be derived pursuant to interagency consultation with the federal agencies as provided for under Section 7 of the ESA.

4.4 Hydraulic Project Descriptions

4.4.1 Bank Protection and Stabilization

WDFW defines[2] bank protection structures as “permanent or temporary structures constructed parallel to and immediately adjacent to the shoreline and landward of the shoreline for the purpose of protecting or stabilizing the bank (e.g., bulkheads, retaining walls, etc.).” This category of activities is distinguished from shoreline modifications, which are structures constructed perpendicular or nearly perpendicular to the shoreline that extend into the water (e.g., jetties, groins, breakwaters, and bank barbs).

Particularly useful technical details for bank protection and stabilization techniques are presented in the *Integrated Streambank Protection Guidelines* (Cramer et al. 2003) and *Stream Management* (Fischenich and Allen 2000). The HCP-covered bank protection activities would include an array of these techniques as discussed below. This list is not intended to be exhaustive, but addresses many of the most commonly applied techniques. Photographs and designs of these techniques are available in Cramer et al. (2003).

Bank protection methods are described using the categories of hard approaches and soft approaches, following Williams and Thom (2001). Hard approaches armor the bank with material intended to resist shear forces experienced at the project site, such as riprap, concrete, or timber bulkheads that would prevent erosion of the bank. Soft approaches attempt to mimic natural processes with the use of biotechnical methods such as live plantings, rootwads, and large woody debris (LWD); soft approaches are used where shear forces are relatively low. Many projects integrate both hard and soft approaches, as described in the *Integrated Streambank Protection Guidelines* (Cramer et al. 2003).

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[2] The definition of bank protection structures was provided to the authors of the white paper by WDFW in Appendix B of Exhibit B of the Request for Proposal for this project, RFP No. 06-0005.

4.4.1.1 Hard Approaches

4.4.1.1.1 Vertical Retaining Walls

Vertical or near-vertical walls along banks and shores have many names, including bulkheads, seawalls, and cribwalls. These features may contain various materials, including concrete, metal, wood, and rock (Zelo et al. 2000). They consist of a vertical wall constructed of sheets of material or of piling with horizontal lagging and backfill.

Vertical walls are typically applied as bank protection on very steep slopes, in instances when landowners want to increase level property adjacent to the water, when floodplain encroachment has occurred, and/or when a near-vertical structure is necessary due to space limitations or to protect an eroding streambank. Issues of material choice, material preservation, and design for these walls typically depend on the project site and habitat concerns.

Cribwalls can be useful in stabilizing steep slopes where a near-vertical structure is required to protect an eroding streambank. Cribwalls are built as log-cabin-shaped structures parallel to the bank to deflect erosive currents away from the bank.

4.4.1.1.2 Revetments

"Revetment" is a generic term for sloping structures placed parallel to the contours of a shoreline in order to absorb incoming energy from stream or wave flow and to protect the slope (Williams and Thom 2001). Most revetments are constructed of rock, but may include other material such as concrete or logs. Revetments include the following:

- **Riprap**: Riprap is large, angular rock used for bank protection. It is typically placed over a filter layer of gravel or synthetic filter fabric. Riprap is the most common material used for bank protection in the United States (Cramer et al. 2003). Recent concerns about reduced habitat value and geomorphic repercussions of riprap have spawned development of alternative techniques. The *Integrated Streambank Protection Guidelines* (Cramer et al. 2003) recommends that new riprap installations be built "only where bank failure would have intolerable consequences or where site conditions are extreme," such as in instances of massive bank failure.
- **Gabions**: Gabions are wire mesh baskets filled with soil or rock material that are used along a shoreline (Freeman and Fischenich 2000). Gabions are often used where available rock sizes for a bank protection project are too small to withstand erosive forces, as well as to achieve a smoother bankside appearance for aesthetic reasons. Vegetation may or may not be incorporated into the structure, depending on needs for long-term stability, weathering, and habitat considerations.
- **Concrete-filled Bags**: These bags are placed in bricklaying fashion on the bank and the concrete is allowed to cure to the shape of the bag.

- **Interlaced Concrete Forms**: These forms consist of flexible, interlocking matrices of concrete blocks of uniform size and weight connected by a series of cables.
- **Cellular Blocks**: These pre-cast concrete blocks are designed to be placed on a prepared bank in a manner that leaves many openings, allowing planted vegetation to grow from cavities.

4.4.1.1.3 Hardened Toes

Hardened toes function to prevent erosion by providing the foundation for upper-bank features such as reinforced soil lifts or vegetative plantings (Cramer et al. 2003). These toes feature angular rock components for roughness attributes. Large woody debris (LWD) may be incorporated into roughened-rock toes as a habitat feature and to provide additional roughness. Rock toes can be used where there is less risk to infrastructure and where habitat mitigation must be incorporated into the treatment. Roughened-rock toes can also be employed as a complementary toe treatment to other bank protection methods, for instance in concert with bioengineered bank protection measures.

4.4.1.1.4 Levees

Levees are not bank protection per se, but are earthen embankments built to provide flood protection from occasional high-water events. Levees are more stable than a continuous form of bank protection, such as revetments on bank curves greater than 30 degrees (Fischenich and Allen 2000). Because they direct flow, levees can cause channel changes and clearly become ineffective when overtopped with high water. Levees are discussed under Flow Control Structures.

4.4.1.2 Soft Approaches

4.4.1.2.1 Log/Rootwad Toes

Log and rootwad toes are added as a preventive measure to stem erosion at the toe of a bank or shore, providing the basis for upper-bank treatments such as reinforced soil or resloped banks (Cramer et al. 2003). Typically, these toes consist of logs installed parallel to the bank and backfilled with gravel and may contain additional LWD features or other rock protection. Log and rootwad toes provide erosion protection and are not intended to function as structural retaining walls. Their top elevation does not exceed the lower limit of vegetation on the bank. LWD for bank protection is intended to resist shear until such time as vegetation can be reestablished, after which it can rot out with little risk. Currently, the *Integrated Streambank Protection Guidelines* (Cramer et al. 2003) considers this technique experimental because so few log and rootwad toe structures have been installed and monitored. The technique is likely best used where there is less risk to infrastructure and when habitat mitigation is required, because habitat elements can be incorporated into the design.

4.4.1.2.2 Beach Nourishment

Beach nourishment in Washington State is most commonly employed using coarse gravel to combat shoreline erosion at relatively small sites (Williams and Thom 2001). This method entails placing fill material either as an independent activity or integrated with hard structures or bioengineered solutions. Fill is typically required to be similar in size to existing native material, be contaminant-free, and have low silt/clay components to preclude turbidity issues. Beach nourishment is considered a temporary fix to a sediment supply problem and is undertaken with an ongoing commitment for periodic maintenance (Williams and Thom 2001).

4.4.1.2.3 Subsurface Drainage Systems

Subsurface drainage systems are typically installed under or behind other bank treatments in order to decrease the saturation of soil and increase slope stability on side banks (Cramer et al. 2003). Techniques include chimney drains, collection drains, and gravel seams, which may be gravity-based or pumped systems.

4.4.1.2.4 Biotechnical Bank Protection

Soft approaches to bank protection include a suite of developing biotechnical protection methods in which natural materials are used or vegetation is planted to address slope stability. Current biotechnical bank protection methods are as described below and in much of the available literature (e.g., Allen and Leech 1997; Cramer et al. 2003; Zelo et al. 2000; Saldi-Caromile et al. 2004; Fischenich and Allen 2000; Williams and Thom 2001):

- **Riparian Plantings**: Plantings may be added to bank protection projects in an effort to stabilize banks by the establishment of root material at the shoreline. Native herbaceous cover and woody plants of various species are added, depending on the project goals.
- **Live Stakes or Poles**: Live stakes or poles are the simplest form of vegetation planting along a shoreline, consisting of stakes of live material inserted into the ground, providing reinforcement of surface soil layers. Sometimes a row of stakes or poles features a basket-like live brush mat called a wattle. The live cuttings eventually root and provide long-term reinforcement and may provide some control over internal seepage.
- **Brush Packing, Layering, and Mattressing**: Brush packing involves alternating layers of live branches and earth to fill localized slumps. The branches protrude beyond the face of the slope and reinforce the bank, while the stems provide frictional resistance to shallow slides. The live cuttings eventually root and provide long-term reinforcement. Brush layering involves alternating layers of brush packed materials across larger areas than in brush packing. Brush mattresses lie along the slope with their root ends in a trench at the toe of the slope, as opposed to being planted along the slope.
- **Live Fascines**: Live fascines are sausage-shaped bundle structures made from cuttings of living woody plant material that are placed in a shallow trench along a bank slope contour (Sotir and Fischenich 2001). The live cuttings eventually root and provide long-term reinforcement. The live fascine is constructed from the

elevation of baseflow along the face of an eroded streambank. Live fascines are used for bank and toe protection as well as improvement of erosion control, infiltration, and other riparian zone functions.

- **Roughness Trees/Tree Revetments:** Roughness trees, which are also called tree revetments, function to slow down the water velocity in an active channel and reduce hydraulic shear stress, helping sediments accumulate at the site and enabling the establishment of vegetation (Cramer et al. 2003). This process ultimately results in the protection of vulnerable or eroding banks. These revetments may be expanded by installation of LWD, which is often anchored for stability, in the channel or along the banks (Fischenich and Morrow 1999).

4.4.1.2.5 Bank Reshaping or Regrading

Bank reshaping or regrading is employed to stabilize an eroding streambank by reducing the angle of its slope without changing the location of the toe. This technique is almost always conducted along with other bank protection treatments and may include vegetated components and a new toe installation. Regrading is most often applied along vertical and/or eroding banks, but the ability to reshape banks may be limited where access is difficult for heavy equipment, and regrading may be unsuitable where mature riparian vegetation or infrastructure exists. The technique is not considered effective to prevent continuing erosion at a reach level because it does not address the actual mechanisms of failure.

4.4.1.2.6 Soil Reinforcement

Soil reinforcement refers to a system of soil layers or lifts encapsulated or otherwise reinforced with a combination of natural or synthetic materials and vegetation, sometimes in a terraced fashion. These systems are also known as fabric-encapsulated soil, fabric-wrapped soil, soil burritos, vegetated geogrids, or soil pillows. This technique is best used on eroding banks on small creeks, large rivers of lower gradients, and estuaries where a resilient and bioengineered or biotechnical treatment is needed and where a wide range of bank-failure mechanisms occurs, including toe erosion, mass wasting, and scour.

4.4.1.2.7 Coir and Straw Logs

Coir and straw logs are similar to soil reinforcement in that they provide a system of layered materials, typically with integrated vegetation. Coir logs are long, sausage-shaped bundles of coir (coconut fiber) or straw, bound together with additional coir or synthetic netting (Allen and Fischenich 1999). They may be planted with herbaceous or woody vegetation and function to provide temporary biodegradable protection to banks while the vegetation develops. In addition, they also encourage sediment retention during overbank flows.

4.4.1.3 Integrated Approaches

Integrated approaches to bank protection have been developed to incorporate some of the best attributes of both hard and soft approaches (Cramer et al. 2003). One important general goal of integrated bank protection is to use habitat features that can deteriorate and ultimately allow the bank to protect itself through maturation of the design. For example, woody toe protection will deteriorate as native vegetation matures and begins to provide support and structure to a bank. Further examples of these approaches include integrating vegetation, coir logs, and woody debris into gabion or riprap structures; integrating vegetation and woody debris into rock or log toes to create habitat structure at the bank; and integrating rock toes with biotechnical soil reinforcement for toe and bank stability. Many of the hard and soft approaches discussed above can be similarly combined to protect against bank erosion while allowing habitat-forming processes to occur.

4.4.2 Shoreline Modifications

Shoreline modifications are oriented perpendicular to the direction of dominant sediment transport, and usually perpendicular to the shoreline. They include jetties, groins, bank barbs, and breakwaters. This category of activities is distinguished from bank protection structures, which are parallel to and immediately adjacent to the shoreline and landward of the shoreline for the purpose of protecting or stabilizing the bank.

Shoreline modification structures include:

- A **jetty** is a structure constructed at navigational channels to prevent sand from depositing in the channel and to provide wave protection for vessels (Dean and Dalrymple 2002). **Weir jetties** are submerged at most water levels for some portion of their length, usually the landward-most end. These features allow the passage of sediment for localized deposition in some inactive portion of the navigational channel (Seabergh and Kraus 2003).

- A **breakwater** is a structure that is built seaward of the breaker line parallel to the shoreline to protect nearshore infrastructure and prevent shoreline erosion. Breakwaters are often used in series (Dean and Dalrymple 2002).

- **Groins and bank barbs** are fingerlike, bank-protection structures keyed into one bank and oriented obliquely to the flow. Groins and bank barbs are typically constructed in sets along the outside of a meander bend, with the primary function of redirecting flow and bed material away from the bank and toward the middle of the channel. These structures reduce near-bank velocities, increase centerline velocities, retard bank erosion, cause local bed scour around the groin tip, and trap fine sediment and debris between structures (Li et al. 1984).

    - Groins are vertical barriers extending perpendicularly from the shore/bank that impede the downdrift/downstream movement of sediment. Groins are typically exposed above high water and are designed to divert flow (and bed sediment) around the structure. The primary purpose of a groin is to store sediment on the bank adjacent to the structure and prevent erosion to the updrift shoreline of the groin. Groins can be installed in rivers, lakeshores, and marine shorelines (NRC 2007).

    - A bank barb is a specific type of groin. It is a low-elevation structure projecting from a stream bank and angled upstream to redirect flow away from the bank, thereby controlling bank erosion (WDFW 2003). Bank barbs are typically submerged at or below low water. Weir-type structures, like bank barbs, are intended to redirect flow toward the center of the channel using weir hydraulics over the structure. They are often used in series. Because submerged structures are relatively ineffectual as a result of the large suspended load in high-wave-energy environments, bank barbs are often not associated with marine and lacustrine environments.

- Shoreline structures that intercept and disrupt normal transport processes, but whose primary purpose is not shoreline protection, are also considered shoreline modifications. Examples include beach-access stairways and boat ramps that project beyond the ordinary high water mark (OHWM). Such structures are hereafter called **analogs**. Typically, these structures would affect the aquatic environment in a similar manner as groins if they do not influence the flow or exchange of groundwater or surface water with the main water body, or act similar to a jetty if they do.

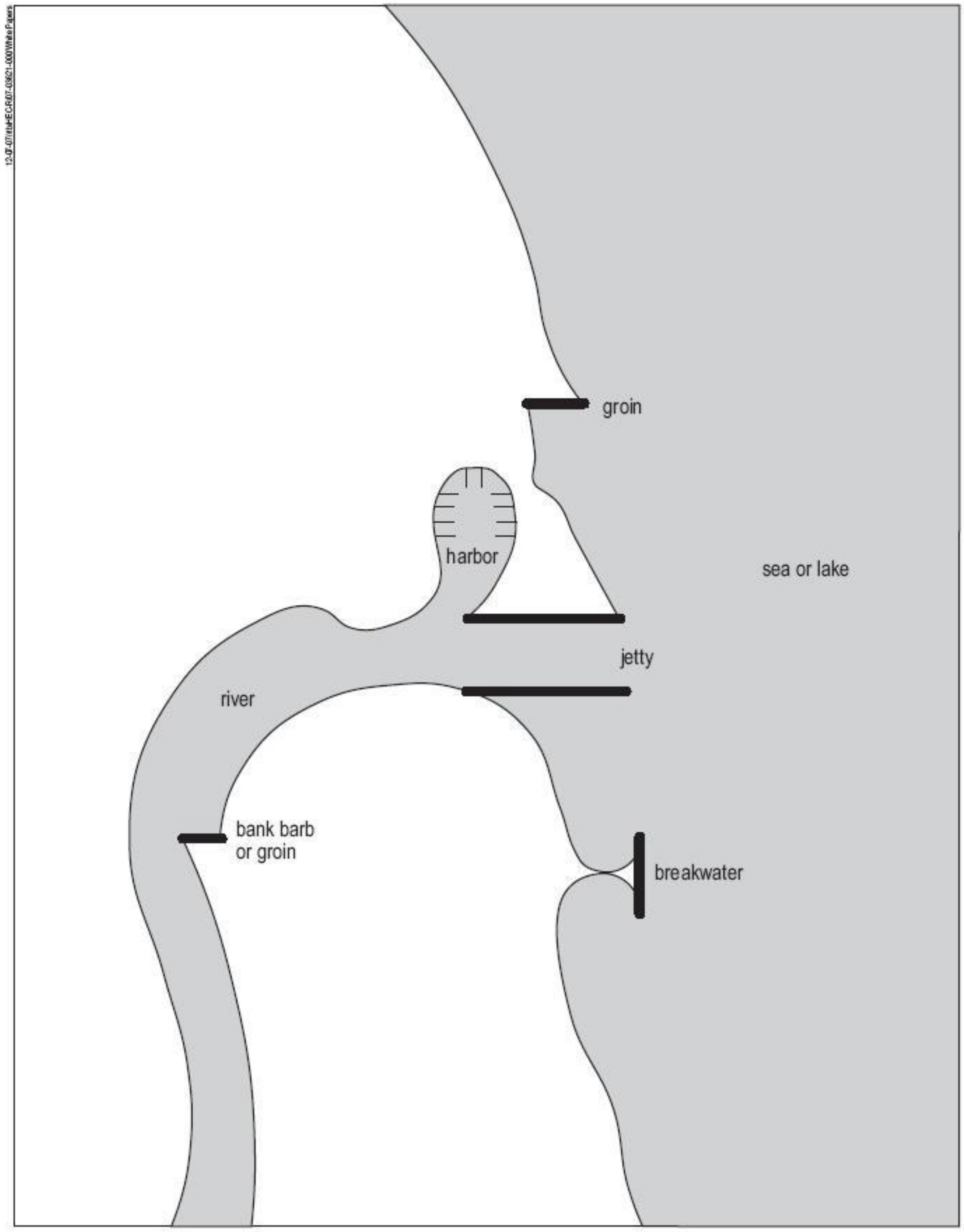

Figure 4-1. Location of Shoreline Structures

4.4.3 Overwater Structures

Overwater structures are simple structures located above and on the water to provide boat moorage and other sorts of access to the water. Single-family residential docks are a common example of overwater structures. Non-structural piling are discussed with overwater structures because of the overlap in potential impact mechanisms associated with the construction and presence of these structures. Larger and more complex structures, such as marinas and marine terminals, are discussed separately.

- A **pier** is an elevated and stationary walkway supported by piling that extends waterward of the shoreline.
- A **float** and a **dock** are walkways or other surfaces that float on the water.
- A **ramp** is a walkway connecting a pier or other shoreward structure to a float and providing access between the two.
- A **wharf** is an elevated and stationary structure oriented parallel to the shoreline, such that ships can lie alongside to load and unload cargo and passengers.
- A **piling** or pile is a pole, usually made of wood, steel or concrete, that is driven into the stream, lake, or ocean bed to support shoreline infrastructure. Non-structural pilings are individual pilings, including utility poles. Marinas and Terminals Project Description

A **marina** is a public or private facility providing vessel moorage space, fuel, or commercial services. Commercial services include but are not limited to overnight or live-aboard vessel accommodations (RCW 77.55.011(9)).

A **marine terminal** is a public or private commercial wharf and used, or intended to be used, as a port or facility for the storing, handling, transferring, or transporting of goods, passengers, and vehicles to and from vessels (RCW 77.55.011(10), with passengers added for purposes of this paper).

Marinas/terminals incorporate many individual components of overwater structures, including pilings and vessel access facilities. Marinas or terminals have a number of components, including:

- A **pier** is an elevated and stationary walkway supported by pilings that extends waterward of the shoreline.
- A **float** and a **dock** are walkways or other surfaces that float on the water.
- A **ramp** is a walkway connecting a pier or other shoreward structure to a float and providing access between the two.

- A **wharf** is an elevated and stationary structure oriented parallel to the shoreline, such that vessels can lie alongside to load and unload cargo and passengers.

- A **dolphin** is a buoy, pile, or group of piles used for mooring boats or group of piers used as a fender at a dock.

- A **fender panel** is a structure for protecting other nearby structures from collision with ships.

- A **piling** or **pile** is a pole, usually made of wood, steel or concrete, driven into the stream, lake, or ocean bed to support shoreline infrastructure. It includes both structural and nonstructural pilings. **Non-structural pilings** are individual pilings, including utility poles.

- An **access ramp or boat ramp** is "a uniformly sloping platform, walkway, or driveway common in the coastal environment as a launching area for small watercraft (Mulvihill et al. 1980). Ramps extend into the water at a slope of 12 percent to 15 percent (Mulvihill et al. 1980) and are typically oriented perpendicular to the shoreline. The design of ramp widths (3m to 15 m) varies with patterns and intensity of human-use needs, whereas lengths often depend on the slope of the shoreline and tidal amplitudes. Ramps extend from the terrestrial zone to below the low intertidal zone and are usually constructed in protected areas with access to fairly deep water close to shore. Construction materials commonly consist of gravel, concrete, or asphalt…" (Williams and Thom 2001).

- A **boat hoist** is a piece of equipment used to move boats from uplands to water. It may be free-standing or affixed to a dock or bulkhead.

- A **boat basin** is the area within a marina where multiple vessels are docked.

- A **pump-out station** is a facility used to remove sewage and/or gray water from the holding tanks of vessels. It is usually located on a dock within a marina for easy access by vessels.

- A **water intake site** is used to supply potable water to vessels. It is usually located on a dock within a marina or terminal for easy access by vessels.

- A **refueling facility** is used to supply fuel, such as marine grade gasoline or diesel fuel, to vessels. It is usually located on a dock within a marina or terminal for easy access by vessels.

Marinas/terminals also typically include considerable shoreline modification or bank protection structures in the form of breakwaters, wingwalls, bulkheads, seawalls, and nearshore buildings.

The area of potential alteration associated with a marina or terminal includes all the overwater structures and their associated dredged area; the area affected by changes in light regime from shading and artificial lighting; and the area affected by vessel propeller scour, vessel emissions and exhaust, and boat wakes. Furthermore, pollution from spillage and accidental discharges of toxins, waste, or stormwater may extend the area of alteration beyond the marina itself. The area of alteration and the effects on habitat-controlling factors may be limited, if enclosed by breakwaters (WDNR 2007).

4.4.4 Habitat Modifications

Habitat modifications are generally projects which are designed to improve habitat for fish and invertebrates. Although many of these activities may provide a net benefit to aquatic habitat and HCP-listed organisms, most are associated with short-term negative impacts during the construction phase. Beaver dam and large woody debris removal can be regarded as having longer-lasting negative impacts on the aquatic environment.

Habitat modifications have been widely applied in fluvial environments in the state of Washington over the past twenty years. The majority of these restoration measures are designed to create refugia within the river-floodplain system so that organisms can survive during extreme low flow and high flow conditions. In-channel habitat modification has been widely practiced but some research has indicated that these projects have a relatively high failure rate (Frissell and Nawa 1992; Roni et al. 2002) and practitioners and researchers have begun to recommend focusing on off-channel habitat creation and modification (Roni et al. 2002).

4.4.4.1 Beaver Dam Removal/Modifications

Beaver are ecosystem engineers that can drastically alter fluvial environments through the conversion of lotic habitat to lentic habitat (Naiman et al. 1986). The mosaic of connected aquatic habitat patches created by beaver are utilized by numerous aquatic species (Pollock et al. 2003) and beaver dam presence is widely believed to be a net benefit to aquatic organisms (Clifford et al. 1993; Ray et al. 2004; Sigourney et al. 2006). However, until relatively recently it was thought that beaver dams acted as barriers to fish migration and that beaver dam removal would benefit migratory species (Naiman et al. 1988). This, combined with concerns of flooding caused by beaver activity has lead to the modern day removal and modification of beaver dams.

Beaver dam removal is conducted using various methods. Most common is the removal of the dam with hand held tools. This removal method has the least impact on aquatic habitat because it generally is a more gradual process than the other methods. Other methods include using explosives and heavy machinery to remove dams. These methods are usually reserved for large dams and are associated with greater impacts on the aquatic ecosystem. To reduce impacts associated with dam removal but still control beaver-induced flooding, beaver dam modification has become a popular alternative to removal. The use of “beaver deceivers,” a trapezoidal device installed at the mouth of a culvert that would otherwise be dammed by beavers, can stabilize the pool volume and water level while conserving the ecological function of the dam and associated impoundment.

4.4.4.2 Large Woody Debris Placement/Movement/Removal

Large woody debris (LWD) placement, movement, and removal are the most common habitat modification activities in the state of Washington. Almost all LWD additions involve the use of natural materials taken from on-site riparian zones and off-site areas as well. The wood is often secured to the bank or bed of the channel using rebar, cable, or chains. Some wood additions involve burying the bole or root wad of the tree in the bank or bed, driving timber or steel piles, and layering rack member and key members through the structure. LWD additions range in scale from single logs to massive engineered logjams.

The removal of LWD from river channels began in earnest in 1829 with the launching of the first snagboats on the Ohio and Mississippi Rivers (Wohl 2004). Snags, or submerged large wood, were a menace to ferrying boats and as commerce along these riverine corridors grew so did the need for clear passage. The practice of “snagging” (also called de-snagging) a river did not however stop at lowland rivers. With clear passage up the mainstems of rivers loggers could more easily access heavily wooded tributaries. These smaller channels were also snagged and what wood was not removed by hand was later scoured out by log drives. Studies of paired streams, some with a history of log drives and some undisturbed, have shown that channels which have had a history of log drives contained 10 to 100 times fewer logs and significantly fewer pools (Wohl 2001; Napolitano 1998). With the realization that the habitat created by instream wood is vital for resident aquatic organisms, people began in earnest to put wood back into streams.

4.4.4.3 Spawning Substrate Augmentation

Gravel augmentation for the purpose of spawning habitat improvement has been promoted episodically by various government agencies since the 1960s (Bunte 2004). The two most common methods of spawning substrate augmentation are direct gravel placement and passive gravel placement.

Direct placement involves shaping the channel (by adding or removing gravel) to ensure that the 1.5-year recurrence interval flow fills the channel to its morphological bankfull stage. One form of this method involves providing bed material that is partially mobilized at bankfull flow and long-term gravel additions to match the post-restoration transport capacity. Another form of this method involves using a gravel size which will be minimally mobilized at bankfull discharges; this reduces the need for future augmentations but increases the probability that the gravels will become clogged with silt and organic material. Machinery must enter the channel and deposit gravel in various locations. This process involves front-end loaders, excavators, and/or bull dozers repeatedly entering and exiting the channel, usually along a constructed gravel ramp (Bunte 2004).

Passive gravel placement involves the dumping of gravels from a stream bank (Bunte 2004), supplying gravel to the channel at a logistically convenient location. The gravel is placed en-mass and mobilized by the stream during high-discharge events. As the gravel is entrained and deposited downstream, spawning habitat is created. This method is either conducted independently or in concert with direct gravel placement augmentations.

4.4.4.4 Riparian Planting/Restoration/Enhancement

Habitat modifications involving riparian vegetation involve a combination of invasive species removal and native species planting. Invasive species removal temporarily removes cover and destabilizes banks, while native species planting will increase cover and bank stability once plants have become established and grown. Riparian vegetation modifications generally do not involve potentially damaging work within the aquatic habitat. It is widely practiced in the state of Washington.

4.4.4.5 Wetland Creation/Restoration/Enhancement

Wetland creation, restoration and enhancement usually requires a considerable construction effort involving heavy machinery, the construction or alteration of weirs and other flow control structures, and/or planting. Wetland manipulations are conducted primarily by adjusting the hydroperiod of a parcel of land. This is done by either altering geomorphology in such a way as to increase or decrease the duration of wet or dry periods, or by adjusting the system hydrology. Initial construction phase activities are typically be associated with negative impacts on fish and invertebrates but, in time, the ecosystem functions provided by the wetland habitat can result in a net ecosystem benefit.

To control hydroperiod and create optimal habitat, wetland creation, restoration, and enhancement activities may in certain instances require partial wetland filling. Wetland filling is associated with localized habitat degradation, but if the project is properly designed a net ecosystem improvement can result.

- Wetland creation and restoration in riparian systems occurs via three primary methods:

- Floodplain activation through the removal of levees (Florsheim and Mount 2002). This type of wetland restoration usually involves regrading a hydraulically disconnected floodplain and subsequently removing portions of the levee. Consequently, the impact on the channel occurs only at the points where the levee is breached.

- Floodplain activation through base level or floodplain elevation alteration (which may require wetland filling) (Collins and Montgomery 2002).

- Channel realignment to connect a channelized reach to an active river-floodplain system (Whalen et al. 2002).

Wetland creation and restoration in estuarine systems typically involves the removal of dikes or levees, regrading to restore dendritic channels, and sometimes the installation of self-regulating tide gates.

Wetland enhancement typically involves removing noxious weeds, and replanting areas to improve native habitat and species diversity. Occasionally, enhancement includes changing the site’s water regime through excavation, construction of weirs, or removal of ditches and drains. Enhancement has historically focused on habitat, but other wetland functions can also be enhanced.

4.4.4.6 Beach Nourishment/Contouring

Beach nourishment, as it is practiced in Washington State, is primarily designed to restore a more natural (gradual) beach profile in response to either the loss of sediment supply (usually by dams or armored bluffs), increased wave energy associated with shoreline armoring, or to supplement and protect placed fill (Shipman 2001).

In Washington State, most beach nourishment occurs in sheltered, coarse-grained (i.e., gravel and cobble) settings (Shipman 2001). It also occurs in sandy, exposed environments, such as on the outer coast.

In sandy settings, a variety of mechanisms of nourishment have been used. One common method is to pump sandy material excavated from offshore the project site. This is most common where erosion problems are caused by the transport of sand offshore due to suspension from large waves (Dean and Dalrymple 2002). It is also common to use dredge spoils to nourish beaches. Jetty Island in Everett is an example of this type of nourished beach (Everett 2006). It is also conceivable that in Washington, where quarried sand is readily available, nourishment materials could originate from onshore, but past nourishment activities have primarily relied on dredged material as a nourishment material source (USACE 1983).

In coarse-grained environments, the most popular method is to use upland quarried alluvium. Delivery to the site is most often by truck, not barge (Shipman 2001). The material added can be from a range of sizes from pebble (0.1 inch in diameter) to cobble (several inches in diameter).

4.4.4.7 Reef Creation

Reef creation is probably the most well-studied fish habitat enhancement activity in the world (Baine 2001). Reefs have been created for habitat and recreational purposes for over seventy years in Washington State (NSC 2007). Early reefs were often harbor or coastal structures slated for demolition (NSC 2007). Wastes that would ordinarily be landfilled or incinerated (e.g., used tires) have also been used to create reefs (Hartwell et al. 1998). Derelict vessels have been used, though they are often stripped of potentially toxic or leachable materials before they are submerged at the project site (Baine 2001).

Often in the scientific literature, the terms reefs and breakwaters are used interchangeably (Pondella and Stephens 1994). Strictly speaking, there is no difference between these terms – both are structural elements seaward of the shoreline, and often permanently submerged. However, their purposes are distinctly different. Breakwaters are employed to protect the shoreline from wave energy (Dean and Dalrymple 2002), while reefs are placed to create habitat and to potentially increase the numbers of fish and invertebrates (West et al. 1994). As a result, a reef could be installed that has no effect on the wave environment.

4.4.4.8 Eelgrass and other Aquatic Vegetation Planting/Restoration/Enhancement

Eelgrass planting is a relatively new habitat enhancement activity. Although planting plans have been implemented for 25 years (Thom 1990), successful programs where eelgrass has been reintroduced to areas where it occurred prior to development, have only occurred recently (Thom et al. 2005). Successful programs must have an adaptive management plan, including the potential planting in successive years to ensure a viable stand (Thom et al. 2005). A number of mechanisms have been proposed to introduce new eelgrass. The most common is to manually plant shoots previously grown in a greenhouse (Fonseca et al. 1998). However, more recently broadcast seeding has been demonstrated to be successful when performed under certain conditions (Pickerell et al. 2005).

4.4.4.9 In-Channel and Off-Channel Habitat Modifications

In-channel and off-channel habitat modification is a broad set of activities which includes the placement of structures within the channel, bank protection measures, channel realignment, side channel creation/connection, and the creation or enhancement of backwater sloughs and pools. Such modifications are discussed in more detail in "roughened channels" under Fish Passage Projects. Artificial realignment and relocation of channels specifically designed to reconfigure the aquatic environment to promote human uses are discussed briefly under Channel Modifications.

The most common method of off-channel habitat rehabilitation is to work in a dry off-channel area and then connect the rehabilitated habitat to the main channel once the work is completed.

In-channel work can range from the placement of rock weirs which will have minimal impact on channel form, to complete channel realignment which will drastically alter the channel form. A goal of most in-channel habitat modification is to create habitat diversity and, in particular sheltered areas where organisms can reside during both high and low flow conditions. Many instream structures such as weirs are designed to locally elevate base-level and promote aggradation and pool formation. Weirs are also discussed under fish passage structures (as "weir-type fishways" and as "weirs") and under flow control structures.

4.4.5 Channel Modifications

Hydraulic projects pertaining to channel modifications include dredging, gravel mining and bar scalping, sediment capping, and channel creation and alignment.

- **Dredging** includes the removal of substrate from riverine, lacustrine, and marine environments for purposes of improving vessel navigation, the maintenance of channels and sediment traps for flow conveyance and flood control, and hydraulic suction dredging to manage aquatic vegetation. Dredging may also be used in cleaning up contaminated sediments. Dredging related to mineral prospecting is addressed in a separate white paper (Anchor 2006).

- **Gravel mining and bar scalping** is the extraction of gravel resources from the active channel or floodplain by means of pit mining, bar scalping or "skimming," bar excavation, gravel traps, or channel-wide instream gravel mining.

- **Sediment capping** refers to the placement of a subaqueous covering of clean material over contaminated sediments to isolate contaminants from riverine, lacustrine, and marine environments and biota.

- **Channel creation and alignment** includes the relocation, straightening, or meandering of an existing channel or the creation of a new channel where none existed before.

4.4.5.1 Dredging

Dredging is conducted for various purposes.

- Navigational and maintenance dredging is carried out in larger bodies of water (e.g., Columbia, Snake, and Cowlitz rivers; Puget Sound) and the embayments of the outer coast to allow the passage of deep-draft vessels in channels and marinas. Large-scale navigational dredging is generally conducted from a vessel or barge.

- Maintenance dredging to increase conveyance for flood and erosion control occurs primarily in relatively smaller channels at bridge and culvert crossings, along highways, in roadside and irrigation ditches, and in sediment traps constructed for this purpose. Small-scale navigational dredging may be performed from land using a clamshell bucket operated from a crane, a backhoe or excavator or a suction dredge.

- Dredging has been conducted to remove contaminated sediments. This type of dredging is often associated with sediment capping.

- Hydraulic suction dredging is used specifically for vegetation management in freshwater environments.

- The USACE (1983) describes two primary dredging techniques:

- **Mechanical dredges** include clamshell, dipper, and ladder dredges. Mechanical dredges remove material through direct force and are used both for new and maintenance projects. They can be used to remove loose or hard, compacted materials. Mechanical dredges result in more sediment resuspension when dredging occurs in fine, loose, or noncohesive substrates.

- **Hydraulic dredges** include cutterheads, dustpans, hoppers, hydraulic pipelines, plain suction, and sidecasters. Hydraulic dredges remove material in slurries and are generally used for maintenance projects. Hydraulic dredges are generally faster than mechanical dredges. Although hydraulic dredges create less resuspension of sediment than mechanical dredges, considerable resuspension can occur. Additionally, hydraulic dredging entrains considerably more water from the dredge site than mechanical dredging. Smaller, shallower dredging projects typically use different equipment than that required for deep water dredging projects.

4.4.5.2 Gravel Mining and Scalping

Gravel is extracted from riverine environments for use as base material in the construction of roads, highways, and railroads and as aggregate mix in the construction of roads and buildings. Gravel sources include active river sediments and glacial sediments deposited during the Pleistocene by meltwater streams. Sources are ideally located close to markets to reduce transportation costs and maximize profit. Extraction methods can include the following (Kondolf et al. 2002):

- **Dry-pit mining** is the excavation of gravel within the active channel on dry intermittent or ephemeral streams beds.

- **Wet-pit mining** is the excavation of gravel within the riverine floodplain below the groundwater table, requiring the use of a dragline or hydraulic excavator.

- **Bar scalping or "skimming"** is the extraction of gravel from the surface of gravel bars above the low-flow water level.

- **Bar excavation** involves pit excavation at the downstream end of the gravel bar for gravel extraction.

- **Gravel traps** are channel-spanning hydraulic controls that promote ponding and sediment deposition. The collected sediment is then extracted during low-flow conditions.

- **Channel-wide instream mining** occurs in rivers with variable flow regimes and involves the excavation of gravel across the entire active channel width during the dry season.

- **Floodplain and terrace-pit mining** is similar to wet-pit mining but includes dewatering of the pit to work in the dry.

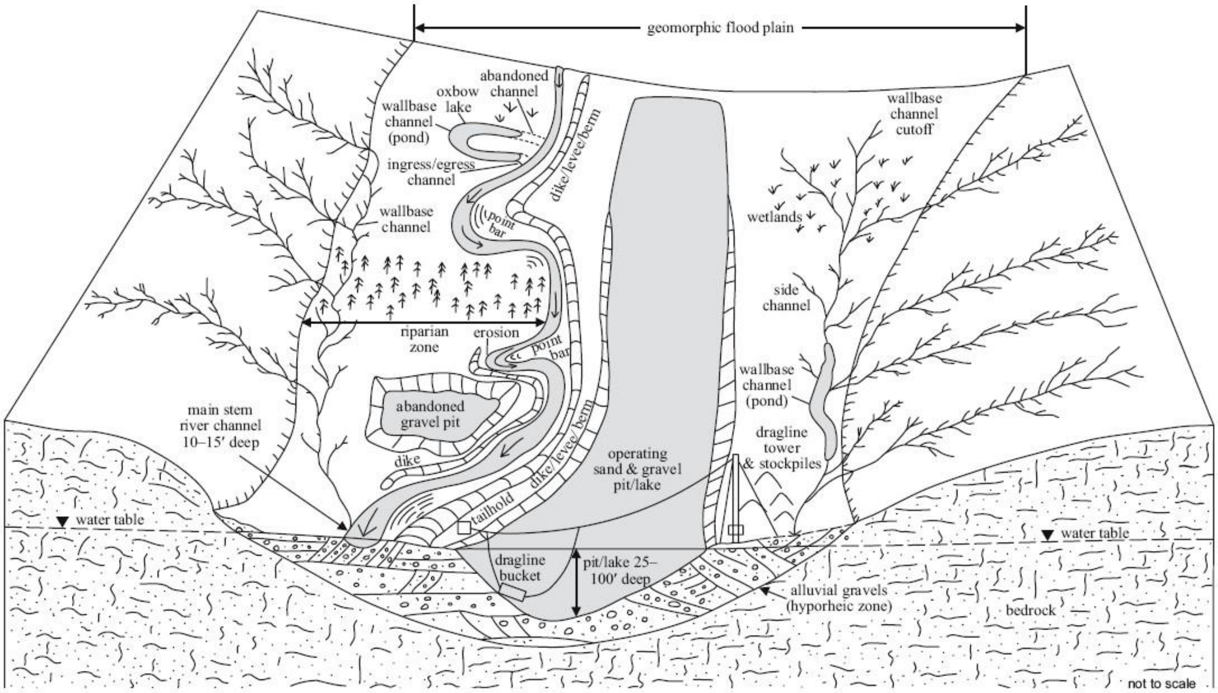

Figure 4-2. Schematic illustration of typical gravel extraction methods within the active floodplain (Norman et al. 1998).

4.4.5.3 Sediment Capping

Sediments contaminated with heavy metals, nutrients, polychlorinated biphenyls (PCBs), polyaromatic hydrocarbons (PAHs), and other organic pollutants are frequently present in urbanized marine and freshwater benthic habitat. In most situations, contaminant levels are sufficiently low such that a “natural recovery” (Garbaciak et al. 1998) or no-action alternative is the most effective form of remediation. However, when contaminant concentrations reach levels that require a more rapid solution, sediment capping or dredging may occur. Sediment capping is the placement of a contaminate-free isolating material over a contaminated sediment deposit (Palermo et al. 1998).

Sediment capping and dredging are frequently conducted in tandem. Sediment capping material is frequently dredged from an adjacent clean sediment source (USACE 1991a).

Two primary forms of sediment capping are practiced:

- The placement of a sediment cap over contaminated dredging spoils. Capping of dredge spoils is sometimes associated with the use of a confined aquatic disposal (CAD) cell. These cells are frequently constructed using piles and other treated wood products.

- The placement of a sediment cap over in-situ contaminated sediments.

The advantage of capping dredged sediments is that the practitioner has control over the physical location of the spoils and cap. A low-energy environment with low densities of aquatic life can be selected to minimize cap erosion and the impact on aquatic biota. However, the impacts associated with dredging can be significant and consequently, in-situ sediment capping (ISC) is frequently a preferred alternative. ISCs commonly have less of an environmental impact than dredging and capping, but the practice is associated with more uncertainty in terms of cap erosion and maintenance (Reible et al. 2003). ISC is a remediation technique that is becoming more common on a global scale (Palermo et al. 1998) but is still a relatively uncommon remediation technique in Washington State. Despite this, some of the most widely studied sediment capping projects in the world have occurred in Puget Sound.

A sediment cap most frequently consists of sand or silt (Palermo et al. 1998), but more recent efforts have focused on the use of active barrier systems (ABS), that incorporate various supportive materials (Jacobs and Forstner 1999; Murphy et al. 2006). The sorptive materials (e.g., activated carbon, zeolite, calcium carbonate) reduce contaminant leaching, while the sediment itself acts as a physical barrier and stabilizing force. Sediment caps can also include geotextiles, liners, or the addition of material such as organic carbon, to attenuate the flux of contaminants into the overlying water.

A sediment cap serves multiple functions including isolation of the contaminated sediment from benthic organisms, physical stabilization of the contaminated sediment, and prevention of contaminant leaching into the water column.

- Physical isolation of the contaminated sediment sufficient to reduce exposure due to direct contact and to reduce the ability of burrowing organisms to move contaminants to the cap surface

- Stabilization of contaminated sediment and erosion protection of sediment and the cap sufficient to reduce resuspension and the transport of contaminants into the water column

- Chemical isolation of contaminated sediment sufficient to reduce exposure from dissolved contaminants that may be transported into the water column.

- Sediment capping has been practiced in large rivers, lakes, estuaries, and coastal marine environments (Palermo et al. 1998; RETEC 2002). Capping has occurred most frequently in marine settings.

- There are six general techniques for constructing a sediment cap, but each technique can be placed in one of two categories (USACE 1991b):

Point dump methods include pipeline placement, hopper placement, and barge placement. All of these techniques entail releasing a large quantity of capping sediment near the water's surface. These techniques are economical and produce a well compacted cap.

Pump down techniques entail creating a sediment slurry and delivering it through a pipe to the surface of the contaminated sediment. Pump down methods include submerged diffusion, sand spreader placement, and gravity-fed downpiping (tremie).

- Tremie equipment consists of a large diameter vertical pipe through which capping material is gravity fed. This technique is similar to point dump techniques in that the velocity of the capping material is not controlled. Consequently, benthic displacement by capping material may become an issue (USACE 1991a).

- Submerged diffusion and sand spreader placement both control the capping material velocity through the use of pumps and diffusion techniques. These methods are characterized by a high degree of placement control and minimal displacement of the contaminated benthos (USACE 1991b).

HPA authority over capping is limited by the WAC. For instance, certain remedial actions conducted under a court order or performed by the Washington State Department of Ecology are exempt from the procedural requirements of the Hydraulic Code but must comply with the substantive provisions of the Hydraulic Code.

4.4.5.4 Channel Creation and Alignment

A primary purpose of channel creation and alignment activities is to relocate the alignment of a waterway away from an eroding bank. Relocation may be used where a significant building or road is directly threatened by erosion. Channel relocation is often a means to solve problems of channel encroachment and/or confinement, and to foster the development of a new, static channel with healthy riparian buffers. A channel can be entirely relocated to a new alignment, or just moved laterally within the existing alignment. Channel relocation permanently changes the location of the channel while preserving or recreating other characteristics, such as the overall channel profile, pattern, cross-section, and bed elevation. Channel relocation is a major undertaking involving the reconstruction of the channel bed, habitat features, channel banks, and floodplain. Channel creation and alignment conducted primarily for purposes of habitat restoration are discussed briefly as "in-channel and off-channel habitat modifications" under Habitat Modifications.

Channel creation and alignment occur primarily in riverine environments but may also include the creation of tidal channels in estuarine environments.

4.4.6 Water Crossings

Two closely-related analyses of "water crossings" and of "fish passage" were conducted in this series of white papers. The distinction has to do with the purpose of installing a particular structure.

Water crossings are defined by WDFW as "structures constructed to facilitate the movement of people, animals, or materials across water from bank to bank. These structures include bridges, culverts, fords, cable cars, tunnels, conduits (regardless of what the conduit is conducting), etc." Water crossings in the form of bridges, culverts, or conduits collectively represent 93 percent of all water crossing HPAs issued by WDFW between 1998 and 2006. Water crossings in the form of fords, cable cars (which would have effects similar to conduits that cross above waterbodies), and tunnels usable by humans (which would have effects similar to conduits placed in a tunnel) are not discussed separately.

- A **culvert** is used for conveying water through a fill. Fish passage aspects of culverts are discussed separately in the Fish Passage activity.

- A **bridge** is used for conveying goods or materials from one side of a water body to another.

- A **conduit** is used for conveying goods or materials. Examples of conduits authorized under HPAs include sewer lines, pipelines, and cables trenched or tunneled across streams and comparable structures trenched, tunneled, or laid on the bottom in marine waters. Conduits can also be attached to bridges, but there are no significant ESA-related risks associated with such installations, and conduit crossings attached to bridge structures do not require HPAs (WAC 220-110-100). Conduit approaches to bridges likely require HPAs.

4.4.7 Fish Passage

Two closely-related analyses of "water crossings" and of "fish passage" were conducted in this series of white papers. The distinction has to do with the purpose of installing a particular structure.

Fish passage structures are built to facilitate the passage of fish through or around a barrier. They are intended to restore upstream and downstream fish access to habitats that have become isolated by human activities (e.g., placement of culverts, dams, and other artificial obstructions). Fish passage facilities can be mitigation measures for adverse effects associated with flow control structures.

The baseline condition for assessing the effects of the fish passage facilities is the predeveloped state of the ecosystem (i.e., the natural stream channel with no dam, road crossing, or barrier), rather than comparison to the existing baseline (i.e., the ecosystem as modified by some anthropogenic passage barrier).

Current WDWF policy does not allow for the creation of passage around natural barriers, but some of the literature reviewed may include the effects of passage around natural obstructions (e.g., waterfalls, and changes in channel configuration imposed by landslides).

Five fish passage related subactivity types are currently recognized:

- A **culvert** is used for conveying waters of the state through fill. The “fish passage” discussion of the effects of culverts analyzes the effects of culvert removal, replacement, or retrofitting specifically for fish passage. Culverts that are meant to convey water and not fish are considered Water Crossings.

- **Fish ladders and fishways** are artificial structures that are used to provide passage through, over, and/or around artificial barriers (e.g., culverts, flumes, and/or dams). The artificial barriers themselves are discussed under Flow Control Structures.

- A **weir** is a low dam, usually with water flowing over the top. They can partially or fully span the channel. This discussion covers weirs used to prevent, facilitate, or manage the passage of fish, and includes weir-type fishways. Weirs for purposes of flow control and water diversion are discussed under Flow Control Structures.

- **Roughened channels** are intentional changes in channel configuration designed to facilitate the passage of adult and juvenile fish.

- **Trap-and-haul** operations involve three steps: (1) the capture of fish within some type of permanent structure, such as a weir or dam with an integrated trap structure, or using a temporarily placed trap device (e.g., a screw trap for capturing smolts); (2) the transport of the fish in a truck or barge to an upstream or downstream release point; and (3) release into the aquatic environment.

4.4.7.1 Culverts

To improve fish passage, culverts may be removed, replaced, or retrofitted. The distinctions between removal, replacement and retrofitting are:

- Removal – Complete removal of a culvert in conjunction with decommissioning of the roadway or flow control structure, or replacement of the culvert with a bridge.

- Replacement – Replacement of a culvert with a design that accommodates fish passage, using one of the approaches described below.

- Retrofit – Modification of an existing culvert with baffles, internal weirs, or similar structural elements to enhance fish passage.

Current WDFW guidance focuses on three culvert design options (Bates et al. 2003): the no-slope option, the hydraulic design option, and the stream-simulation option. The stream-simulation and no-slope options have emerged as the agency’s preferred approaches for providing fish passage for most new culverts and culvert replacement projects. The hydraulic design option is not favored for removal and replacement but is applicable where an existing culvert is being retrofitted to improve fish passage. WAC 220-110-070 currently recognizes only the no-slope and the hydraulic design options.

4.4.7.1.1 No-Slope Option

The no-slope design option is employed in low-gradient channel environments, which allows for the culvert barrel or box to be placed at a zero slope. No-slope designs incorporate culverts of sufficient dimensions to support the accumulation of bedload within the structure at a natural channel slope, allowing the channel to maintain some degree of natural function. In ideal circumstances, channel morphological features such as gravel bars and a thalweg will form inside the culvert.

The no-slope option can be applied only to culvert replacements and new culvert installations; it is not applicable in retrofit scenarios. It is expected to provide unhindered passage for a broad range of aquatic species and life-history stages, provided that design objectives are met. Specifically, fish passage is expected to be provided when the culvert supports accumulation consistent with the natural upstream and downstream channel gradient, promoting the formation of natural channel features within the structure.

A no-slope culvert has the following characteristics:

- The culvert width is equal to or greater than the average channel bed width at the dimension where the culvert meets the streambed.
- The culvert is set at a flat gradient (i.e., zero slope).
- The downstream invert[3] is countersunk below the channel bed by a minimum of 20 percent of the culvert diameter or rise.
- The upstream invert is countersunk by a maximum of 40 percent of the culvert diameter or rise.
- There is adequate flood capacity.

The no-slope design option is usually applicable in the following situations:

- New and replacement culvert installations in low-complexity settings
- Low to moderate natural channel gradient (generally <3 percent slope)
- Site conditions that permit culvert width of at least 1.25 times the natural channel width upstream of the structure
- Shorter length culverts

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[3] A culvert "invert" is the bottom of the culvert. (Bob Barnard, personal communication December 8, 2008)

- Complex passage requirements for a range of species and life histories
- The likelihood of upstream headcutting can be avoided.

The upper limit for application of the no-slope option is at sites where the product of the channel slope and the culvert length does not exceed 20 percent of the culvert diameter or rise. The method can be applied with a certain degree of flexibility around these limits, provided the necessary hydraulic engineering expertise is available to account for the implications of constricting the upstream end of the culvert with the accreted bed or by installing a larger culvert. A typical no-slope option culvert configuration is shown in Figure 4-3.

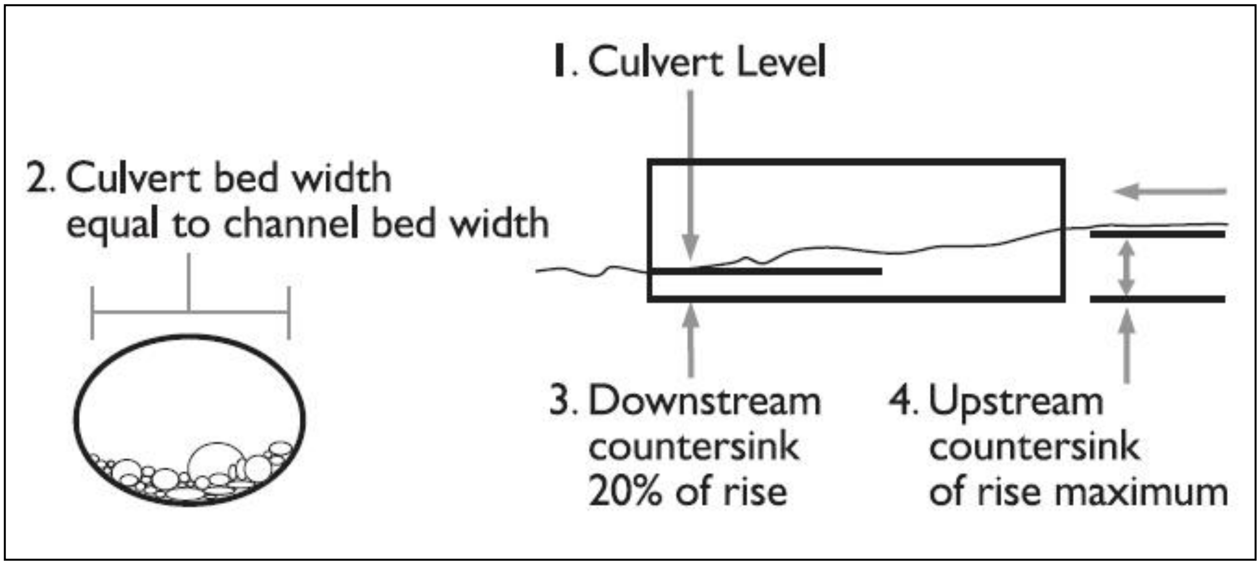


Figure 4-3. Profile and cross section for a typical no-slope culvert design (source: Bates et al. 2003).

4.4.7.1.2 Hydraulic Design Option

The hydraulic design option is used to design a culvert structure based on the swimming abilities of specific target fish species and age classes. The hydraulic design option can be applied to retrofits of existing culverts as well as to the design of new or replacement culverts, although the latter case is increasingly rare. Hydraulic design option culverts may employ features such as baffles, internal weirs, or other features that create the roughness necessary to promote fish passage.

Generally, the hydraulic design option may be employed in the following situations:

- New, replacement, and retrofit culvert installations
- Low to moderate culvert slope without baffles
- Moderate culvert slope with baffles (as retrofit)
- Target species have been identified for passage.

This design option requires a high degree of expertise in hydraulic engineering and hydrologic and geomorphic modeling capabilities, thorough understanding of the swimming performance and biological requirements of the target species, and site-specific survey information. Historically, this method was the standard approach used to design culverts for fish passage. It has become less favored, however, because of uncertainty related to fish passage performance, a limited range of applicable settings, and a number of ecological limitations. Specifically, the passage requirements of many target species are poorly understood, which contributes to design uncertainty. Even when the passage requirements of target species are adequately addressed, the structure may fail to provide passage for nontarget species. This may lead to a range of unforeseen ecological consequences. Finally, this type of structure may not provide adequate transport of sediment and organic material, contributing to broader effects on ecosystem function and declining performance over time.

Because of these limitations, the hydraulic design option is most commonly used for temporary retrofits of existing barrier culverts in circumstances where replacement or removal is not practicable in the immediate future. A typical hydraulic design option culvert schematic is shown in Figure 4-4.

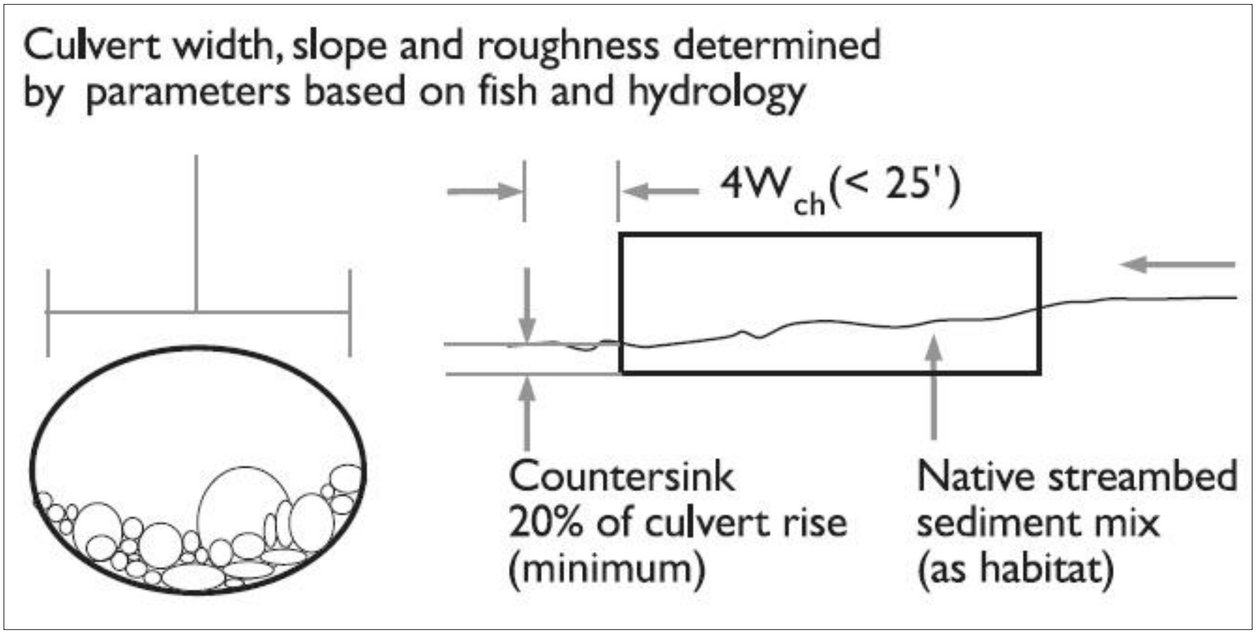


Figure 4-4. Profile and cross section for a typical hydraulic design option culvert, employing native sediment materials (source Bates et al. 2003).

4.4.7.1.3 Stream-Simulation Option

The stream-simulation option is similar to the no-slope option in that it attempts to mimic the natural streambed form to the greatest extent possible. Unlike the no-slope option, however, the culvert is installed at a slope matching or near the upstream channel gradient. This allows bed simulation to be employed over a broader range of gradients. The structure is placed at or near the natural channel slope and incorporates natural substrate features that mimic the streambed, provide for fish passage, and are transparent to the transport of sediment, wood, and organic debris.

Generally, the stream-simulation option is an appropriate method in the following circumstances (Bates et al. 2003):

- New and replacement-culvert installations.
- Complex settings, including sites with moderate to high natural channel gradient, sites requiring long culverts, or narrow stream valleys.
- Locations where passage is required for a broad range of aquatic species.
- Systems where passage must be provided for species with poorly understood requirements.
- Ecological connectivity (i.e., transparency to downstream transport of wood, sediment, and organic material) is required.

Culverts designed to simulate streambeds are sized wider than the channel width, and the bed inside the culvert is sloped at a similar or greater gradient than the upstream channel stream reach (i.e., no more than 125 percent of the upstream gradient). This type of culvert is filled with substrate material that emulates the natural channel, erodes and deforms similar to the natural channel, and is unlikely to change grade unless specifically designed to do so. This design method is intended to allow for minor adjustments in response to changes in upstream and downstream channel dynamics. The most basic stream simulation culvert is a bottomless culvert placed over a natural streambed. More complex designs may involve substrate intermixed with immobile bedform elements (e.g., boulders) to maintain bed conditions within the structure. Typical low-gradient and high-gradient stream-simulation schematics are shown in Figures 4-5 and 4-6.

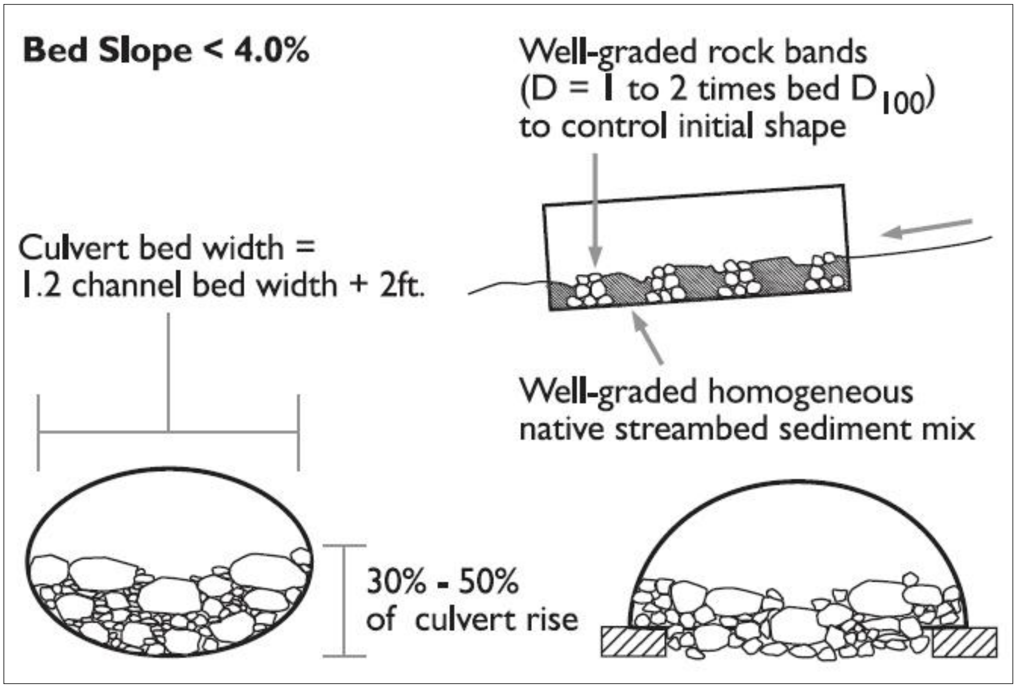


Figure 4-5. Profile and cross sections for typical stream simulation option culverts for low to moderate gradient settings (less than 4 percent slope) (source: Bates et al. 2003).

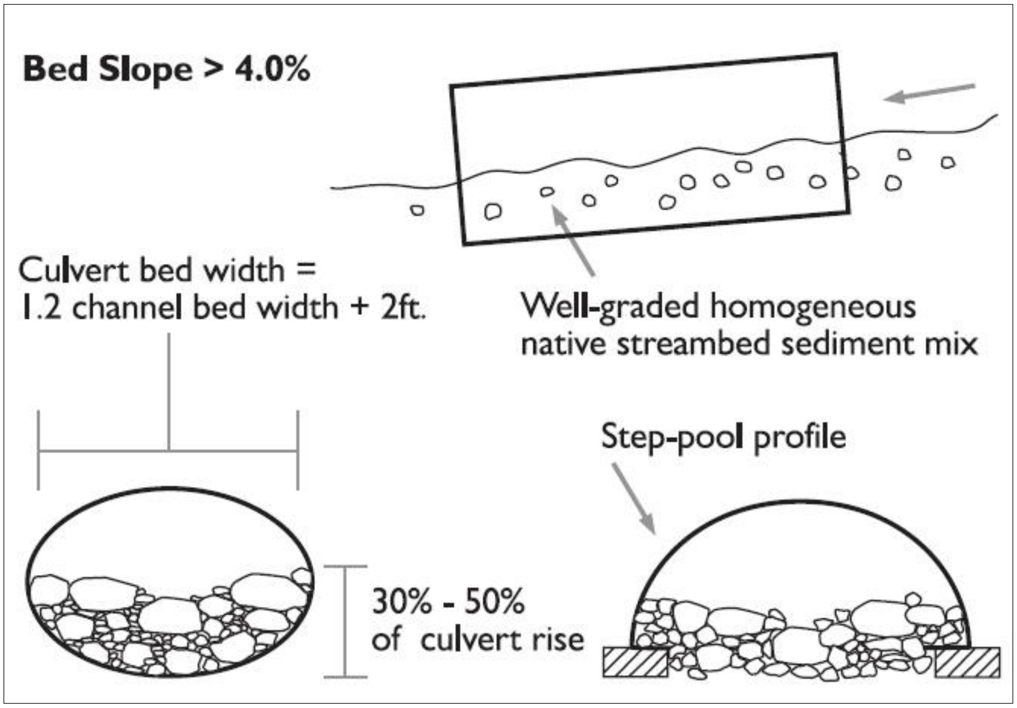


Figure 4-6. Profile and cross sections for typical stream simulation option culverts for higher gradient settings (greater than 4 percent slope) (source: Bates et al. 2003).

4.4.7.1.4 Gated Culverts

Gated culverts are culverts with a flap gate on one end that prevents the backflow of water through a channel modification, such as a dike or a levee. They are used to prevent landward inundation caused by high streamflows or tidal fluctuations, and are often employed in agricultural settings to aid in the draining and conversion of floodplains for human uses. Culverts of this type in tidally influenced environments are referred to as tide gates, which can affect both riverine and marine (i.e., estuarine) habitat types. In riverine environments, gated culverts are referred to as flap or flood gated culverts.

A gated culvert system is considered to be a flow control structure and is also discussed under that heading. New tide gates and flap gated culverts can be designed to allow for some degree of fish passage, and existing structures can be retrofitted for this purpose. For example, self-regulating tide gates (SRTs) include a flap gate fitted with a float system that allows the gate to remain open to backflow for specified periods, thereby providing improved fish passage in exchange for permitting some inundation of upstream lands.

4.4.7.2 Fish Ladders and Fishways

Fish ladders and fishways are artificial structures that are used to provide passage through, over, and/or around artificial barriers (e.g., culverts, flumes, and/or dams) or natural barriers (e.g., waterfalls) (although current WDWF policy does not allow for the creation of passage around natural barriers). Typically, fishways incorporate a sloping channel partitioned by internal weirs, baffles, or vanes with openings for fish to swim through. The sloping channels are designed to flatten hydraulic gradients and velocities to create conditions that target fish species can successfully navigate (Katopodis 1992). Examples of fishway designs include vertical slot, baffled, and weir type structures.

4.4.7.2.1 Vertical Slot Fishways

Vertical slot fishways incorporate a sloping channel partitioned by baffles spaced at regular intervals throughout the structure with passage through a vertical slot between the baffles. The hydraulic shadows behind the baffles provide refuge areas where organisms can rest before attempting to navigate the high-velocity flows in the slots between the baffles. A schematic of a typical vertical slot fishway design is shown in Figure 4-7.

A key advantage of this type of design is the ability to function over large variations in water levels. The design presents a number of disadvantages. This type of structure is limited to applications having slopes of 10 percent or less. The design also tends to produce uniform internal velocities between the baffles that may limit the passage of smaller or juvenile fish species. Finally, this design is also prone to sediment and debris accumulation, requiring routine maintenance.

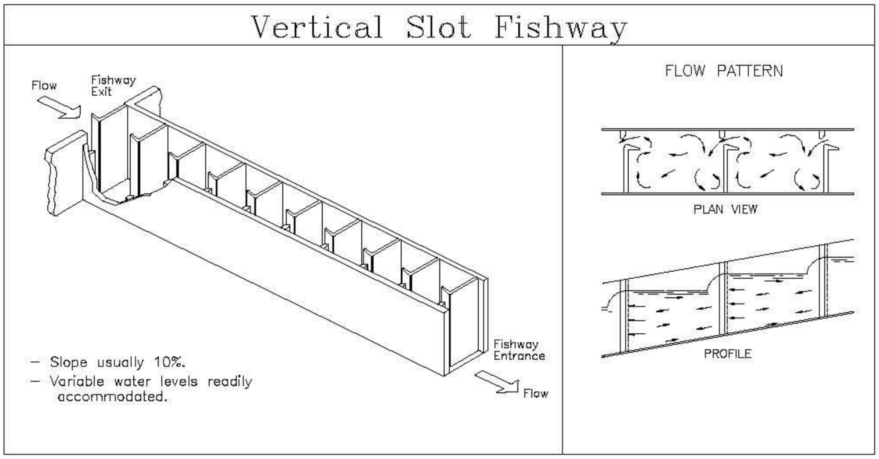


Figure 4-7. Typical vertical slot fishway (Source: Katopodis 1992).

4.4.7.2.2 Baffle Type Fishways

Baffle type fishways include a range of design types applied in a variety of settings. These include placement of baffles within existing culverts or other structures to address sheet flow (depth) and velocity barrier conditions, as well as structures designed to provide passage over man-made or natural vertical drop barriers. The Denil fishway is an example of the latter category. They incorporate a rectangular chute with a series of uniform, closely spaced baffles or vanes along the sides and bottom. Flow through this type of structure is turbulent with high energy dissipation, reducing the need for resting pools and similar features. A schematic of two typical baffle type fishway designs is shown in Figure 4-8.

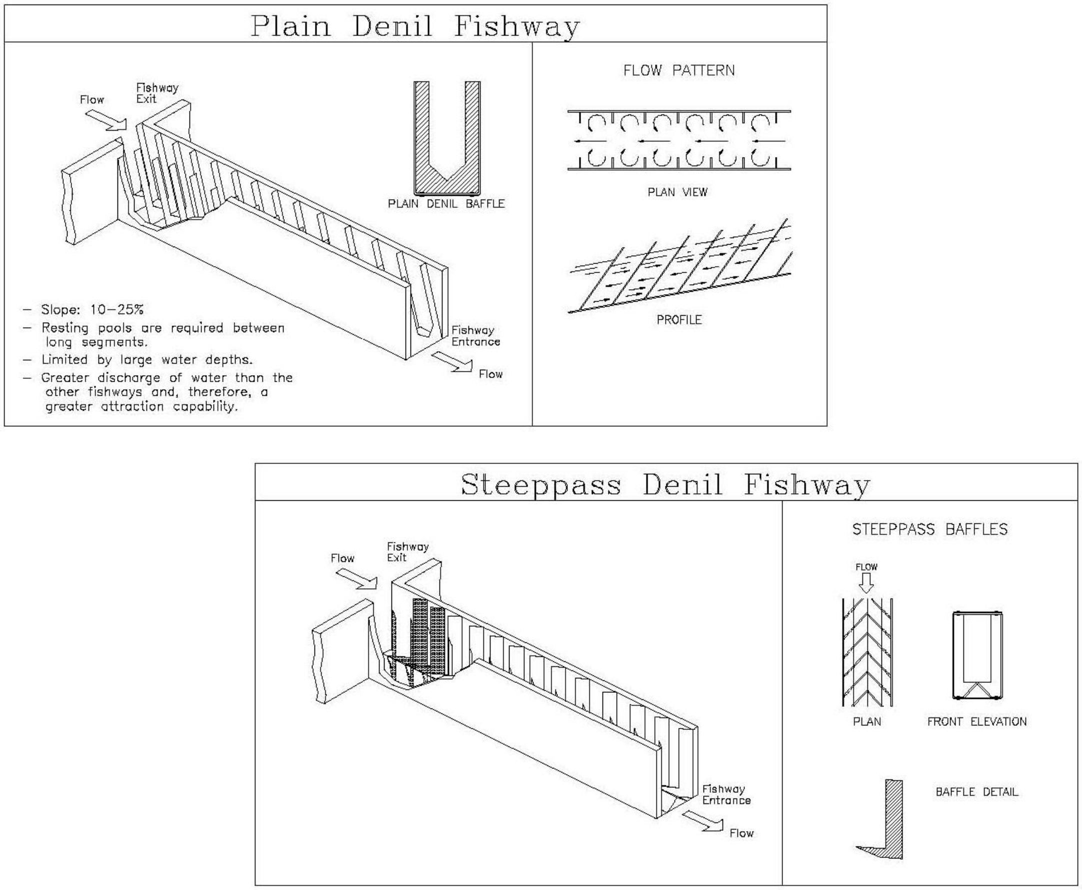


Figure 4-8. Typical baffle-type fishways (Source: Katopodis 1992).

The advantages provided by baffle type fishways vary depending on the environment in which they are employed. For example, barrier culverts are often retrofitted with baffles to create a fishway-like environment that improves passage conditions. However, this type of structure may not provide passage for the full range of species and life-history stages present under all relevant flow conditions. Moreover, retrofitted structures commonly require increased maintenance to maintain passage performance. As such, baffle retrofit projects are typically permitted only as an interim remedy until a long-term solution can be developed.

Alaskan steep pass fishways and similar designs are typically implemented in environments where artificial barriers such as dams and weirs present a vertical barrier to fish passage. This type of fishway can provide passage at gradients of up to 20 percent. Because they don’t require resting pools, these compact designs can be implemented in settings where space is limited. The relatively high flow capacity provides good attraction flows and creates turbulent conditions inside the structures that discourage sediment accumulation.

A key disadvantage of Alaskan steep pass and similar baffle type fishways is that they may not provide passage for a broad range of species and life-history stages. Because these structures create high flow velocities and turbulence, fish using them must swim constantly. This may hinder passage of smaller or juvenile fish with weaker swimming performance. This shortcoming may be overcome by the inclusion of resting pools, but these features would negate the advantages of compact size and low maintenance. Baffles and vanes commonly employed in this type of structure are also prone to sediment debris accumulation that can interfere with passage performance. In some cases, baffles can accumulate large debris that can overload and damage the structure. This leads to maintenance requirements and structural failure risk that negate to some degree the general benefit of limited coarse sediment accumulation.

4.4.7.2.3 Weir Type Fishways

Weir type fishways consist of a rectangular chute with weir-separated pools of uniform length arranged in a stepped pattern. This creates a long, sloping channel that gradually steps down the water level. This is the oldest type of fish ladder design. A schematic of a typical weir type fishway design is shown in Figure 4-9.

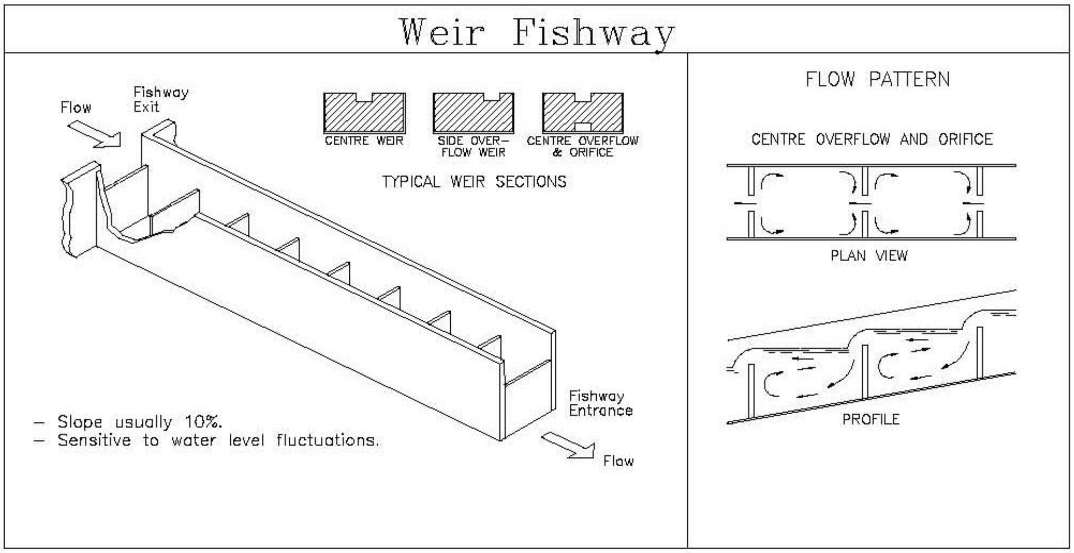


Figure 4-9. Typical weir-type fishway (Source: Katopodis 1992).

A weir type design requires fish to leap over the weir separating each step pool in the structure. However, an advantage of this type of structure is that the weirs can be configured with multiple notches and orifices to provide passage for fish of different sizes and life-history stages. The pools between weirs provide resting areas that enhance passage.

The weir type design presents several disadvantages. This structure is limited to sites permitting design slopes no greater than 10 percent. Fishway function is sensitive to water level fluctuations, and performance varies depending on flow rates. Flow occlusion may lead to dewatering and fish stranding. The pools between the weirs are prone to sediment aggradation, meaning that maintenance requirements are more extensive than for other fishway designs. In addition, stoplogs commonly used as design elements in weir type fishways have a tendency to become dislodged, requiring adjustment or replacement.

4.4.7.3 Roughened Channels

Roughened channels are specifically designed to facilitate the passage of adult and juvenile fish. They may be used to provide passage around abrupt hydraulic drops (i.e., falls or cascades) or uniform channels with high-velocity flows lacking refuge areas. The roughened channel typically moderates gradient and provides sufficient hydraulic complexity to allow for fish to pass the obstruction. Roughened channels have been seen as a more aesthetically pleasing and "natural" way to pass fish around a barrier than fishways, particularly in areas where land adjacent to a barrier is available and inexpensive. Generally speaking, the channel bottom is comprised of naturally occurring or processed quarry rock that is rounded and of sufficient size to ensure stability of the channel. Sometimes designers of these channels impose channel structure by designing the channel with a series of small steps or meanders, although this is not always the case.

Roughened channels can be broken into two broad categories:

- Roughened channels that exploit an existing channel or side channel.

  Advantages: Can utilize existing streamflow without diversion.

  Disadvantages: Large impact on existing ecologic communities.

- Roughened channels that are constructed through an upland area where no channel existed before.

  Advantages: Limited or nonexistent impacts on existing ecology.

  Disadvantages: More difficult to design; more prone to hydraulic and geomorphic effects that may lead to decreasing function over time.

Roughened channels are currently in the experimental stage of development. While conceptually simple, the design of a roughened channel is not as straightforward as one might expect. Natural channels are the result of extended periods of geomorphic evolution. The structure within the channel (riffle-pools, step-pools) is in dynamic equilibrium with material both underlying the channel and sediment supplied from upstream. Duplicating these relationships in an engineered or other design is extremely difficult. Also, natural channels often have riparian vegetation on the immediate edges of the channel, while newly constructed roughened channels must remove some vegetation in the vicinity of the channel to construct it. This may compromise the utility of the roughened channel for aquatic species. Roughened channels, particularly those sited in upland areas, can have longitudinal slopes that are out of equilibrium with respect to water flow and sediment supply. If out of balance with these factors, channels either erode or aggrade (accumulate) sediment such that they ultimately block fish passage and have negative impacts on the geomorphic character of adjacent water bodies. In addition, the coarse sizes of rock often used in roughened channel projects can initiate unnaturally high groundwater recharge, causing subsurface flow conditions during drier periods, limiting habitat capacity, presenting the potential for stranding and mortality of aquatic organisms, and posing barriers to fish passage.

4.4.7.4 Weirs

The term "weir" applies to a number of different structure types that are intended to serve a variety of purposes. Weirs include:

- Large channel-spanning structures, typically made of concrete, such as hatchery weirs. The effects of this type of weir are addressed under Flow Control Structures.
- Weirs installed in natural channels (e.g., a series of step pools formed by grade control structures composed of natural or man-made materials) to restore channel bed profiles and enhance passage.
- Weirs used to provide passage through barrier culverts. A series of weirs may be used to provide access into the culverts isolated by outfall drops, or to backwater culverts that present velocity or depth barriers.
- Fish passage control weirs constructed of natural or man-made materials intended to prevent upstream dispersal of invasive species or of hatchery fish that might produce detrimental effects should they spawn in the wild. These structures may integrate electrical barriers to increase the selectivity of fish passage management.
- Temporary or movable weirs, such as smolt panels, fence weirs, and similar structures intended to control upstream and downstream fish migrations, or to facilitate the counting of adult fish returning to spawning grounds.

4.4.7.5 Trap and Haul

Trap-and-haul activities are specialized operations involving the capture of fish for transport around fish passage barriers such as flow control structures. Trap-and-haul activities involving adult fish are often conducted at a dam, weir, or similar form of flow control structure that allows for the control of attraction flows used to direct fish into capture areas. Juvenile fish may be captured at similar structures, or may be captured using equipment and techniques (e.g., beach seining, rotary screw traps) that do not have a lasting physical effect on the environment.

Most of the relatively limited number of trap-and-haul facilities operating in Washington State are associated with a dam. Examples include trap and haul of sockeye salmon around barrier dams on the Baker River (Skagit River system) and downstream barge transport of migratory salmon smolts.

In one case in Washington, trap and haul activities are conducted at the base of a natural falls. Salmon, steelhead, and native char are released annually above Sunset Falls on the Skykomish River.

4.4.8 Fish Screens

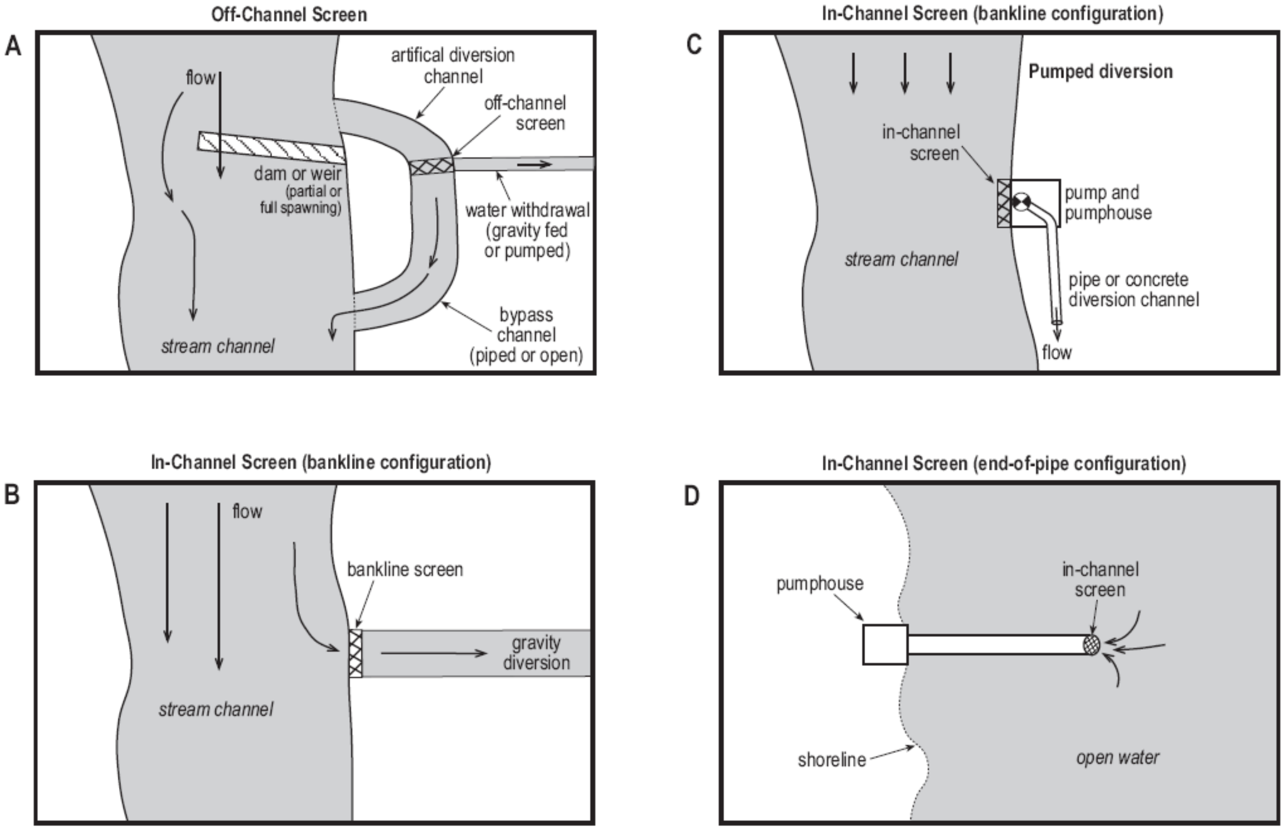
Fish screens range from small, temporary structures used on a seasonal basis to large, permanent structures associated with agricultural diversions or industrial or municipal water intakes. They are divided into in-channel screens and off-channel screens. Some screen designs can be used in either in-channel or off-channel configurations. Fish screens are continuously operating structures so long as the water intakes or diversions they are associated with are withdrawing water.

Summary descriptions of these types of screen designs are based on information in the most recent design guidance from WDFW and NMFS (NMFS 2004; WDFW 2001a).

In-channel screens are used as permanent, seasonal, and temporary screens in rivers, lakes, reservoirs, estuaries, and marine waters. These include “end-of-pipe” style screen systems and bankline screen designs.

Off-channel screens include both temporary and permanent screen systems located off of the main stream channel, adjacent to or downstream of the flow control structure providing the diversion, within artificially constructed irrigation canals or similar off-channel diversions.

Typical configurations for these two subactivity types are shown in Figure 4-10.



In riverine environments, fish screens are employed on both gravity-fed (A & B) and pumped (C) diversion systems. In marine environments, intake systems are commonly constructed on the shore and pipelines extend out into the open water (D). In lacustrine environments, several configurations are possible including those shown in C and D, with type D being favored in most circumstances.

Figure 4-10. Typical in-channel and off-channel screen configurations.

4.4.9.1 In-Channel Screens

In-channel screens are used in various environments, ranging from small lakes and streams to off-shore marine, riverine, or lacustrine environments. In-channel screens operate effectively only when fully submerged and intake flow is distributed over the entire surface, meaning that debris accumulation or partial exposure will reduce screen effectiveness. In smaller streams, lack of water depth necessary to fully submerge the screen and the intake system may also limit the effectiveness of the screen.

In-channel screens include both end-of-pipe configurations and bankline screens.

4.4.8.1.1 End-of-pipe Configurations

End-of-pipe screens, also referred to a pump screens or intake screens, are placed at the mouth of an intake pipe or outfall outlet to prevent the movement or entrainment of fish into or out of the intake or outfall.

End-of-pipe structures do not have a flow control device between the screen and the source body. The scale of end-of-pipe screens varies widely. On the small end of the scale, end-of-pipe structures can include small, relatively simple structures on temporary diversion pumps used for small water withdrawals, such as wire mesh screens on small temporary or permanent intake pipes for private water systems. On the large end of the scale, end-of-pipe structures can include elaborate screen systems on large water diversion structures such as hydropower penstocks; industrial, municipal or agricultural water intakes, or spillway outlets. Many different screen configurations are commercially available that are consistent with current screen guidance (WDFW 2000, 2001a).

Regardless of the nature of the screened structure, the predominant in-channel end-of-pipe screen is a barrier composed of an intake covered by perforated metal, wire, mesh, or some other permeable material. The designs are typically intended to limit organism entrainment and to diffuse the intake flow velocity to reduce the potential for impingement. However, in certain cases, screens that incorporate sharp metal grids, grinders, or similar features that are purposefully designed to entrain and kill fish or other organisms may be employed in the outlet structures of flow-controlled lakes or reservoirs to prevent the downstream dispersal of undesirable exotic species.

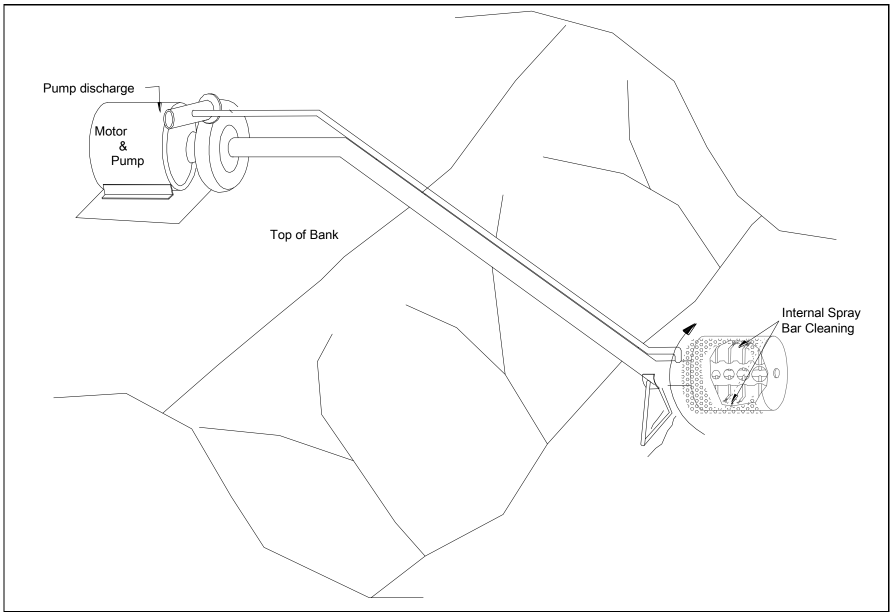
End-of-pipe screens are typically built in a chamber configuration, typically in a box or cylindrical shape, and attached to the end of a pipe. Smaller designs range in capacity from less than 1 cubic foot per second (cfs) intake capacity for small irrigation pumps, to larger designs for intakes with a capacity of 50 cfs or greater. Screen configurations vary depending on the application, with fixed drum and tee-screen designs being common. Removable pump screens associated with temporary diversion systems also fall into this category. Some models for small screens (up to 5 cfs) have extremely efficient water jet clearing systems. Small end-of-pipe screens are commonly used in conjunction with temporary diversion pumps. This type of system is in widespread use in Washington State.

Industrial or municipal water intake systems and power plant cooling water intakes commonly employ large end-of-pipe style screen systems. This type of system is used in association with high-capacity intake systems. They commonly incorporate an air-burst or water jet debris-clearing mechanism. Large end-of-pipe style screens are typically integrated into the mouth of the intake structure. This type of screen system is commonly used in lacustrine and marine environments. In these settings, the intake and screen system are usually located in deeper water away from nearshore areas used by sensitive organisms.

The advantages provided by end-of-pipe screens are that they are functional for both deep and shallow water intake systems. The disadvantages are primarily associated with the clearing of debris. End-of-pipe screens require sufficient ambient water velocity to carry debris away from the screen. Air burst clearing systems, the most common system used with in-channel screens, may not adequately remove debris accumulations, especially from the bottom of the screen. For HCP species, this is only problematic when debris accumulation decreases intake diffusion to the point that risk of impingement results. Otherwise, debris accumulation is a problem only for the water user.

Example schematics of end-of-pipe fish screens are shown in Figure 4-11.

a) Self-cleaning system, internal spray bar



b) Passive debris clearing system, T-screen

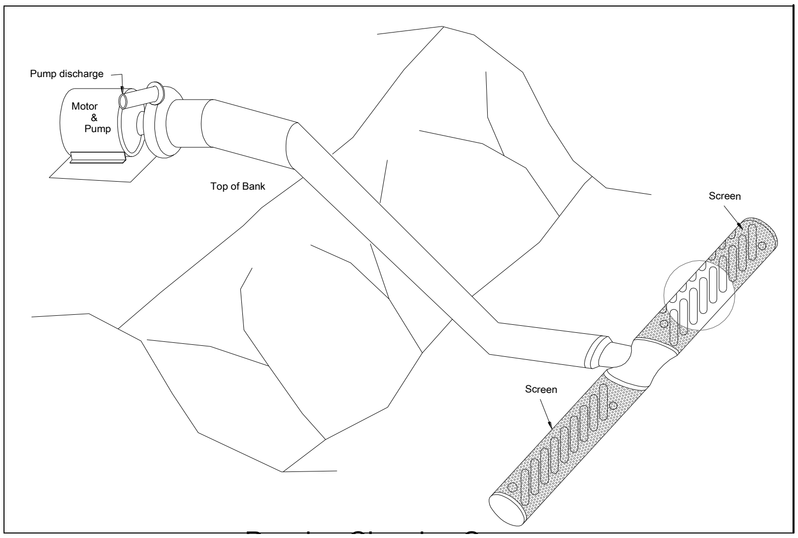


Figure 4-11. Typical end-of-pipe style fish screens with (a) self-cleaning and (b) passive debris clearing systems.

4.4.8.1.2 Bankline Configurations

Bankline screens are fixed or moving belt and panel type screen designs installed flush with the stream bank, providing a barrier between the diversion canal or gallery and the aquatic environment. Bankline screens differ from off-channel screens in that they lie between the source body and the diversion, without an intervening flow control structure such as a dam, weir, or artificial diversion channel.

Because of its location in the channel, construction and maintenance of this type of screen structure imposes a greater range of effects on the aquatic environment than a comparable off-channel screen system.

Screen designs used in bankline configurations include fixed and traveling screens, which can be installed in either a vertical or an inclined position. Fixed screens used in bankline configurations, whether installed vertically or inclined, typically have an air or water cleaning system on the back side of the screen to protect from in-stream debris. (Patrick Schille, WDFW, personal communication, March 2009). Examples of different types of fixed and traveling screens are discussed in more detail under off-channel screens in the following section.

Bankline screen systems do not always require an associated bypass channel. However, in certain circumstances, particularly when bankline screens are placed in sheltered embayments off the main channel, successful fish exclusion may require incorporation of pumped bypass systems. Sheltered embayments lack the necessary head loss to drive flow through a bypass, even if it is provided. In such cases, fish have no guidance away from the face of the screen, can become trapped within the screen chamber, and must be pumped or lifted into bypass systems and returned to the aquatic environment. However, bypass systems are more commonly associated with off-channel screen designs.

4.4.8.2 Off-Channel Screens

Off-channel screens are constructed in artificial diversions off the main stream channel. They are usually, but not always, integrated into or directly associated with a flow control structure such as a dam or a weir. They include an artificial bypass system, either a channel or a pipe, designed to return aquatic organisms and debris back to the main channel. These bypass systems must provide adequate sweeping flows to draw organisms safely past the screen, into the bypass and then discharge them safely downstream. Bypass systems must also pass debris without jamming.

In Washington State, the most common screen designs used in off-channel configurations include the following (WDFW 2001a, Schille 2008):

- Rotary drum screens
- Fixed plate screens (vertical and inclined designs)
- Vertical traveling screens (panel and belt types)
- Modular screens (rotating drum or vertical fixed plate).

4.4.8.2.1 Rotary Drum Screens

The rotary drum screen incorporates both screening and debris removal in a relatively simple configuration. Drum screens can be scaled to accommodate a variety of flows, and they are effective at avoiding impingement and entrainment of juvenile fish.

The rotary drum screen removes debris collected on its face through rotation, and the debris is washed off the screen on the downstream side. Screen rotation is achieved by an electric motor, paddle wheel, solar drive, or hydraulic motor. Its most common application is in open channel flow situations, such as irrigation ditches. Using single or multiple drum configurations, rotary drum screens can accommodate a range of diversion rates. In Washington State, they have been used to screen flows ranging from as low as a few cfs up to 3,000 cfs. Drum screens are typically used in conjunction with gravity diversion canals but can also be used to screen water drawn into a pumping gallery. A schematic of a typical rotary drum screen is shown in Figure 4-12.

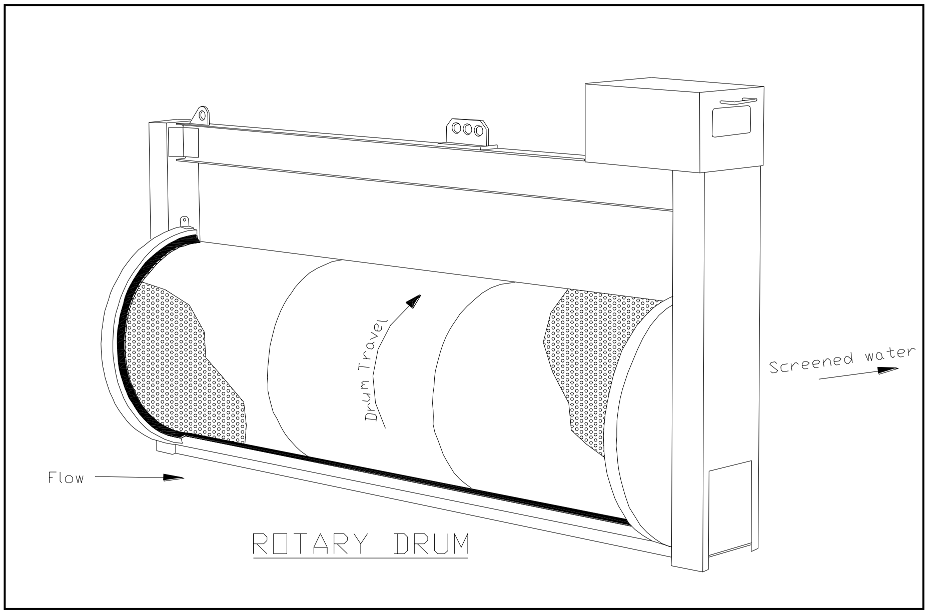


Figure 4-12. Rotary drum screen (Source: Schille 2008).

4.4.8.2.2 Fixed Plate Screens

Fixed plate screens include a variety of design types that are distinguished primarily by their orientation to flow. To suit site-specific design requirements, the screen can be oriented with a vertical, upward sloping, or downward sloping aspect relative to the direction of flow. This design is typically employed with gravity diversions, but it can also be used with pump intakes in certain configurations.

The vertical fixed plate screen, which is characterized by intake flow passing perpendicularly through a vertical screen surface, is commonly used for industrial, municipal, and agricultural water supply systems in the Pacific Northwest. This style can be used in either pump or gravity diversion intake configurations. The plate is commonly composed of punched metal or a profile bar, in either aluminum or stainless steel. Woven wire mesh is also used but is less typical, due to its tendency to accumulate debris that is difficult to clear. This design is relatively simple and tends to require less frequent maintenance because there are no moving parts or wear surfaces between the screen mesh and the structural frame. A major disadvantage to the design is that it does not passively clear accumulated debris readily. Typically, the design integrates a mechanical brush, hydraulic backspray, air burst, or some other type of debris-clearing system to overcome this limitation. A schematic of a vertical plate screen with a mechanical brush system is shown in Figure 4-13.

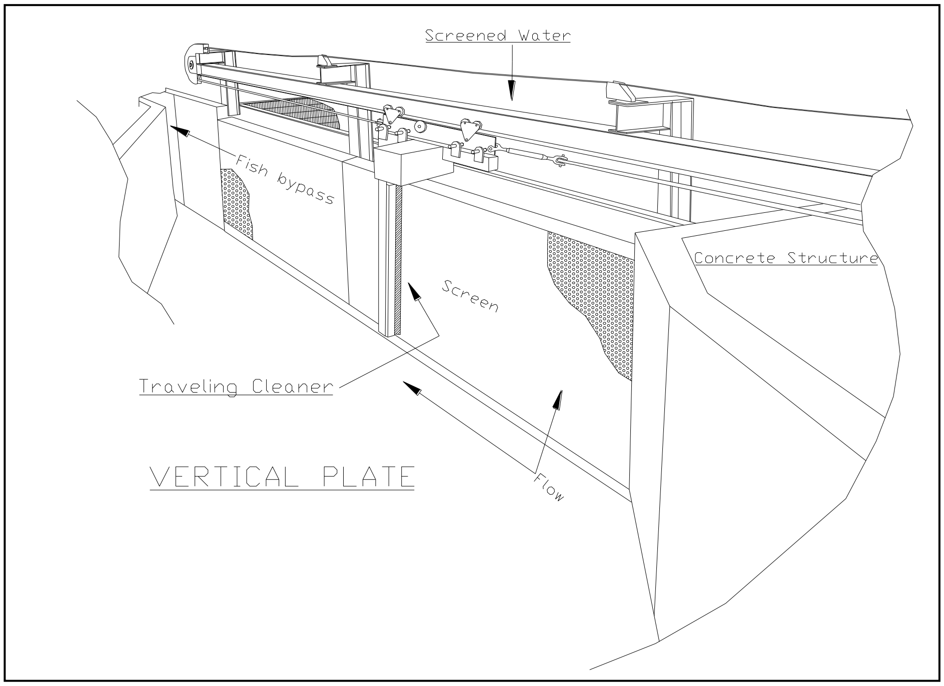


Figure 4-13. Vertical plate screen with a mechanical brush system (Source: Schille 2008).

Upward and downward sloping screens, much less commonly used, are characterized by diverted flow passing vertically through the inclined surface of the screen. They rely on large quantities of bypass flow to provide passive debris cleaning and avoid fish impingement. For this reason, they are used where the diversion rate is small, relative to total flow. Continuous streamflow across the surface of the screen sweeps fish and debris off the surface of the structure. These designs are typically used in conjunction with a gravity diversion. However, specific sloping screen designs may be paired with pumping galleries and incorporate a bypass channel to return water and fish back to the mainstem channel. Certain sloping screen designs, such as Eicher[4] screens, are used in hydropower systems to direct fish away from turbine intake systems.

Downward sloping screens can either be flat plate or contoured plate style designs (examples include the Coanda screen and the Farmers screen[5]). Water is directed from an impoundment created by a flow control structure (e.g., a small dam or weir) over the surface of the screen and into a bypass channel returning to the main channel. A portion of this flow passes through the screen and into the pump or gravity diversion. These designs are occasionally used in in-channel settings, but are most commonly used in off-channel configurations. An example schematic of a typical inclined plate screen is provided in Figure 4-14.

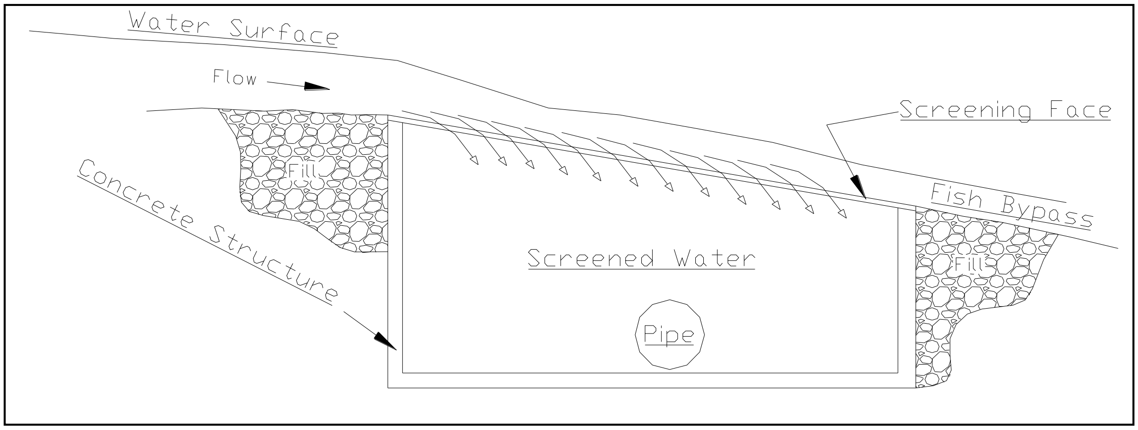


Figure 4-14. Typical inclined plate screen (Source: Schille 2008).

Upward sloping screens are quite similar in design except that their profile rises in the direction of the water flow. Excess water flowing over the top of the screen provides fish and debris bypass. Upward sloping screen designs do provide some degree of reliable passive debris clearance; however, they can become overwhelmed by large debris loads. This presents some risk of structural failure as the combined weight of water and debris may overcome the structural strength of the screen support frame. Active clearing systems are sometimes incorporated with these designs to reduce this risk.

The advantage of inclined plate screens is that there are no moving parts and they require no additional in-river diversion structures. Because this screen relies on passive hydraulics to clear debris and provide fish passage, it provides a reliability advantage over mechanical clearing systems. However, screen performance and reliability are highly dependent on precise flow control. Flow rates must be carefully balanced between the required rate of diversion and

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[4] Examples do not constitute a recommendation by the Washington Department of Fish and Wildlife.

[5] See previous footnote.

providing sufficient flow to clear debris and avoid fish impingement. Due to their sensitivity to debris and the need for consistent flow control to maintain performance, upward facing screen designs would typically not be permitted in Washington State (Schille 2008); however, the WAC does not specifically preclude their use, meaning there is some potential for such designs to be permitted in the future, and a number of legacy structures are in operation. Examples include Eicher screens integrated into hydropower dams and hatchery water system intakes. Because these structures may be maintained under existing or new HPAs, they are considered in this analysis. Inclined plate screen performance is sensitive to flow control, but they are less prone to debris accumulation and structural failure. Some newer downward facing screen designs, such as the contoured Coanda screen, are considered experimental and may be permitted in certain circumstances.

4.4.8.2.3   Vertical Traveling Screens

Vertical traveling screens are similar in concept to rotary drum screens in that the mesh of the screen cycles continuously to remove debris collecting on its face. Two design configurations are commonly used: panel-type screens, with individual mesh panels; and belt-type vertical traveling screens with a continuous mesh belt. Both types of screens are usually driven by electric motors and are commonly used in conjunction with pump diversions. A schematic of a vertical traveling screen design is shown in Figure 4-15.

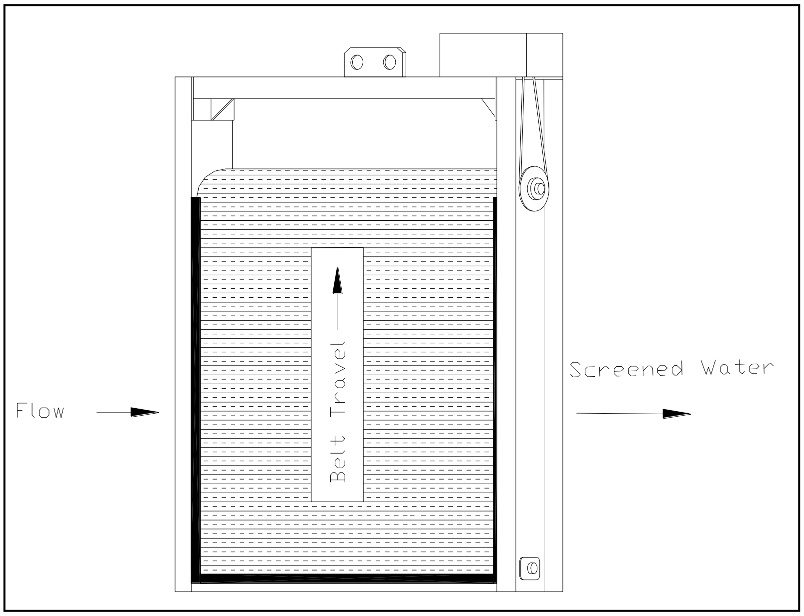


Figure 4-15.   Vertical traveling screen (Source: Schille 2008).

The primary advantage of belt screens is they can be installed in deep water. The screen can be built to any length within the structural capacity of the frame and drive shafts. This design provides effective debris clearing across a range of water depths.

Other advantages of the vertical traveling screens are that they can be installed in bankline configuration (thereby requiring no bypass system); the associated foundation and frame are relatively compact; and they are self-clearing. Additional debris-clearing capacity can be added using jet spray or brush systems if needed.

Vertical traveling screens have historically been constructed with horizontal troughs, or ledges, built onto the face of the screen. The purpose of the troughs is to lift debris and fish with the screen as it rotates. A high-pressure spray bar, near the drive shaft, washes the debris and fish into a stationary trough on the deck of the structure. The debris can then be collected for removal. However, the troughs are problematic for fish protection. Fish entangled with debris and exposed to the spray bar prior to being deposited in the troughs may be injured or killed in the process. Once in the troughs, capture and removal may be difficult, increasing risk of stress and injury. Like upward facing plate screens, this type of screen system would typically not be permitted in Washington State today. However, the WAC currently does not preclude their use, meaning future permitted structures are possible, and a small number of legacy structures are in existence that may require permitting for future maintenance.

4.4.8.2.4 Modular Screen Systems

Modular screens are a recent addition to the suite of available screen design options (Schille 2008). Developed in the early 1990s by WDFW at their Yakima Screen Shop, various forms of modular screens are currently in wide use throughout the Pacific Northwest. The modular rotating drum and modular fixed plate systems are the most common forms. Originally designed for remote sites where conventional concrete construction was not feasible, modular screens can be assembled on site and installed in 1 or 2 days. They have proven to be an effective and inexpensive means for addressing numerous small, unscreened diversions. Schematics of the modular drum screen and the modular fixed plate screen are shown in Figures 4-16 and 4-17 respectively.

The modular drum screen is designed for diversions in the 2 to 6 cfs range. This type of system is typically employed in off-channel settings using a piped bypass system to channel fish back to their habitat. They are paddle wheel driven and can be fabricated to provide an angled orientation to flow. The plate screens were developed for diversions in the ½ to 3 cfs range and are used in both in-channel (i.e., bankline) and off-channel settings. The off-channel version uses rotating brushes driven by a paddle wheel to clear debris.

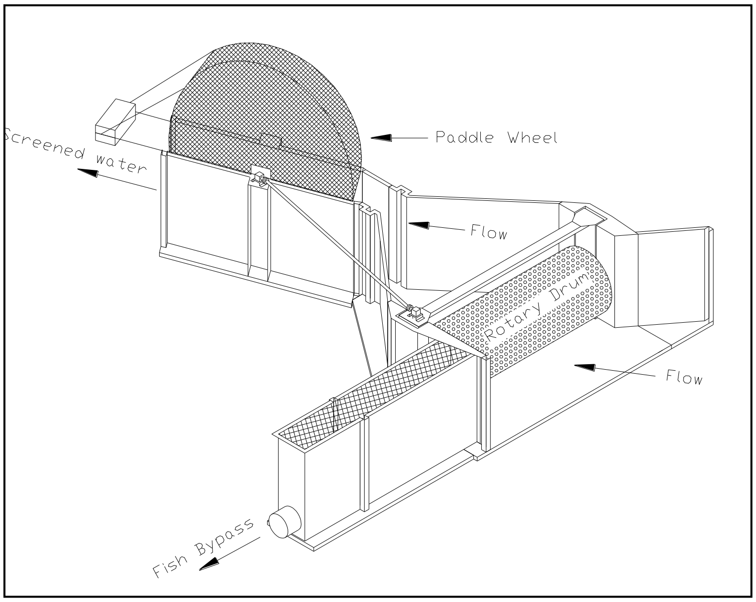


Figure 4-16. Modular drum screen (Source: Schille 2008).

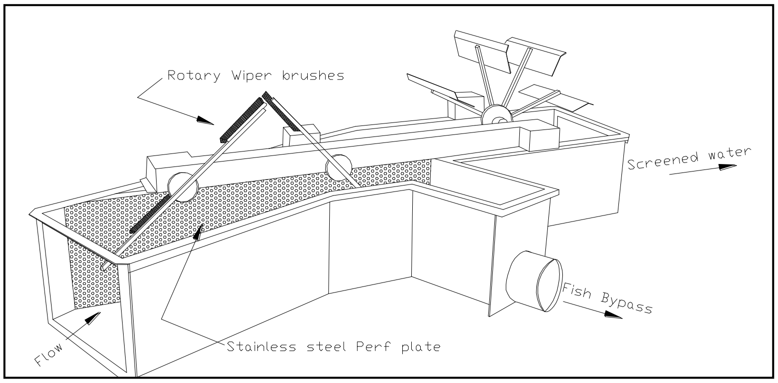


Figure 4-17. Modular fixed plate screen (Source: Schille 2008).

4.4.9

4.4.9.1 Additional Screening Systems

Other fish screen technologies are in use in Washington State that are not considered in detail. These include:

- Behavioral modification using environmental stimuli: Flashing strobe lights, underwater noise, or other forms of disturbance intended to induce avoidance of hazardous areas that are impractical to screen using traditional methods.

- Infiltration galleries: Intake pipes buried within the active channel that use the overlying alluvial bed material as a screen.

These types of screen designs represent a small proportion of the number of fish screen proposals submitted for approval under the HPA program. Behavioral modification using environmental stimuli is considered an experimental approach that is still in development. Infiltration galleries are infrequently used designs that represent a form of channel modification.

4.4.10 Flow Control Structures

Flow control structures include: dams, weirs, dikes and levees, outfalls, tide gates, and intakes and diversions.

Dams are structures built within a stream to control flow for flood control, divert flow for irrigation, or to utilize flow for generation of hydropower.

A **weir** is a low dam, usually with water flowing over the top. They are structures that can partially or fully span the channel for purposes of flow control and water diversion. Weirs are also used to prevent, facilitate, or manage the passage of fish, discussed under Fish Passage as “weir-type fishways” and as “weirs”.

Dikes and levees are built to maintain flows within a confined channel for flood control purposes, or are used to convert estuarine habitat into agricultural fields or freshwater habitat (e.g., used on WDFW lands and federal wildlife refuges to provide waterfowl habitat/hunting areas).

Outfalls move water from one place to another, typically into a body of water. They may convey irrigation water, stormwater, or other waste materials. Submerged outfalls open under water. They are most common in lakes and marine waters, often associated with municipal and industrial wastewater and stormwater discharges. Marine outfalls that emerge at intertidal elevations are also considered submerged outfalls, as they are submerged at least some of the time. Exposed outfalls open above water. They typically occur in riverine environments. Submerged and exposed outfalls are sometimes screened to prevent fish entering the outfall pipe and to prevent large debris from exiting the outfall.

Tide gates (also referred to as flood gates or gated culverts) are built to control tidal or floodwater inundation in low-lying areas. These structures are typically integrated into dikes and levees and are commonly used to drain river deltas and estuarine lowlands for conversion to agricultural or industrial uses. They allow water to drain from low-lying areas to marine or estuarine receiving waters while preventing the backflow of tidal or floodwater. In agricultural areas, tide gates prohibit salt water from entering croplands. In addition, tide gates lower the water table, pushing the anoxic layer deeper in the soil and promoting crop growth. Tide gates are commonly located at the mouths of streams or rivers where the estuary begins, or where tidal nonriverine channels drain ditches, fields, marshes, and small tributaries (Figure 4-18).

Tide gates come in many forms—from simple culverts through an earthen dike, to complex concrete structures that include deflecting walls and pilings both upstream and downstream of the structure (Figure 4-19). Associated with these structures are tide or flood boxes that restrict flow in one direction. Tide boxes can be either top-hinged or side-hinged and, depending on the type of gate, it will be open for shorter or longer times. The amount of time a gate is open is a function of the design, size, and weight of the tide box. The magnitude of tidal or floodwater fluctu

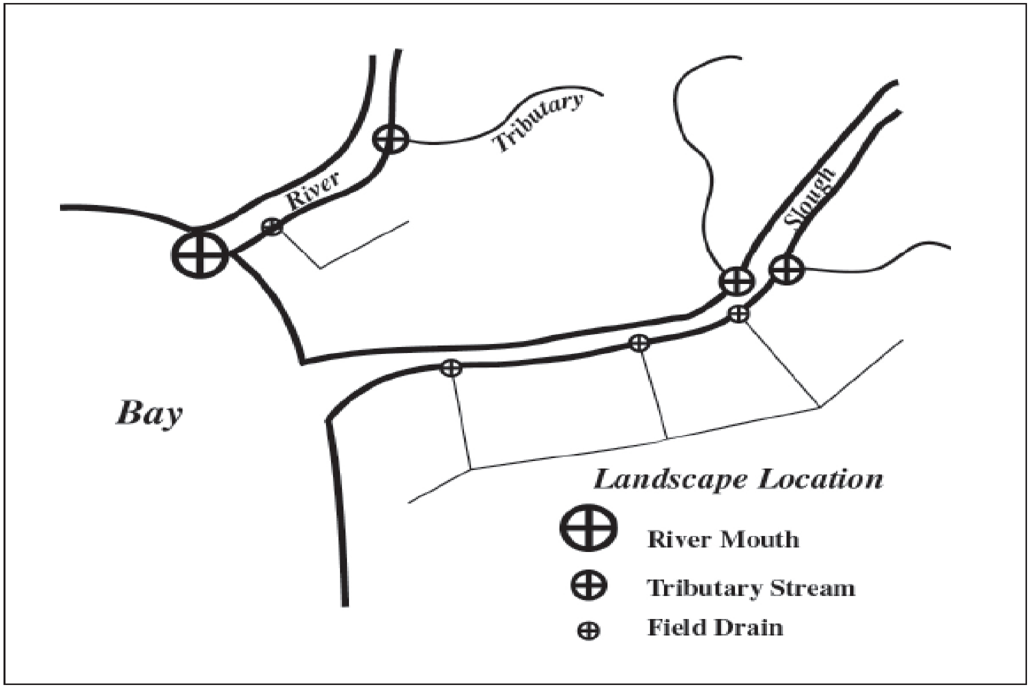


Figure 4-18. **Common tide gate locations at the mouth of estuaries, tributary streams, and tidal nonriverine channels. Adopted from Giannico and Souder 2005.**

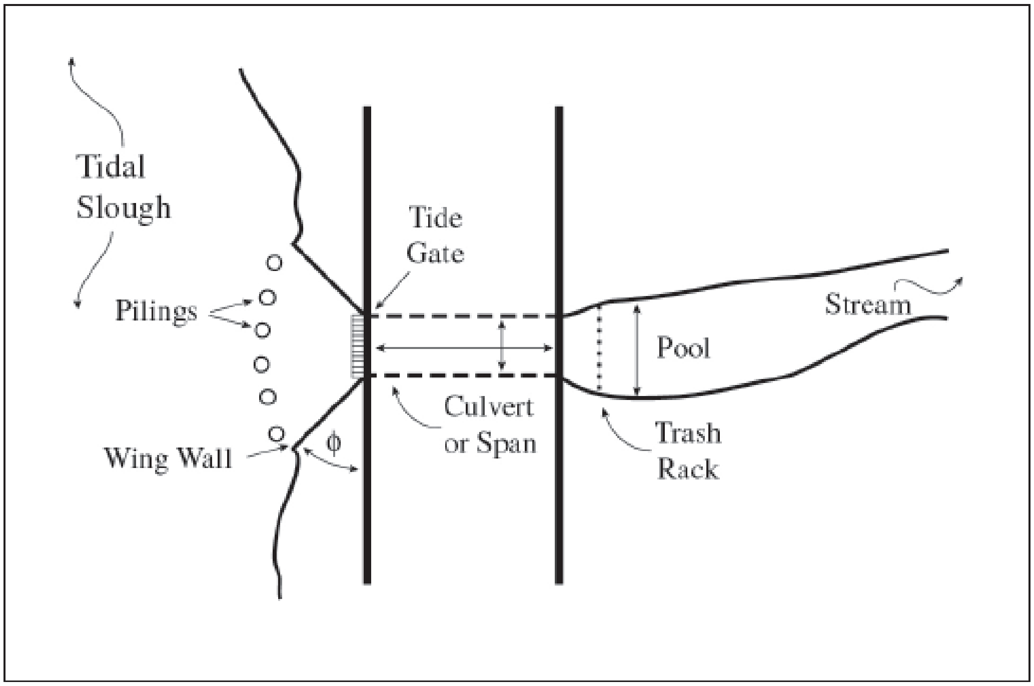


Figure 4-19. View of tide gate and supplemental features such as wing walls and pilings. Adopted from Giannico and Souder 2005.

Water intakes and diversion structures are used to divert water from a stream to another place, or to maintain water in an existing or new channel for flood control. Water diversion systems are built for a variety of reasons including, but not limited to: irrigation, domestic use, stock watering, hatcheries, power plants (hydropower, fossil fuel, and nuclear), water supply, general manufacturing, timber processing, and creation of fish habitat. Most diversion systems route water through a concrete channel and/or enclosed pipe.

Figure 4-20 illustrates general schematics of the most common forms of water diversion and intake systems. Diversion systems built in freshwater environments can either work by gravity or water pump, with gravity systems employed predominantly in riverine systems that provide the necessary head loss. For both, the diversion channel or pipe may run parallel or away from the stream channel.

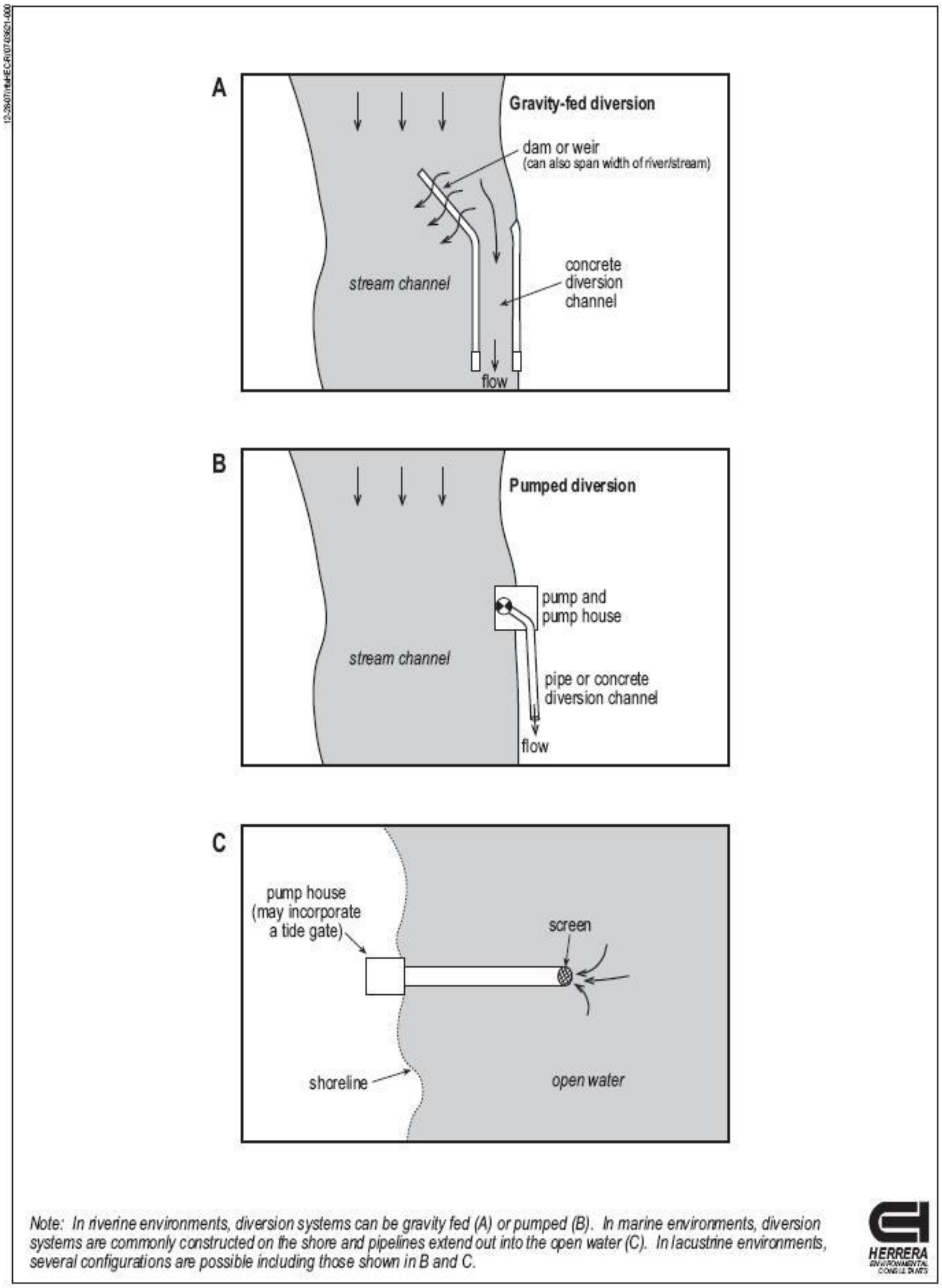
Gravity fed diversions usually include a dam or weir-like structure that partially or fully spans a river or stream channel. The flow control structure is used to create the hydraulic head necessary to divert the water out of the channel (Figure 4-20A). Construction of a gravity-fed diversion system includes the design and installation of flow control dam or weir and a diversion channel. This diversion channel is typically made of concrete but can also consist of a metal pipe. This type of diversion system typically includes a fish screen located at the downstream end of the diversion channel.

Pumped diversion systems typically take the form of a pump house and intake pipe or gallery with an associated concrete channel or a pipe used to transport the diverted water to its intended use (Figure 4-20B). This type of system is commonly located along the bank of a stream/river or lake. This type of system is used where water must be pumped up and out of the source body because the necessary hydraulic head for a gravity diversion is not available. This type of diversion system typically includes a fish screen at the pump intake.

Gravity-fed and pumped diversion systems can also be combined by having a pump station located at the end of the diversion channel. In these cases, fish screens are typically located at the pump intake.

In marine and lacustrine environments, water intake systems typically consist of an intake pipe with an associated pumping system. The intake may extend some distance into the water body while the pumping system is located onshore (Figure 4-20C). This type of intake system typically includes a fish screen located at the pipe’s mouth, although some configurations may incorporate additional internal screening mechanisms.

Intake systems fed by tidal exchange may also be employed in certain settings. This type of configuration may incorporate a tide gate on the shoreline to regulate intake flows. Construction of intake systems includes the design and installation of a pipeline and pump house and, potentially, a shoreline tide gate in marine environments. As with outfalls, the pipe associated with these diversion systems can be categorized as submerged intakes (typical in reservoirs, lakes, and marine environments), and exposed intakes (which are found in stream and river environments). Intakes are usually screened.



Note: In riverine environments, diversion systems can be gravity fed (A) or pumped (B). In marine environments, diversion systems are commonly constructed on the shore and pipelines extend out into the open water (C). In lacustrine environments, several configurations are possible including those shown in B and C.

Figure 4-20. Types of diversion systems.