Chapter One- Designing for Stream Simulation

Introduction

This manual documents the procedure for the selection and design of crossings for fish and other aquatic species on forest and county roads in Southwestern Oregon. The manual references design procedures established by state agencies in Oregon and Washington in addition to those used by the author.

In the past 20 years numerous structures were replaced or modified to improve fish passage . Using the lessons learned from those designs this manual was developed. During that time we constructed hundreds of crossings.

This manual is a working paper which will be improved and added too over the next several years. The importance of the research and procedures developed by the States of Washington and Oregon cannot be understated and provided an excellent reference to any fish passage library. The State manuals and many of their research documents are available on the Web.

References and Prototype

When we began work on fish passage structures, we tried to find good examples that worked with technical references that supported their design. Many of those references are included in the bibliography. The solutions proposed in this report for passage of fish and wildlife are not “new” but often another look at older ideas.

This manual is intended to provide guidance for designing road stream crossings. Alternatives at a crossing site can include culverts, fords, bridges, or perhaps a decision to remove the crossing all together. There is no best alternative for all sites. A hierarchy of options is presented with evaluation criteria to assist managers and designers.

Designing Culverts for Fish Passage Design Methodologies

Twenty years ago we designed culverts that provided passage of adult and large juvenile fish passage through culverts. We estimated the ability of salmon or trout to swim through a culvert or jump into a culvert from a pool below. That design methodology is now referred to as the “Hydraulic Design method.” Culverts were sized or checked for their ability to pass an adult salmonid at high flows and a six-inch trout at low flow. Culverts were often still barriers to juvenile passage.

A significant improvement was realized while working on several projects with Professor John Orsborne, we learned about placing weirs and baffles in culverts to create a series of cascading pools. We contacted several manufacturers and developed a sloping weir as a self cleaning fish way. The fishway is factory installed and arrives at the project site built into the culvert. Improvements to our original design have included removing the weir jumps, optimization of the design at the inlet and outlets, and sizing the pipes to remove inlet constrictions. This design provides passage now for both adult and juvenile fish. Passage of juveniles through culverts can be achieved to at least 13% gradients. I refer to this design methodology as the “Fishway Design method.” See Chapter Five for details.

The next significant change in our design methodology occurred as we attempted further improvements to our crossings for passage of all stream organisms. We had observed that several of our fishway structures had filled in with gravels. Biologists who monitoring these sites observed that all fish species were able to move through these structures. Maintaining sediments within the culverts also provided passage for all stream organisms in addition to fish.

We concluded that a culvert which retained a natural substrate would provide passage for all sizes and species of fish and non fish species. The objective is to trap natural substrates in a structure which simulate the adjacent stream reaches. This method of design is now called "**stream simulation**."

Objectives for selection and design of road/stream crossings.

Historically structures were selected for their ability to transport water and debris under a road at the least cost to the owners. Designs were optimized to achieve those results at the least costs. Today we develop alternatives for multiple objectives. These objectives at times seem to be at odds with each other.

1. Structures should allow for unobstructed movement of fish at the time the fish are moving. Biological variables include species of fish, life stages of fish to be impacted, and migration timing of affected species and their life stages.
2. Structures should be consistent with road system, and it's maintenance expectation:
    A. High use: Public Access Roads
        1. Designed to AASHTO standards
        2. Maintenance of Structures is expected
        3. A temporary closure is a major impact
        4. The U. S. Forest Service(USFS) and Bureau of Land Management(BLM) identify these as Level four and Level five roads.

    B. Medium Use: Public access roads:
        1. Public Use may be restricted seasonally.
        2. Roads are designed to agency or land owner standards. A county road will normally be designed to AASHTO standards for public funding.
        3. Maintenance of structures may be delayed after a major event.
        4. A temporary closure can be made but will require public involvement and potentially a detour road.
        5. The BLM and USFS identify these as Level 3 roads.

    C. Low Use: Administrative or resource level roads:
        1. Roads are designed to agency or land owner standards as a commercial access road.
        2. Public often has access to roads for recreation use but that access can be administratively closed.
        3. Maintenance of structures may be delayed indefinitely.
        4. The BLM and USFS identify these as Level 2 roads.

    D. Zero Maintenance Roads
        1. Roads are allowed to close and/or reconstructed for zero maintenance.
        2. Surfacing is pit run with grass planted for connectivity
        3. Trees and brush form a canopy over road providing overhead connectivity.
        4. Use of a road as a trail is encouraged as the desired level of recreation use.
        5. Crossings may be removed, constructed as fords, or designed with removal decks.

3. Structures should adhere to State and Federal Fish and Wildlife guidelines pertinent to the endangered species act.
    A. Structures should provide connectivity for all species both fish and wildlife.
    B. Avoid designs which are passable to only selected species
    C. Minimize disturbances to the habitat.
4. Structures should have adequate diversion potential or "storm proofing."
5. Structures should be sized for a storm event of 100 years for federal projects and Q50 for state projects.
6. Structures should be cost effective.
7. The construction of Structures should comply with all state and federal law.
    A. OSHA - Workers safety
    B. In stream guidelines for protection of fish and wildlife
    C. Water quality guidelines for sedimentation and turbidity.

Steps in Restoring Fish Passage in a Basin or Land Ownership

1. Inventory and prioritize site with barriers to the passage of fish and other species.
2. Develop alternatives for sites: Repair, replace, road closure, monitoring requirements.
3. Evaluate alternatives with all affected parties.
4. Select preferred alternative and prepare plans, specifications and contract.
5. Administration of contract: review all changes with affected parties.
6. Monitor and Maintain road /stream crossing structure

Inventory and Assessment of Culverts on Fish Bearing Streams

There does not seem to be any shortage of inventory forms and data base programs. The best today are connected to a GIS mapping system and have methods of prioritization.

1. The States of Washington and Oregon have both published manuals on assessing barriers in stream.
2. The USFS in Region 6 has a centralized inventory created and published by the "stream team "at San Dimas. There web site is noted below. They have links to the manuals developed by the State of Washington and also forms that are used with an assessment program called FISHXING.
3. The Oregon Road Stream Crossing Guide contains a sample form for evaluation of culverts as blockages.

ROAD / STREAM CROSSING DESIGN METHODOLOGIES

The following are the current methodologies used for designing culverts. The preferred method will depend on the site characteristics, alternatives considered and goals for the crossing.

1. **Traditional method**: Culverts and hydraulic structures are selected for efficiently moving water. Culverts were selected that would have high velocities and flows. The goal was to move water efficiently stressing cost effectiveness. Structures were selected that had reduced roughness, improved inlets, and layouts that minimize the effects of back-watering. These structures were successful for moving water but often created barriers to fish movement upstream. This method of designing is used today for ditch relief culverts and storm drains which do not have wildlife or fish passage concerns.

2. **" Hydraulic design" method**: Culverts are designed to allow passage for a targeted fish species and age class. The Hydraulic design option can be applied to retrofits of existing culverts as well as to the design of new culverts. Hydraulic open channel flow and hydrologic computations together with specific site data are required. " The design can be checked using the FISHXING program to verify that the minimum depth of flow and velocity occur when fish are moving. This method is described in detail in the Washington Department of Fish and Wildlife fish passage design guide.

3. **" Stream Simulation" method**s: Culverts or crossings designed for stream simulation create and maintain a a natural channel inside the pipe which simulates the adjacent stream. This method is preferred for passage of all fish and non fish species.
   - A. A stream road crossing designed for stream simulation allows unimpeded movement of all fish and wildlife in the stream. We achieve that objective by simulating the characteristics of the stream when fish and organisms are moving. Fish passage is unrestricted. The crossing has a natural substrate through its full length with shadow rocks added to create resting pools..
   - B. The preferred crossing will have a natural bottom or substrate. Fish movement occurs between rocks, gravels, and boulders, which provide reduced velocity sections. Average velocity is often checked but is not a criterion for fish passage. The channel is embedded with rock which traps gravels moving during higher flow events. The goal is to create a graveled reach withing the structure having substrate similar to adjacent reaches in the stream. Inside the culvert the gravels l re-grade into small rivulets creating sufficient depth for movement of fish and other organism.
   - C. During low flow periods the streams may totally dry up. During these events fish movement through the crossing structure will be minimal similar to adjacent reaches in the natural channel. Likewise during high flow events the water flow in the culvert may prevent fish movement as would be the case in the adjacent natural channel.

D. Stream Simulation designs include the following methods.

1. "No slope method": The Washington Dept of Fish and Wildlife (WDFW) coined this phrase for those designs where a culvert is placed flat with 20 percent of the culvert countersunk. The goal is create a sloping channel inside the culvert.
2. Embedded or buried culverts design: An approved method in Oregon. The culverts maintain a natural substrate by embedding or setting such that they will naturally embed.
3. Full Simulation ; Stream Simulation method proposed by WDFW . The culvert is designed wider than the natural channel to improve stream
4. Roughened Channels: A variation on embedded culverts allowed in Washington as an experimental option at this time. The procedure is very similar to the embedding methods approved in Oregon. The design proposes to use rock collectors for retention of substrate.
5. Roughened Chutes: The construction of steepened stream reaches to connect a reach of stream that has degraded.

4. "**Fishway Design" method**: Culverts are constructed with sloping weirs that provide fish passage for selected stream flows. This procedure requires a good knowledge of design flows when fish are moving. When used correctly culverts will have a cascade of pools from beginning to end that allow both juvenile and adult passage during the times they are moving. See Chapter Five for additional details.

Other Considerations in Selection and replacement of Structures at road crossings.

Amphibian movement and dispersal

Most existing culverts, even those designed to allow juvenile salmonid passage ***may function*** as barriers to upstream movement and dispersal of stream and riparian associated amphibians. Due to the extensive road network, culverts are abundant, and can isolate less mobile amphibian in small meta-populations. These meta-populations are vulnerable to human or natural disturbances. Barriers to movement can prevent amphibians from decolonizing these impacted habitats once they recover. There is limited knowledge at this time on their capabilities' Designs for stream simulation are recommended for sites with known amphibian populations.

Fish movement and dispersal

Many existing culverts only allow adult salmonid passage while others allow for fish with higher swimming speeds. Those culverts may function as barriers to juvenile or non-salmonid fish species such as sculpin or dace, as well as other aquatic species including crayfish and aquatic invertebrates. These species may be incapable or unlikely to enter a culvert which is not in direct contact with the stream bottom, or they may be incapable of moving through a structure which does not provide a natural surface stream bottom. Stream improvements that have vertical barriers such as small concrete walls or weirs that extend across the entire channel are not recommended.

Water Quality, Wetland and Riparian Habitats

Undersized, rusted, and/or minimally maintained culverts and surrounding fills have a potential for failure during high precipitation events (20, 50, and 100-year events). Resource level roads are often not maintained to design standards due to budget constraints. Additionally, these failing culverts would probably only be replaced on an emergency basis, that is after the road has failed. These situations typically lead to excessive sediment delivery to the aquatic system resulting in impacts to macro-invertebrate, amphibian, and fish populations. Additionally, culverts installed as emergency replacements are often inadequately designed to address the movement and dispersal needs for aquatic organisms. Critics have noted that the sediments delivered when a culvert fails occurs during large storm events. At those times the streams are naturally sediment laden and the effects from the failure may not be significant.

Large Woody Debris Delivery

Due to the extensive road network present on public and private lands many streams are crossed multiple times by roads, substantially affecting the quality and continuity of aquatic ecosystems. Coast Range streams depend heavily on debris slides and torrents for the recruitment of in-stream material, especially coarse sediment and wood, to provide aquatic habitat components. This large material is also critical in the dissipation of stream energy. Roads and stream crossing structures function as dams, primarily during storm events, that constricts flow through a single narrow outlet. These constriction points cause deposition and channel widening at the inlet and increased velocities and scour at the outlet.

The damming affect of road structures prevents the transportation of material down the channel and may limits the function of the flood plain. Large material that would be delivered to the stream channel is also trapped when debris torrents or slides are stopped by the roadbeds.

Diversion Potential

Diversion potential is the potential damage that will occur when “stream capacity is exceeded (i.e.,the culvert plugs), the stream rises behind the fill and flows down the road rather than flow directly over the road fill and back into the natural channel. (Weaver and Hagans 1994).Diversion potential exists on roads that have a continuous climbing grade across the stream crossing or where the road slopes downward away from a stream crossing in at least one direction.”

The effects of diversion of water are large and recently documented in a U.S. Forest Service Publication the Water Road Interaction Technology Series. Readers are encouraged to download updates of this manual from their website.

In order to complete a design or a design review, we make a prediction of the flows in the stream for high fish passage flows and low fish passage flows. This is not an exact science. Data is often limited on the flow variations in a stream reach and the ranges of times that fish are moving in those reaches

Typical Selection Criterion for replacing Structures

1. Maintain, protect, or improve the existing infrastructure of our transportation system .
2. Reduce barriers to movement and dispersal of stream-associated amphibians and invertebrates.
3. Reduce barriers to movement and dispersal of anadromous and resident fish..
4. Reduce the risk of culvert failure and input of large quantities of fine sediments from the road fill to the stream systems.
5. Properly size and install culverts to withstand a 100-year flood event. This should include storm proofing of the roadway should the inlet become plugged.
6. Improve the transport of coarse Sediments and woody debris material.
7. Selected design should be cost effective.

Structures designed and build using the stream simulation method should make a seamless transition from the natural channel through the new structure and into the channel below.

Road Stream Crossing alternatives

For new stream crossings, the following structure types are proposed in order of preference. Each of these structures are reviewed in details in subsequent chapters to this report. A brief summary of the pros and cons of each of the structure types is included below.

1. Fords allows complete passage of all woody debris and aquatic organism

2. Bridge (flow through design with no approach embankment into the main channel)..

3. Open Bottom Culverts or “three-sided boxes’.

4. Culverts which simulate the existing channel by holding or collecting a natural substrate. Examples of these designs include buried culverts and embedded culverts with rock collection systems.

5. Culverts with fishways constructed with sloping weirs and baffles designed to create backwater pools and collect substrate.

6. Fishway or ladders designed to pass adult fish within a specified flow range such as an Alaskan Steep Pass.

Fords

Like a bridge the ford allows complete passage of woody debris and the deposition of a natural substrate across the channel. Stream crossing fords are used commonly in the South-Western Portion of the United States. In the Pacific Northwest, streams have flows year around and traffic will normally cross open water. This creates concerns with public safety, transport of noxious weeds and has a potential for road related sedimentation to enter the stream. Stream crossing fords are recommended when road use is managed. They are economical and can meet all passage and stream simulation objectives..

The Edson Creek Ford

Bridges

A bridge will normally span the full stream channel and allow a stream to cross unobstructed below. Bridges meet the majority of stream /road crossing objectives. During major flood events bridges will often prevent the movement of woody debris as debris hangs up on their superstructure or substructure. For stream simulation designs bridges are the preferred alternative.

The costs of bridges on resource level roads is significantly less than on roads designed to AASHTO standards.   Companies such as Big R and Sure Span are marketing bridges that are competitive to culverts. See Chapter nine for details.

For some sites a bridge is not a good choice. A bridge can create a barrier to movement of some fish if the stream gradient under the proposed bridge is very steep or on a bedrock ledge. Existing streams are often aggraded at their inlets and degraded at the outlets. Connecting the two stream segments with a rocked chute could create a barrier to passage In those circumstances a pipe that allows fish passage may be the best option.

Open Bottom Structures

An open bottom structure has many of the same benefits as a bridge. They have a natural channel that can have the same complexities of the stream in which it sets. They normally are placed on concrete footings or on metal footings plates. Open bottom structures are often the only alternative for achieving stream simulation on steeper sites. Common types of open bottom structures include

1. Multi plate metal arches
2. Half round pipes metal arches
3. Concrete arches such as " three sided boxes" or "conspans"
4. Mini- bridge modular culverts

Open bottom structures are an excellent choice when bedrock is near the surface or scouring can be controlled. . Footings can be placed on the bedrock resolving concerns over rock excavation, erosion and bearing capacity. See chapter five of this manual for open bottom arch details.

Woody Debris Concerns with open bottom structures

Increasing the end area of the structure will improve it's ability to pass woody debris. The larger the end area the less likely the structure will plug and overtop from the movement of woody debris. If the structure does not completely bridge the natural channel, during major events the stream becomes partially constricted. Large woody debris will build up behind them creating the same risks as culverts of an over topping event and road failure. Metal arch culverts are particularly sensitive to complete failure if overtopping occurs. A metal arch relies on the fill for structural integrity. The arch will collapse during an overtopping event if the fill is washed out. Concrete open bottom structures such as "3 sided boxes" and "conspans" remain structurally intact after an overtopping event..

Resistance to Scour and Erosion- open bottom structures

The foundation of an open bottom structure is sensitivity to scour, settlement, or damage from erosion. If the footings are grouted or set on rock, erosion is not a concern. In actual practice open bottom structures often do not set on rock and require a riprap foundation for protection of the footings. In those cases, we design the foundation first and then size the open bottom structure to match the required minimum channel width. The design and construction of the rocked channel is a critical item. Open bottom structures are not recommended for soft soil conditions,

Pipe Arch and Circular Culverts

Pipe arch and circular culverts are frequently used for stream simulation.   They can have similar spans to open bottom structures without the risk of a foundation failure.

Culverts are designed to trap natural substrates in the bottom of the culvert ,mimicking the natural streambed within the culvert and providing habitat continuity between the stream above and below the road crossing. The conditions inside the culvert are similar to the existing stream. Small thalways develop . Fish movement is unconstricted when fish are moving. Amphibians and invertebrates are able to move either across the moist exposed substrates, or in the water course.

These designs are normally significantly less expensive than bridges or open bottom arch alternatives. In areas of soft foundation materials a culvert is the only reasonable alternative.

Using embedment and rock collectors metal pipes will trap and retain substrates.   Pipe arches are recommended over circular culverts for stream simulation.

Characteristics of buried or embedded culverts:

1. An acceptable size substrate is maintained for the full length and width of the structure. That substrate allows fish movement during low flows and higher velocities and also movement of non fish species through the structure .Embedment rock traps and retains stream substrate.
2. The inlet width is unrestricted. Flow into the inlet of the culvert is subcritical and not turbulent when juvenile fish are moving through the culvert. The width of the structure at the level of the top of the substrate should be at least as wide as the active channel width . A minor turbulence is acceptable during periods of adult passage only.
3. Downstream control weirs or other systems backwater flow into the culvert .
4. The culverts grade approximates closely the natural stream gradient or is slightly less.

Pipe Arch Culverts with a sloping weir fishway:

A culvert installed with a sloping weir fishway does not attempt to totally simulate a natural stream. The fishway is modeled as cascading pools between the weirs. Fish movement is unimpeded. We have attempted to refine the design to collect some substrate. Many of our more recent designs do trap substrates. Under that condition they are acting more as pipes with rock collectors than as pool and weir fishway. In either case they have provided passage for juvenile and adult fisheries when the fish are moving. This is a good design for fish passage on steeper slopes.   These structures are also some good candidates for grades over 5% up to 13%, when other pipe arch designs are suspect.   They are culverts and can be placed with minor or no risk on soft sub-grades. These structures offer a reasonably priced road crossing that can be installed quickly with a minimal impact on public road use.

Characteristics of culverts with fishways.

1. The fishway is designed to create a series of interconnected pools through the pipe.   Where portions of the pipe are back watered. Those pools will eventually fill with a substrate. The back watered portion of the pipe acts in stream simulation mode similar to culverts with baffles noted above. The pools are designed to provide resting areas during higher flows. Plunging flow or stream simulation is maintained within the flow range that fish are moving through the structure.
2. The inlet width is unrestricted. Flow into the inlet of the culvert is sub-critical and not turbulent when juvenile fish are moving through the culvert.
3. The outlet and each weir is back-watered allowing a swim-thru condition for fish entering and moving through the culvert.
4. Fishway weirs are sloped to allow passage of woody debris material through the culvert.
5. Notches placed in the weirs to allow juveniles to move in areas of very low velocity.
6. Fishway weirs designed to provide plunging flow when fish are moving.

Pipe arch culverts with sloping weirs have unique design requirements. See Chapter 5 on Sloping Weir Fishway for details.

Evaluation of Alternatives

The evaluation of alternatives is normally done in the federal sector as an interdisciplinary team (ID team), in the private sector a team is developed by the funding agency to include fish and wildlife representatives and the sponsoring agencies and the land owners. A typical report might include the following:

1. Prepare a site map and report which includes:

   A. A profile of proposed stream crossing extending several hundred feet upstream and downstream
   C. A description of the stream bed conditions
   D. Measured widths of active channel in similar reaches to the proposed design.

2. Hydrology of Crossing

   A. Design flows: Q100, Q50, Q10, Q2 using several methods.
   B. The estimated high monthly flows and low monthly flow when fish are moving. Include a separate range for adult and juvenile fish if they are different.
   C. Note local information such as proximity of dams, other rivers, previous flood history, and characteristics of referenced gaged stations .

3. Provide a brief description of the site with photos. Include a description and assessment of the barriers that presently exist at the site. Include support data in appendices. A spreadsheet evaluation is often sufficient for most teams. Describe how the alternative will resolve the barriers at the site.

4. Stream Channel Characteristics:
   A. Define the channel characteristics: location, skew, gradient, foundation, bed materials. Be brief using photos when possible.
   B. Estimate the potential of a debris flow plugging the culvert, diversion potential and need for storm proofing.
   C. Estimate the expected depth the channel will regrade at the inlet and outlet. This estimate may include a brief commentary on substrate movement through the stream.

4. Provide a cost estimate for each alternative. Many public agencies require a present worth cost analysis that include maintenance, replacement costs, and risks of failure. Discount to present worth at 6% and 0%. The cost estimate should include : Initial costs, cost of a structure without fish passage, future maintenance and future replacement costs. Show costs in report with details in the appendix.

3. Describe the biological impacts of each alternative and their relative importance. Consider the following.
   A. Anadromous fish passage both upstream and downstream
   B. Resident fish passage juveniles and adults.
   C. Presence and movement of non fish species through system.
   D. Ability of a stream reach to support extra fish
   E. The relative importance of the habitat gained up stream to other projects.

4. Compare the maintenance requirements between alternatives. Comparison should be in measurable units such as in workdays per year. Some designs such as an Alaskan Steep Pass may require daily checks and cleaning.

5. Construct a time line for the project.

   A. **Permits:** List all required permits and when they are possible to obtain.
   B. **Work Window**: Define the available construction work period. Most areas have in stream work periods and wildlife restriction.
   C. **Funding** : Make a list of all contributor and when there funds will be come available for use. Some projects are funded at the end of construction other sources provide up front moneys for design.
   D. **Quality Control**: Determine who will administer and inspect the construction.

6. Define the physical features at the the crossing.

   A. Soils and Geology: If a site has soft or weak soils a culvert alternative is preferred over an open bottom structure with a concrete or rigid footing
   B. Calculate the Design Flows and estimated high and low fish passage flows.
   C. Describe the backwater effects from adjacent streams and how they influence the design.
   D. Provide a profile of the site with an explanation of how the new structure is orientated to the existing stream. Describe an potential impacts such as upstream down cutting.
   E. Review the diversion potential of the proposed design.

7. Field Review final Design.

   As a final check on the process the evaluation team may wish to field check the “as staked” preferred alternative. Staking should indicate where all four corners of the structure will set, the proposed cut or fill at each of those corners, the location of the downstream control weir, the perimeters of the waste and/or borrow sites, and the location of the upstream de-watering pond.

Selection of Preferred Alternatives

The chart below compares the effectiveness of alternative Structures. .

STRUCTURE	Retain Natural Stream Sbstrate Throughout full length of Structure\	Maintain Unimpeded Upstream Access Through Structure for All Aquatic Species	Pass Gravel and Debris through structure	Constructability on soft foundations	Constructability on rock foundations	cost efficiency 10= high, 0 = low
Fords	Effective	Effective	Very Effective	Very Effective	Very Effective	3
bridges	Effective	Effective	May limit during very peak events	Very Effective	Very Effective	9- new designs may reduce
Open Bottom Arch or three sided box culverts	Effective	Effective- if width correct	Partially effective	not recommended	Very Effective	6 to 7 for metal, 9-10 for concrete
Embedded,sunken or Pipe Arches with roughening baffles	Effective	Effective on lower grades	Partially effective	very effective with proper design	marginal may require blasting, depends on rock	4-GETS HIGHER ON BIGGER STRUCTURES
Pipe Arch with sloping Weir Fishway	Ineffective- may hold substrate on lesser grades	Effective for all fish passage, may limit non swimming species	Partially effective	very effective with proper design	marginal may require blasting depends on rock	4-GETS HIGHER ON BIGGER STRUCTURES

Retrofitting Existing Structures

The following retrofit alternatives are suggested for improving an existing culvert as an interim action.

1. Add rock collection device or baffles inside the existing culvert to embed or add roughness.

2. Add sloping weirs or a combination of baffles and weirs to culvert when grades are not appropriate for rock collection or roughening baffles. Examples of pipes retrofitted with lexan weirs are included in the case studies..

3. Add a second culvert adjacent to the existing pipe designed with a fishway.

4. Add rock weirs at outlet, creating a chute for fish to enter pipe. See commentary on rock chutes in chapter 11.

5. Construct rock weirs at the outlet to backwater into the culvert. See details in chapter 4.

6. Construct a fish-way, rock chute, or fish ladder into the existing culvert.

Design Criterion for Replacement Projects:

The following recommendations are appropriate for most stream crossing structures.

1. Culverts should be sized approximately as wide as the active stream channel to maintain the natural stream bed width, create an unconstricted entrance, and control water velocity within the structure.

2. Install the culvert's at or slightly below the natural stream grade to improve substrate deposition and retention. To maintain a suitable gradient, this may require countersinking the inlet below the natural stream bed. This action needs to be carefully evaluated at each site to determine the potential for channel head-cutting.

3. Install culverts so the outlet is in direct contact with the natural stream bottom to provide access for amphibians, fish, and invertebrates into the culvert. The outlet also must be back watered from a downstream structure to submerge the culvert's outlet a minimum of 6 inches and ideally a foot.

4. Embed rock, install baffles or other devices inside the culvert to promote deposition and retention of natural substrates such as gravels and cobbles in the culvert. The substrate will allow passage through culverts of amphibians, fish, and invertebrates.

5. In addition to a downstream control structure consider placing Boulder clusters or large woody material in the channel to encourage deposition of sediments.

6. **A control weir must be installed** below all structures that restrict the stream channel. Place the "control weir" approximately three diameters from the outlet of the culvert. The outlet of the pipe is than placed 6 inches to a foot below the top elevation of the "control weir" weir. A backwater pool is created that floods the outlet of the pipe. That pool provides a swim-thru entrance for fish moving upstream into the pipe and an energy dissipation pool during peak events. Without this weir the stream will down cut at the outlet eventually leaving a perched pipe. A bridge or ford are the only structure in this author's opinion which will not restrict flow.

7. **Monitoring and Adjustments:** The design of fish passage structures even in the best of situations is not a perfect science. We should expect to return and make adjustments. Often they may be very minor such as adding boulder clusters downstream or log weirs to improve the channel. Ideally we will schedule these return visits during year 1, year 5, and year 10.

Construction Concerns

1. Define what water quality controls will be required at the site. Add an additional pay item in the contract for this work if required work is out of the norm. Diversion of flow around the project may require check dams, high volume pumps, sediment control ponds and silt fencing. Provide specifics measurable items rather than vague objectives.

2. The Contractor/Operator is required to submit evidence of a Spill Prevention and Containment Plan consistent with Oregon Department of Environmental Quality and Forest Practices Act, Oregon Department of Fish and Wildlife (ODFW), and B.M. guidelines for in/near stream operations. In addition, a spill containment kit shall be present on site during equipment operations.

3. Remove large fills during low stream flow periods. Use silt dams and filters (such as straw bales) to filter sediment from the water. Earthwork should be completed in the dry season, typically mid-June through mid-October. Install the culvert in the dry, or in isolation from steam flows by the installation of a bypass flume or culvert, or by pumping the stream flow around the work area. The bypass reach shall be limited to the minimum distance necessary to complete the project. Fish stranded in the bypass reach shall be safely removed to the flowing stream.

4. During installation, all fill material removed should be placed at stable locations in such a manner as to avoid sedimentation and aid in soil recovery. Locate permanent and temporary waste areas on the plans and flag on the ground to avoid confusion.

5. Compact all fill materials in accordance with manufacturers recommendations to ensure soil strength is maintained over culverts.

6. Upon completion of construction activities, all exposed soils and waste areas should be stabilized with a mixture of seed, fertilizer, and mulch. A native seed mix is preferred but often is not available. Locally a mixture of an annual and perennial rye seed is used.

7. The contract should include standard stipulations for cultural resources, hazardous materials, noxious weeds, and special status species.

8. Contract administrators should be familiar with OSHA safety regulations. The contractor's foreman should be certified as a "competent person".

9. Wastewater from project activities and construction site de-watering , shall be routed to an area outside the ordinary high water line to allow removal of fine sediments and other contaminants prior to being discharged to state waters.

10. Imported fill which will remain in the stream after the culvert is removed and replaced shall consist of clean rounded gravels ranging in size from one-quarter to three inches in diameter. Wash fines into large rock with a high pressure hose to stabilize channel and minimize sedimentation.

Bibliography Chapter One

Web site references for additional information:

http://www.wa.gov/wdfw/hab/engineer/habeng.htm
http://www.stream.fs.fed.us/fishxing/