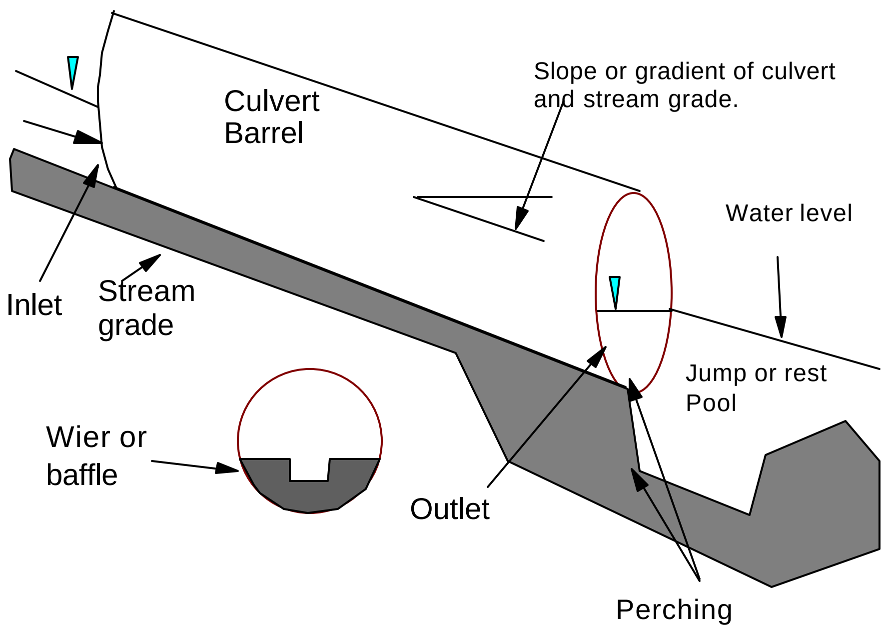
Oregon Road/Stream Crossing Restoration Guide:

Spring 1999



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Advanced Fish Passage Training Version

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Contents

Introduction

Scope of this Guide

The primary purpose of this guide is to provide guidelines to land and fish and wildlife managers that are assessing, planning, designing, or installing repairs or replacements for road/stream crossings under the Oregon Plan for Salmon and Watersheds.

These current guidelines are an attempt to organize together and embellish the current rules, regulations, and guidance regarding road/stream crossing installations. **This current training document along with other guidance (Appendix D and E) is designed to replace earlier guidance memorandums (i.e., Robison 1995 and 1997) for fish passage guidance for state and private forestlands. For other landuses, the Oregon Department of Fish and Wildlife guidelines (Appendix A) along with other information in the Appendixes are the official rules and guidelines for fish passage.** This training should prove useful for fish passage designs on other landuses (i.e. agricultural, state and county transportation, and urban) when designing for fish passage and applying for various available grants but is not regulatory. A new guidance memorandum that has excerpts from this guide that focuses on the essential elements of designing and installing replacement culverts is also available from ODF.

Using this Guide

The introduction largely deals with background information. If you have a known problem culvert and have some ideas of the basics and definition of terms regarding culverts you can quickly skip ahead to step two of the methods section which deals with information needed regarding a problem culvert. If you know that you want to replace the culvert you can then skip ahead to steps four and five in the methods section which deal with deciding which alternative to use and how to develop a design and plan for crossing replacement. The introduction sections as well as the rationale sections provide background information about fish passage for those interested in learning more. The Appendixes provide official rules, guidance and regulations as well as some useful checklists and how to guides. Washington State has also developed a similar guidance document to this one and is available on the world wide web at [http//www.wa.gov/wdfw/hab/engineer/cm/toc/htm].

The importance of properly functioning road/stream crossings (why fix them)

1. Fish Passage blockage or impediment

Stream channel crossings by roads have been the cause of serious losses of fish habitat due improperly designed culverts. One study estimated the loss in habitat from culverts on forest roads as 13% of the total decrease in coho salmon summer rearing habitat in the Skagit river basin in Washington state (Beechie et al., 1994). This percent decrease in summer habitat was considered greater than the sum total effects of all other forest management activities combined. Another paper reported that as many as 75% of culverts in given forested drainages are either outright blockages or impediments to fish passage based on field surveys done in Washington state (Conroy, 1997). Surveys of culverts for county and state roads have found hundreds of culverts that at least partially block fish passage (Al Mirati, Personal Communication).

Loss of fish passage at road crossings has many potential effects. One obvious effect is that if the crossing blocks upstream fish passage of both adult and juvenile anadromous fish the reach will no longer be accessible as habitat. However, there are many other potential effects which include the following:

1. The loss of genetic diversity in an upstream reach for resident fish as fish can go downstream but not back upstream.
2. The loss of range for juvenile (anadronmous) and resident fish that may migrate upstream at certain times of the year.
3. The loss of nutrients (from the anadromous spawning adults) to reaches upstream of passage blockages.
4. Changes in fish genetics or community assemblages upstream of fish passage impediments because certain stronger swimming fish species or life stages can pass upstream while the weaker swimming fish can not.
5. The loss of resident fish on small streams after extreme flood of drought events that evacuates fish from the reach and fish are not able return.

There are other examples as well. An excellent review of the various problems associated with loss of fish passage is discussed in a recent paper by Washington Trout (Conroy, 1997).

2. Chronic Sediment Input

Road/stream crossings represent the places where the road system and stream system intersect. Often times improperly designed or maintained fills will input significant amounts of fine sediment into the stream system. The storm events required to cause a road fill to input fine road based sediment into the stream are often not large, so sediment enters the stream at times when there is not as much energy available to transport the sediment and the fine sediment is able to intrude into the stream bed degrading spawning and other gravel deposits.

3. Catastrophic crossing failure

Undersized and/or improperly maintained culverts have a greater risk of failure than properly sized and maintained culverts. Failures can cause spectacular negative impacts on downstream reaches including dambreak floods and severe sediment scour and deposition as well as damage to riparian vegetation and banks. During the recent 1996 floods, there were a instances where this occurred and the channel impacts particularly from large fill failures were comparable to the most extreme landslide impacts (Robison et al., 1999). Newer designs often include strategies where the primary culvert may fail but over flow dips in the road are in place to convey the flow that prevents fill failures or even erosion of stretches of roads.

Current Oregon regulations and programs on fish passage

The Oregon Department of Fish and Wildlife (ODFW) by statute is the lead state agency for all types of fish passage concerns in Oregon. In keeping with this role, ODFW has produced guidelines regarding fish passage (Appendix A). The statute (Appendix B) requires that fish passage be provided where anadromous, food or game fish species are present. Oregon Department of Forestry (ODF) and Division of State lands (DSL) also regulate fish passage in a way that is compatible with ODFW on state and private lands (see Memorandum of Agreement between agencies Appendix C). On federal lands, the Forest Service and other federal land holders are to comply with ODFW rules and statutes. In areas with endangered species listings, fish passage authority is also given to National Marine Fisheries Service and U.S. Fish and Wildlife Service.

The ODFW guidelines specify maximum velocities, entrance drops, and minimum water depth criteria for culverts. The ODFW guidelines have a preference for using bridges but also allow for culverts that simulate natural streambed conditions, non-embedded culverts placed essentially flat, and culverts using baffles or weirs in order of decreasing preference.

ODF has also produced regulatory guidance (Robison 1995, 1997, and proposed guidance in Appendix D) designed for landowners and operators regarding fish passage in terms of crossing alternatives that will likely pass fish under different situations. The differing situations include stream gradient, stream valley fill present and specific type of strategy involved. These guidelines (both old and new) require that culverts designed to have no sediment in them, be placed essentially flat (less than or equal to 0.5% gradient) and that culverts designed to simulate natural bed conditions be designed for stream widths similar to natural stream width and be placed at a gradient similar to or somewhat below natural stream gradient. **This current training document along with other guidance (Appendix D and E) is designed to replace these earlier guidance memorandums for fish passage guidance of state and private forestlands. Note also that ODF is providing a streamlined guidance memorandum that contains excerpts from training that is focused on culvert design and**

installation.

The expedited general authorization approval process as well as fill and removal permit information for road construction on non forest lands, which is regulated by DSL, is available on the world wide web at [http:/statelands/dsl.or.us/roadinfo.htm] or by calling local DSL offices or the main office in Salem at 503-378-3805.

There are several other non-regulatory programs regarding fish passage in Oregon. Within the Oregon plan for Salmon and Watersheds there are two forestry measures that relate to fish passage (ODF1S and ODF2S). These two voluntary measures regard the identification and correction of all road related problems on private industrial forest lands over the next ten years. Each year hundreds of culverts are being replaced. This training in large part is being sponsored to support these efforts.

In addtion the Governors Watershed and Enhancement Board (GWEB) and ODFW's Restoration and Enhancement Board has been funded to give grants to projects that enhance fish habitat and watershed function including fish passage improvement projects. One purpose of this training is to provide guidance to those preparing grant applications that regard fish passage improvements.

Biological Elements of Fish Passage

A number of factors have been attributed to the reduced number of salmonids (salmon and trout). Most frequently fingers are pointed at dams, ocean and freshwater fishing, oceanic habitat conditions, loss and degradation of freshwater habitat due to forest and rangeland management, hatcheries and predation by marine mammals and exotic fish species. Barriers and delays to fish passage such as those found at road crossings have been added to this list of factors.

One of the most basic improvements land managers can make in the attempt to recover salmonid stocks is at stream crossings. Our public and private transportation system has thousands of stream crossings that determine whether or not upstream habitat will be accessible as habitat for juvenile and adult salmonids. It is the intent of this portion of the guidebook to investigate how stream crossing structures are problems for fish passage and why it is important for fish to be able to move into different parts of the stream network.

The Fundamental Problem of Culverts

Streams are complicated systems conveying and storing large amounts of water, energy, woody debris, sediment and bedload material. The combination of these elements results in an elaborate pattern of flow, water temperature and channel forms such as riffles, pools, runs, glides and side channels over both space and time. The natural forces that created these patterns also resulted in barriers and delays to fish passage at waterfalls, landslides, debris jams, channel constrictions and during times of extreme flows and temperatures. Pacific Northwest salmonid stocks, their behavior and their swimming capabilities developed in conjunction with these diverse habitat and flow conditions. Adding manmade barriers such as dams, pollution, excessive turbidity, temperature, water removal, landslides, debris jams and impassable road crossings to the stream network has likely increased the number of delays and barriers to fish passage beyond natural levels.

Fish Movement and the Road Network

Some of the primary motives fish have to move or migrate are to satisfy basic requirements for:

1) reproduction
2) habitat (i.e. food, cover)
3) refuge.

The upstream migration of adult salmon is likely to be the first image of fish migration that comes to mind. Spawning salmon, however, do not arrange themselves haphazardly in a watershed but instead seek particular habitats according to stream size, substrate and water velocity. For example, pink and chum salmon do not stray far from the estuary while steelhead and cutthroat trout can be found in small headwater streams. Selecting certain niches in the freshwater network for spawning is beneficial to the resultant juveniles by reducing competition for limited resources.

While the upstream movement of reproducing salmon and young salmon heading down river to reach their ocean feeding grounds are familiar phenomena, other occasions of fish migration or movement are not popular knowledge. Both juvenile salmon and resident trout have been observed to move both up- and downstream in response to various environmental factors. This includes seeking refuge from elevated stream temperatures, extreme flow conditions and predation or they move seeking less densely populated areas with better opportunity for food and cover (Bustard and Narver 1975, Cederholm and Scarlett 1981, Everest 1973, Fausch and Young 1995, Gowan et al. 1994, Hartman and Brown 1987, Reiser and Bjornn 1979, Shirvell 1994). For some juvenile fish, upstream migration can be an important part of their life cycle such as sockeye salmon fry swimming upstream to reach their rearing lake. Coho juveniles have also been noted in several studies to migrate upstream in the fall into sidewater channels and tributaries (Bustard and Narver 1975, Cederholm and Scarlett 1981, Skeesick 1970). While the exact reason for this migration is unknown, there is growing evidence that coho juveniles overwintering in these areas have higher survival rates (Bustard and Narver 1975).

From this discussion, it is apparent that barriers to movement presented by overlaying the stream system with the road network can prevent fish from meeting their basic requirements for reproduction, habitat and refuge. Delays and barriers due to stream crossings can be divided into three different categories (Dane 1978) each with different potential impacts to fish (Table 1).

Table 1: Barriers to fish passage and their potential impacts.

Barrier Category	Definition	Potential Impacts
Total	Impassable to all fish at all times	1) Exclusion of fish entirely or from portions of a watershed 2) Isolation of fish populations upstream of barrier
Partial	Impassable to some fish at all times	1) Exclusion of certain fish species or ages entirely or from portions of a watershed 2) Isolation of certain fish species or ages upstream of barrier
Temporary	Impassable to all fish some of the times	1) Delay of movement beyond the barrier for some period of time

For example, problem road-crossings identified on Highway 101 along the Oregon Coast have the potential to completely block migrating adult salmon from entering an entire drainage system or change the species composition. Highway 229 which winds along the Siletz River, has likely altered access to a number of tributaries that are crossed. In summary, the number, location and type of road-crossing barriers in a watershed acts as a filter that will determine the amount of habitat available to each species and age-class of fish.

Culverts from the Fish Eye View: Components of the Fish Passage Guidelines

The Oregon Department of Fish and Wildlife (ODFW) and Oregon Department of Forestry (ODF) fish passage guidelines were designed with the intent to ensure that any artificial obstructions placed across a stream would not pose a barrier to the movement of adult and juvenile salmonids, both resident and anadromous. While much of this presentation will focus on the complexities of the anadromous species, many of the factors that affect anadromous fish are equally applicable to resident species.

Table 2 provides a general summary of the criteria found in the ODFW fish passage guidelines and the related biological factors. To simplify the complexity of the guidance criteria, ODF has taken a more conservative approach to fish passage by requiring that in all cases road crossings be designed to pass juvenile fish. The design alternatives in the ODF guidelines also eliminate the need for trying to design for specific water velocites in the pipe barrel. Thus, while the alternatives in the ODF guidelines do not explicitly contain the criteria contained in Table 2, their design is based on consideration of these criteria.

While the ODFW design flow and in-stream work period guidelines address important issues for fish and fish passage, the problematic characteristics of culverts most readily identifiable in the field include:

1) High velocities or sudden changes in velocity at the culvert inlet, outlet or within the barrel
2) Jumps to the culvert inlet or outlet
3) Shallow water depths
4) Lack of resting pools at the culvert inlet, outlet or within the barrel.

Since the fish passage guidelines are species and age specific, the first critical step in evaluating the performance of an existing drainage feature or in designing a new one is to identify what species and age-class of fish will need passage.

Table 2: Biological factors related to fish passage criteria. Certain ODFW regulatory criteria differ for culvert length (L), fish species (S) and age of fish (A, adult or juvenile).

Fish Passage Criteria and Related Biological Factors	
General Regulatory Criteria	Biological Factors
Water velocity in culvert (L, S, A)	Swimming Speed
Water Depth in culvert (S, A)	Submergence (sufficient depth for swimming)
Design flow criteria (S, A)	Delays, dispersion
Height between culvert outlet and water surface (S, A)	Jumping ability
Timing of in-stream work (S)	Emergence (silting in of redds) Migration - delays or reduction of adult spawners

1) What is the Design Fish Species, Age and Time of Migration?

In western Oregon, the species you are likely to be designing for include juvenile or adult coho, chinook, steelhead and cutthroat trout. In central and eastern Oregon design species may include juvenile or adult chinook, steelhead, cutthroat or bull trout. Though each species will vary in the time at which migration and spawning will occur as well as the period of time spent maturing in both the fresh- and saltwater phases, the life cycle of the typical anadromous salmonid can be generalized as follows. Upon becoming sexually mature after being in the ocean for 1-6 years, anadromous salmonids migrate to their natal freshwater streams. Upon reaching suitable spawning grounds, the adults will deposit their eggs in redds, or nests, usually located in clean gravels at the pool-riffle interface (Reiser and Bjornn 1979). The eggs will hatch in one to three months, though the alevins will remain in the stream gravel for an additional one to five months. The fry will then emerge from the gravels in spring or summer. Juvenile fish will stay in fresh water for a few days to four years, depending on the species, before the smolts migrate to the ocean. Fish will continue to grow and feed in the ocean for one to four years depending on the species before beginning the cycle again as adults returning to their natal freshwater

streams to spawn.
Resident fish species, such as bull and rainbow trout or non-sea run cutthroat, have simpler life-cycles which occur entirely in freshwater. Some species, however, do make short migrations between and within streams or to lakes for spawning or rearing.

The cycle described above is very generalized. Aside from the fact that these fish often have different runs that begin their migration into fresh water at different times of the year (e.g., summer, fall, winter, spring runs), they also have different fresh- and saltwater residence times (Table 3). The fry of chum and pink salmon migrate downstream to the ocean immediately after emerging from the gravel whereas other salmonids will remain in freshwater streams for a year or more.

Table 3: Expected occurrence of anadromous salmonids in the Siletz River located in Lincoln County, Oregon (personal communication, Randy Reeve, ODFW Fisheries Biologist).

		Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Chum Salmon	Adult										■	■	■
	Young			■	■	■	■						
	Eggs	■	■	■								■	■
Coho Salmon	Adult	■							■	■	■	■	■
	Young	■	■	■	■	■	■	■	■	■	■	■	■
	Eggs	■	■	■	■						■	■	■
Spring Chinook	Adult					■	■	■	■	■	■		
	Young		■	■	■	■	■	■	■	■			
	Eggs	■	■							■	■	■	■
Fall Chinook	Adult	■							■	■	■	■	■
	Young		■	■	■	■	■	■	■	■			
	Eggs	■	■	■							■	■	■
Searun Cutthroat	Adult	■	■	■	■	■	■	■	■	■	■	■	■
	Young	■	■	■	■	■	■	■	■	■	■	■	■
	Eggs	■	■	■	■	■						■	■
Winter Steelhead	Adult	■	■	■	■	■	■					■	■
	Young	■	■	■	■	■	■	■	■	■	■	■	■
	Eggs	■	■	■	■	■	■					■	■
Summer Steelhead	Adult	■	■			■	■	■	■	■	■	■	■
	Young	■	■	■	■	■	■	■	■	■	■	■	■
	Eggs	■	■	■	■	■							■

Obviously, predicting when and where fish will need access is challenging, and that contact with a fisheries biologist is essential for identifying the proper species, age, and time of year to design your drainage feature for. While the ODFW guidelines provide criteria for designing crossings for the adults of different salmonid species, you should anticipate that you will be designing for the passage of juvenile fish in most cases. ODF guidelines are designed to pass juvenile fish in all cases and a site specific plan would be required in scenarios where this may not be possible.

2) Timing of in-stream work

The allowable time periods for in-stream work were established to avoid vulnerable life stages such as migration, spawning and rearing. In-stream work can impact fish and fish passage in a number of ways. This includes direct harm to fish and eggs at the construction site where equipment, turbid water, water diversions and excavation activities can crush or damage fish and eggs or present a physical barrier to passage. Suspended sediment from crossing installations can settle into redds or fish gills, delay migration, increase the incidence of disease, and in extreme conditions will kill fish directly. Sediment is especially detrimental to eggs and fry still in the gravel. Sediment settles into stream gravels, reducing the flow of oxygen to eggs and fry, trapping toxic metabolic wastes within the redds and can act as a physical barrier to fry emerging from the gravels.

It is important to note, however, that the guidelines for the in-stream work periods are not necessarily inflexible. On a site-specific basis, ODFW may consider variations in climate, location, and category of work to warrant special instream work timing considerations.

3) Design Flow Criteria

When flows through a drainage feature create conditions that are impassable to fish, their up- or downstream movement is delayed for as long as that condition persists. This can occur at either extreme of high or very low flow conditions. Adult spawning migrations are commonly timed with freshets that may result in excessive velocities or other impassable conditions in culverts for a period of time. Delay can result in a number of negative impacts on fish (Fish Commission of Oregon 1969, Groot and Margolis 1991, Travis and Tilsworth 1986):

1) Delayed fish may expend their stored energy necessary for successful migration, maturation and spawning before reaching their destination, resulting in weakened fish more disposed to disease or pre-spawning mortality. Salmon usually stop feeding before entering fresh water and depend only on their bodily reserves of fat and protein for migration, further maturation, spawning and redd defense until they die. Changes in body fat reserves of sockeye salmon in the Fraser River were observed to be over 90% depleted in females and less than 90% in males at the time of death after spawning. Considering that some salmon species, like the Snake River runs, will travel up to 900 miles to reach their spawning grounds this is a considerable feat.
2) Delayed fish arrive at holding or spawning areas later than normal. Spawning periods may be timed with crucial flow and water temperature conditions necessary for egg and fry survival.

3) The distribution of spawning fish can be affected by delays. If fish cease to move upstream, headwater areas may be poorly seeded with redds while the number of nests below the barrier may be beyond the carrying capacity of the area. Late spawners in areas with high redd densities may dig up eggs previously deposited, exposing them to certain predation.
4) During a study of the ability of Arctic grayling (Thymallus arcticus) to pass through a 110 ft. long 5 ft. diameter highway-crossing pipe, the fish were prevented from passing through for eight days during a period of high flow (Travis and Tilsworth 1986). The experimenters observed that a substantial number of fish holding in the pool below the culvert were taken by sport fisherman.
5) Female fish subject to harassment, disease, poor environmental conditions, depletion of bodily reserves or high spawning densities have been noted to not fully spawn but retain a substantial percentage of eggs.
6) Juveniles or resident fish seeking more abundant food, cover or favorable water temperature conditions as well as refuge from high flows or predation may have to remain in less than ideal habitat conditions.

A culvert that is a problem to fish passage due to its design flow is often not readily recognizable in the field. Estimating design flows through frequency analysis or another method would likely be necessary to identify over- or under-sized culverts for ideal fish passage conditions.

4) Water velocity and swimming speed

The pattern of water velocity in a natural channel is very complex. A wide variety of swimming conditions are available for fish, ranging from high velocities and turbulence in the main flow to quite slow, calm water along the stream edge, around large boulders and wood, or within side channels. Even though average stream velocities could be much greater than the ability of adult or juvenile fish to pass, there are abundant low-velocity zones near and within the boundary layers of roughness elements such as bed material and logs that allow upstream movement. The velocity profile of a culvert, on the other hand, can present a rather homogenous pattern of high water velocities with few zones of slow, calm water.

To navigate through their stream environment, fish use two muscle systems: red (aerobic) for longer-term, low intensity activities and white (anaerobic) for short, high-intensity activities. Excessive use of the white muscle system leaves a fish exhausted and requires a long period of rest (Webb and Weihs 1983).

Fish use these muscles to achieve three different swimming speeds: cruising, sustained, and darting. Cruising speed can be maintained for extended periods of time, whereas sustained and darting speeds can be performed for only minutes and seconds at a time, respectively (Bell 1986). Migrating fish encounter a variety of flows and water velocities in a natural waterway, though cruising and sustained speeds (red muscles) are adequate for most conditions (Bell 1986). Darting speeds may be required to navigate areas with high water velocities such as rapids, narrow sections, or reaches with steep gradients.

To enter a culvert with a velocity or jump barrier white muscles may be required (sustained or darting speed), but then the fish would likely use the red muscle group to swim the rest. If white muscles are required to swim the entire length of the culvert, the fish may exhaust itself before successfully passing through.

Fish have a disincentive to pass through culverts! "The change in hydraulics and light conditions are enough to cause a fish to hesitate" (Bates 1995). Behlke et al. (1989) speculates that fish navigating through culverts of unknown lengths will not expend energy at their full potential but will move ahead slowly to conserve energy. This theory is supported by field observations where fish passage through culverts took longer than expected.

So how fast and how far do fish swim? Information about the swimming ability of Pacific Northwest salmonids is not abundant, and there is even less available specifically about juveniles. It appears, however, that for most species the greater the fork length (length from nose to fork of tail) the greater the swimming ability (Jones et al. 1974, Bell 1986). The swimming ability of a fish can also be affected by the distance already traveled, turbidity, temperature, size, oxygen levels, water depth, water velocity, and disease. Some swimming ability research of average-sized adult salmonids has been summarized in Figure 1. There is a marked difference in performance between adult and juvenile coho, as well as a demonstration of the superior swimming capability of steelhead.

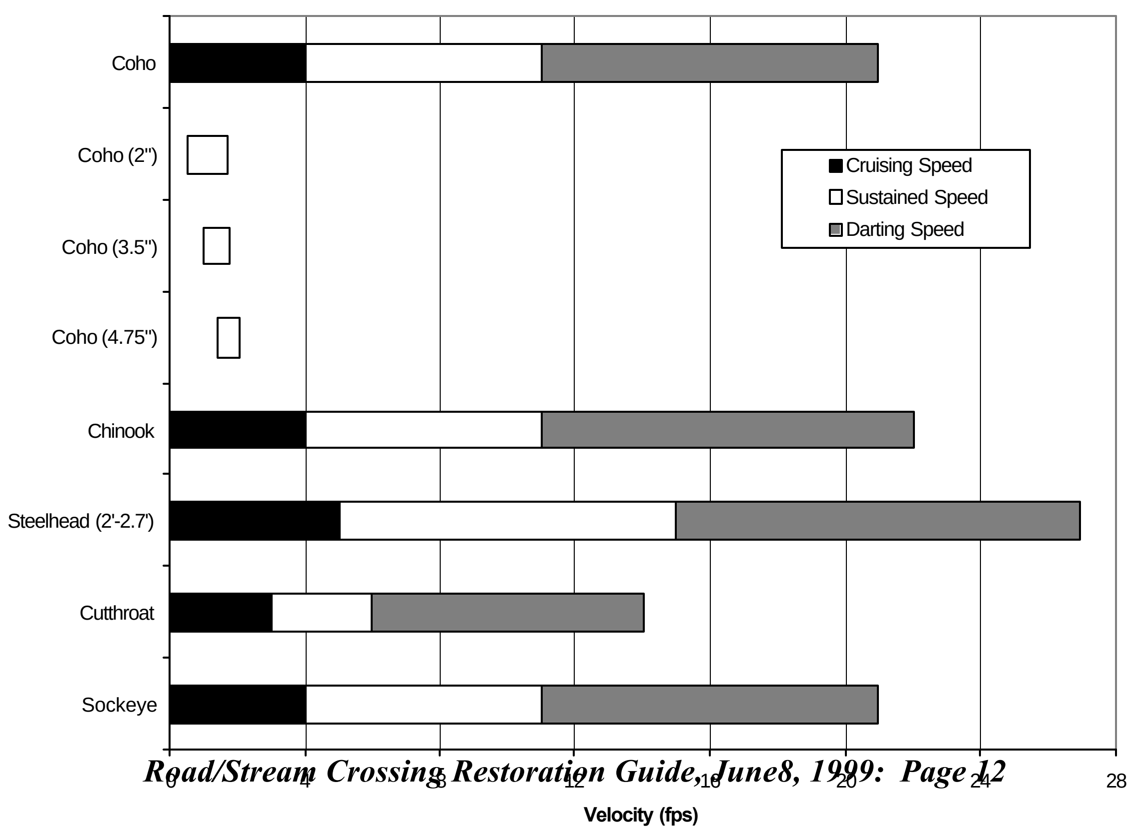


Figure 1: Relative swimming speeds of different fish species and age classes (adapted from Bell 1986).

In order to determine how far a fish can swim without resting it is necessary to assume a velocity (sustained or darting speed), the length of time the fish can sustain that velocity and the water velocity. Powers and Orsborn (1985) suggest that the length a fish can swim can be calculated by:

LFS = (VF - VW)TF

where

LFS = Length the fish can swim
VF = Fish speed
VW = Water velocity
TF = Time to fatigue

As discussed above, fish are likely to move through culverts using a sustained speed unless high velocities or jumps require the use of darting speeds. Coho salmon observed navigating rapids in the Somass River, British Columbia, swam quickly through the rapids then held in a quiet pool for some time (Groot and Margolis 1991). This burst and rest pattern is likely the way that fish maneuver through high velocity zones and jumps in drainage features, fish ladders, weirs or baffle systems. If the maximum time for maintaining either sustained or burst speeds is reached before a resting area is available, however, the fish will be swept back downstream.

Juvenile salmon swimming upstream in culverts have been observed to take advantage of the low velocity zones located close to the culvert wall (Barber and Downs 1996, Figure 2).

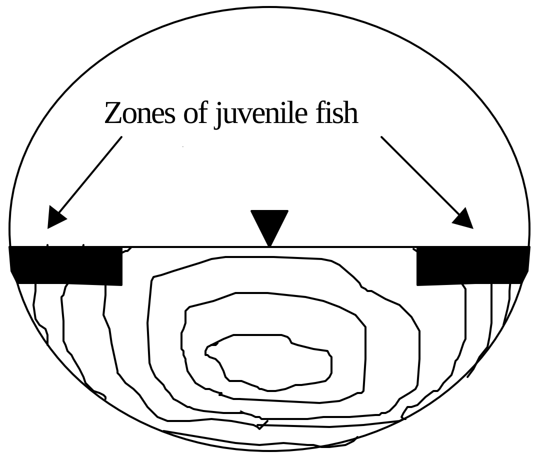


Figure 2 : Zones of juvenile fish passage in culverts (adapted from Barber and Downs 1996).

Apparently, up to certain velocities, the roughness of the corrugated culvert wall provides a low velocity boundary zone where passage for these small fish is possible. At higher velocities, however, the turbulence created by pipe corrugations can overwhelm small, juvenile fish whereas a smooth pipe may still allow fish passage.

Culverts become velocity barriers to fish passage by reducing the cross-sectional area of flow, reducing roughness, decreasing the flow path length and increasing the gradient by straightening the stream channel and presenting a uniform velocity distribution with a lack of resting areas. Placing a culvert at too steep of a gradient is a common cause of excessive velocities though even moderate velocities can be a barrier if the culvert length is beyond the endurance of the fish. Sudden changes in velocity at the culvert inlet, outlet or within the barrel due to debris or culvert design can also be barriers to fish.

The ODFW guidelines regarding maximum allowable velocities in culverts are designed to allow the weakest fish to swim at a sustained speed through a culvert without resting. Streambed simulation designs such as bridges, open arch culverts, and embedded culverts are the preferred design alternatives and do not have design water velocities, but non-embedded culvert designs that can meet the maximum allowable velocities are acceptable.

5) Height between the culvert outlet and the water surface

Fish have been observed to jump considerable heights and distances to clear obstacles, especially adult salmon on their upstream spawning migration. Few studies of the ability of fish to jump have actually been conducted, however, and this is especially true for young and small fish. From laboratory studies, Stuart (1962) determined that ideal jumping conditions for fish occur when the ratio of the jump height to the depth of the pool below the jump is 1:1.25.

Culverts placed at too small of a slope as compared to the stream gradient can result in impassable jumps to the culvert outlet as well as designs that did not adequately account for the potential of the streambed to degrade below the culvert. The lack of a resting pool below the outlet can also prevent fish passage. Again, even a small jump with a resting pool can be a barrier if velocities within the culvert are too great or the water too shallow.

6) Water Depth

Table 4 below summarizes some research concerning conditions for successful upstream migration of adult salmon and trout. The depth of water in a drainage structure is critical to fish passage for the following reasons (Dane 1978):

Table 4: Water temperature, minimum depth, and maximum velocity criteria for successful upstream migration of adult salmon and trout (Table from Everest et al. 1985 *In* Brown, ed. 1985).

Species of fish	Temperature range[1] °Farenheit	Minimum Depth[2] ft (in)	Maximum Velocity[2] fps
Pink salmon	45-60	0.59 (7)	7.0[3]
Chum salmon	47-60	0.59 (7)	8.0
Coho salmon	45-60	0.59 (7)	8.0
Sockeye salmon	45-60	0.59 (7)	7.0[3]
Spring chinook salmon	38-56	0.79 (10)	8.0
Summer chinook salmon	57-68	0.79 (10)	8.0
Fall chinook salmon	51-67	0.79 (10)	8.0
Steelhead trout	----------	0.59 (7)	8.0

[1] From Bell (1973), converted to English units.
[2] From Thompson (1972), converted to English units.
[3] Based on fish size.

1) Partially submerged fish do not get maximum thrust from body and tail movements

2) Incompletely submerged gills promote oxygen starvation and reduced swimming ability and endurance
3) Shallow water increases bodily contact with the channel bottom causing physical injury and increasing the risk of predation.

A number of conditions can lead to insufficient depth in culverts including; placing structures at too steep of a gradient; using wide, flat-bottomed structures; or having a structure in a site where it is necessary to design for highly variable flow conditions (very high and very low flows). Aprons for bridges or concrete box culverts can also result in shallow water depths.

Summary of Guideline Criteria vs. Biological Factors

Culverts with insufficient water depth for swimming, excessive water velocity, or an excessive jump height for bedform conditions and fish species are considered barriers to fish passage. In-stream work resulting in excessive turbidity can also be a barrier to fish, as well as result in weakening or mortality of eggs, juveniles and adults of both resident and anadromous fish. Delays to fish passage due to improper flow design is also an undesirable culvert characteristic.

We are used to seeing images of salmonids in the media performing amazing feats of jumping and swimming ability. It is important to consider, however, that like many engineering problems a factor of safety is desired, a "fish safety factor" (Gebhards and Fisher 1972). A given run of fish may have several different age classes and sizes, so it is desirable to design for the smaller, weaker fish in order to obtain a maximum percentage of fish passage.

Introduction to fish passage hydrology and hydraulics

Hydrology

Hydrology refers to the study of water. When people use this term in relation to fish passage they are usually referring to the quantity of water that can be expected at culverts during different situations. As was introduced in the previous section, the degree of acceptable delay in fish migration influences the level of streamflow that is designed for fish passage. A one day delay results in designing fish passage for higher streamflows than a two day delay (Figure 3).

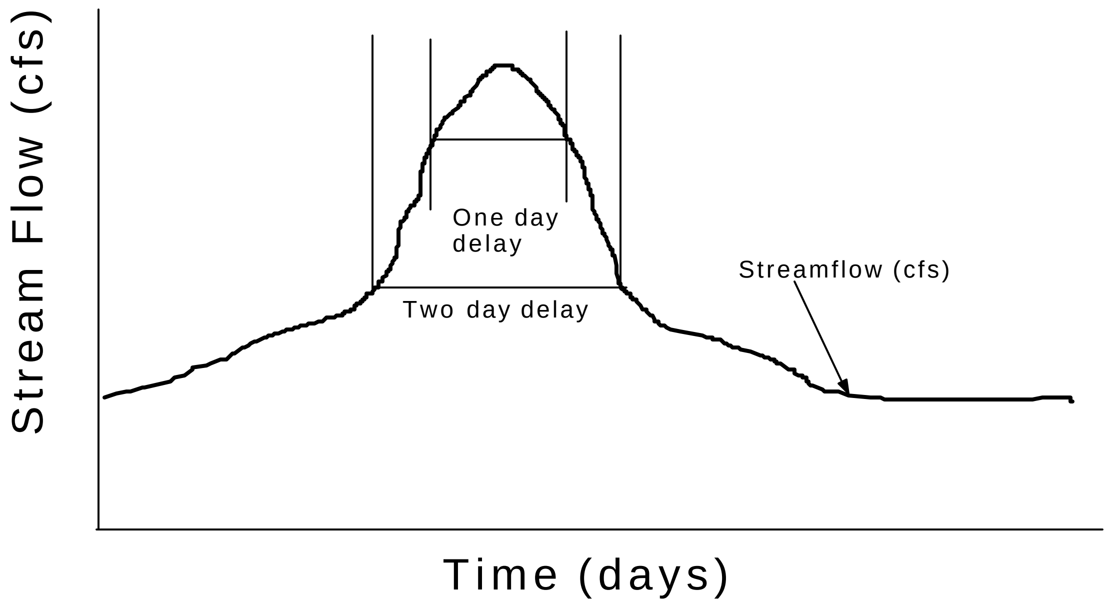


Figure 3. Difference in streamflows between picking a one or two day delay flow for a typical rainfall hydrograph.

In this case, a policy choice on what risk that you want to expose the fish to in regards to delay time, influences the design flow. In like manner, the assignment of risk is also used in determining how big a streamflow the culvert is designed to handle during peak flow events. In the Oregon ODFW guidelines (Appendix A) the chosen flow is the road/stream crossing can accommodate to the integrity of the structure the largest streamflow that would occur in a given hundred year period (i.e. the 100 year flow). The Oregon Department of Forestry in contrast calls for culvert designs for the 50 year flow to the top of the culvert or to three feet below the bridge bottom for bridges. In terms of culvert sizing, the difference between a 50 year and 100 year flood is about 20% in most cases. However, designing to the integrity of the crossing structure would allow for smaller culverts and bridge openings than designing to the top of the culvert (more detail about this fact is given in the culvert sizing section later in this training). Also understanding the integrity of the stream crossing structure requires advanced geotechnical analysis for culvert fills and is difficult to regulate or give guidelines for. For this reason, for the remainder of the document, we will design for the 50 year peak flood flow and use the top of the culvert or three feet below the bridge bottom as design criteria.

The Oregon ODFW guidelines (Appendix A) advise that the culvert should be designed to pass fish for at least 90% of the streamflows for a given season when fish are likely to pass. In other words the culvert should pose a fish passage problem only 10% of the time. In the guidelines, the following equation is given to relate this 90% flow to a two year peak flow:

$$Q_{10} = 0.18 * Q_2 + 36$$ (For two year peak streamflows greater than 44 cfs)

Where: Q_{10} - The 90% exceedence flow where fish passage is a problem only 10% of the time
Q_2 - The two year peak flow

In general, the two year peak flow is approximately 40-50% of the 50 year peak flow.

Culvert Hydraulics Definition of Terms

Before we begin a discussion of culvert hydraulics some key definitions of terminology that is used in describing conditions around culverts is needed. Many of the terms that are used in describing culverts is shown pictorially in Figure 4. A list of the key terms is as follows:

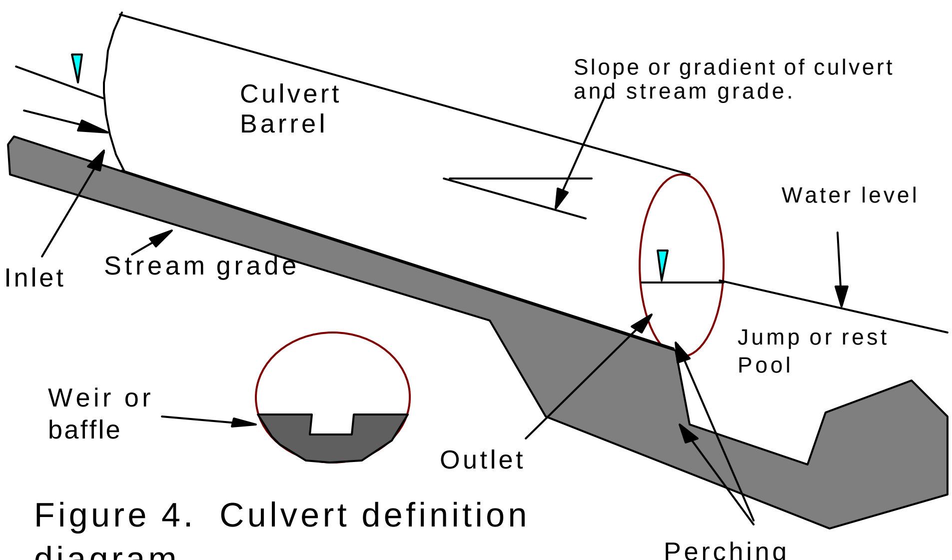


Figure 4. Culvert definition diagram

- **Inlet** refers to the culvert's upstream end.
- **Outlet** refers to the culverts downstream end.
- **Perching or outlet drop** occurs at the outlet end when the culvert outlet is perched over the downstream streambed.
- **Culvert Slope** refers to the culverts vertical rise from the inlet to the outlet divided by its length and

is usually expressed as a percent or in degrees

- **Downstream weir(s)** refers to a structure(s) placed downstream of the culvert that spans the stream and backs up water towards or into the culvert. They are often used for backwatering or for helping control erosion at the culvert's outlet.
- **Roughness** refers to the obstacles inside a culvert that slows down and diverts water flow.
- **Baffles** are small protrusions that stick up from the bed of a culvert to create roughness and/or catch sediment.
- **Weirs** are protrusions that span the bottom of the culvert and back water upstream towards the next weir or inlet of the culvert creating slow water areas with drops at the weirs. At high water a weir instead of backing up water may act more like a baffle simply adding roughness to the bottom of the culvert.
- **"Sinking a culvert"** refers to putting the bottom of the culvert in lower than the existing streambed (Figure 5). It is measured from the streambed that exists after installation of a culvert. Very specific guidelines on how to measure the degree of sinking are given later. In other literature this term is called depressed invert or countersinking (when the inlet is sunk more than the outlet).

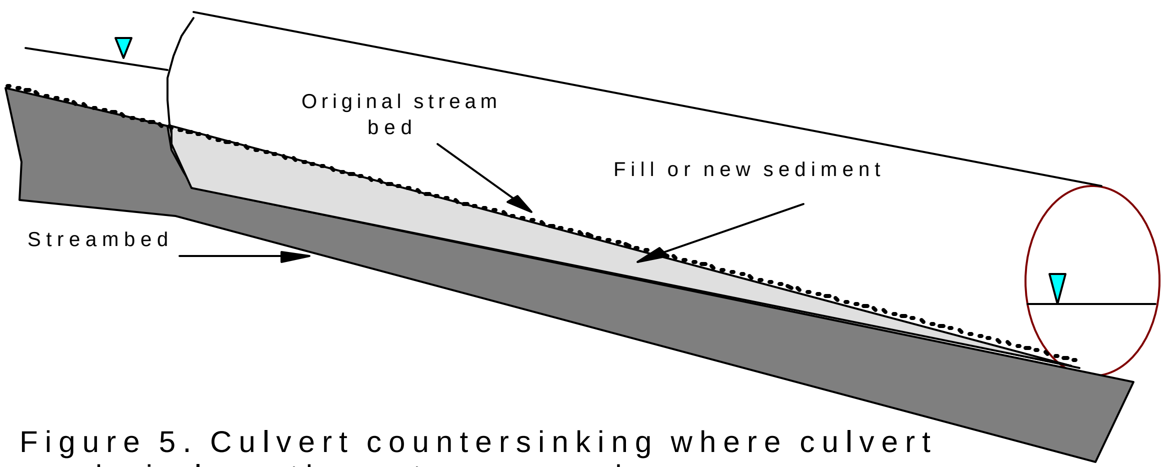


Figure 5. Culvert countersinking where culvert grade is less than stream grade

- **Embedding a culvert** is to put in larger and smaller sediment in a continuous interlocking manner (Figure 6).
- **Seeding a culvert** is putting in scattered larger sized sediment in a discontinuous manner to increase roughness (Figure 6).

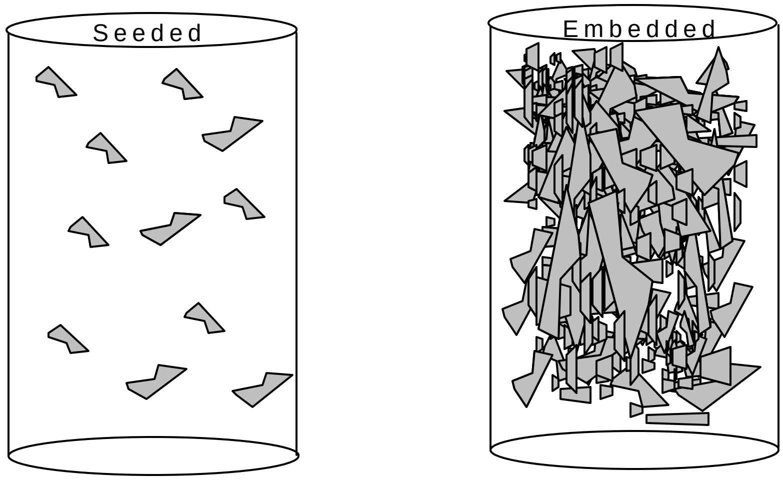
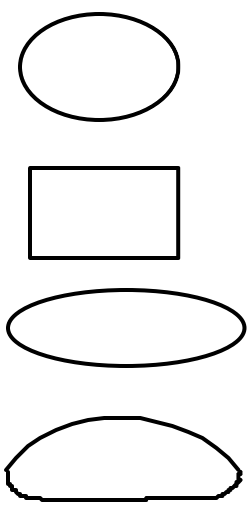


Figure 6. Planveiw of seeded vs. embedded culvert

- **Culvert shape** refers the cross-sectional shape of the culvert. Culverts come in a variety of shapes (Figure 7) that include but are not limited to round, ellipse, pipe-arch, square, and rectangular. Culverts can also be made of corrogated metal pipe (CMP) which is the most common material. They can also be made from plastics, concrete, and even wood.



Round Culverts: High load strength but relatively narrow for given discharge capacity leads to flow constriction. Low priced in comparison to other shapes.

Square Culverts: Typically used with concrete culverts. Square culverts narrow for given discharge like round shape. Rectangular shaped culverts wide and can have widths that do not constrict flow.

Elliptical (squash culverts) and pipe arch culverts typically made with corrogated metal pipe. Higher priced than circular culverts for given flow capacity, but wide design allows for greater flow capacities in low road fills. W idth allows for culverts that do not constrict flow for embedded designs. Lower load strength than circular culverts.

Figure 7. Various Culvert Shapes

- **Streambed simulation** refers to the concept of trying to simulate natural stream conditions inside the culvert by either embedding the culvert with material similar to the streambed or by using an open arch with a natural bottom.

- **Bankfull width** refers to the stream width that occurs when a fairly large storm comes that occurs once every two years. More detail about how to determine bankfull width in the field is given later.
- **Jump or rest pool** refers to a pool below the culvert or below a culvert weir which fish will use for resting and to get momentum to jump over an outlet drop or drop from a weir.

Culvert Hydraulics: Keys to making a culvert fish passage compatible.

In order to make a culvert compatible for fish passage three provisions must occur:

1. Manage water velocities in culvert
2. Prevent drops in and around culvert
3. Provide adequate water depth

Manage Water Velocity

Water velocity occurs when the potential energy due to differences in elevation is converted into velocity and other forms of energy as water moves down hill. The greater the elevation change between the culvert inlet and the outlet the more challenging managing water velocity becomes. On relatively flat streams (streams from 0-3%) there is little elevation change to contend with and several strategies can work to manage the small amount of potential energy. However, on steep streams (greater than 10%) the challenge becomes difficult and few things can be done to reduce velocities to acceptable levels. There are essentially four ways to prevent excessive velocities from becoming a barrier to fish passage inside a culvert.

1. Eliminate Potential Energy – Make culvert flat
2. Create roughness to cause energy dissipation so that most of energy does not go into velocity production.
3. Use backwatering and drops and pools to dissipate the energy instead of constant high velocity
4. Create velocity shadows or hiding places inside culvert so that fish can rest or exist in places inside the culvert with lower velocity than the average velocity.

Placing a culvert flat is one of the design strategies that will be discussed in the methods section to provide for fish passage. In essence, the design is simple in that it eliminates velocity by eliminating potential energy (i.e. change in elevation between the inlet and the outlet). Since culverts typically have very low roughness it is important to place culvert flat as most energy will be converted to velocity in bare culverts. Excessive velocities for juvenile fish passage can be found in culverts with as little as 0.5% gradient so careful installation to get these culverts truly flat is necessary.
Roughness causes the potential energy to be expended in other ways besides velocity creating turbulence beyond what is found in typical flowing water. Streambed simulation designs discussed later,

attempt to mimic the natural roughness of a stream channel inside a culvert. The idea of dissipating energy in ways other than velocity to slow water down runs counter to the longtime goal of making culverts hydraulically efficient. A hydraulically efficient culvert converts most energy into velocity and has very little roughness. Therefore, an efficient culvert could convey more water with the same opening size. Unfortunately for fish, an efficient culvert has extreme velocities and at the outlet the excess velocity and energy is often converted by scouring the streambed at the outlet which creates a drop at the outlet. Adding roughness to a culvert and developing methods to keep roughness in the culvert is a major switch in thinking for many engineers. In thinking about roughness imagine your car going down a road full of boulders and cobbles rather than down a paved road. The end result is you can not move down the road as fast as on pavement as you must dodge around boulders trying to find the path of least resistance. In essence this is the same thing that water must do and as billions of molecules are doing the same thing the water piles up deeper over the boulders and rocks than it did over the pavement.

The most common method of estimating streamflows in natural and artificial stream channels is called the Manning's equation. This equation uses a term for roughness called Mannings N. The Manning's equation for streamflow is as follows:

$$Q = A * 1.49/N * R^{2/3} * S^{1/2}$$

Where:
A = Cross-sectional area in square feet
Q = Streamflow in cubic feet per second
N = Mannings N values available in reference books and varies by stream roughness conditions.
R = Hydraulic radius in feet which is the area of water flow divided by the wetted perimeter. This value is usually similar to average depth.
S = Stream slope in rise over run (i.e. percent divided by 100)

In streams or culverts where there are large obstructions that block and divert flow, the Manning's N is relatively high so the flow and velocity for a given stream depth is lower. What is not commonly known about Manning's N or roughness in general, is that the effect of roughness is flow related and that most Manning's N values are determined during periods of high flow. As water gets shallow the Manning's N increases meaning that roughness affects on lowering velocity increases. This is one reason why wider pipe-arch shaped culverts are advocated when attempting to design for natural streambed simulation with culverts because wider culvert will on average have less depth. Using published Manning's N values in design will have another consequence, people will when using them necessarily underestimate roughness and overestimate average velocity at the lower flows that are used in the design of fish passage in culverts. For this reason, methods that account for the relative submergence of roughness elements (i.e. the water depth over cobbles and boulders for a given design streamflow) should be used to estimate roughness and velocity. Later in the rationale section a method that does this is examined for use in design of embedded culverts.

The use of downstream weir(s) to back water throughout the culvert or the use of weirs inside the culvert attempt to manage the potential energy by concentrating its dissipation at designed drops rather than converting it into high velocity water. In addition, adequate pools are designed to allow fish to rest in between these drops (as well as help dissipate energy from the drop) so that they can move upstream through the culvert.

Fish tend to occupy areas of water that have lower velocities (Powers et al., 1998 and Belhke et al. 1990). These areas that fish use are called occupied areas and the velocities are called occupied velocities. In culverts that have obstructions to flow there tends to be more areas of slower water where fish can occupy and rest between times where they have to negotiate high velocity water. Common areas where low velocity occurs is along the margin of the culvert, immediately downstream of boulders, and along the bottom of the stream. If one examines the average velocity of most steep gradient streams you would find that natural streams are out of compliance for juvenile fish passage! The reason the fish can negotiate these streams is because of these areas of relatively low water velocity. One reason to have wide culverts is to have more opportunities for these low velocity areas. Culverts in which the water is constricted into a narrow flume provides little opportunity for these low velocity rest areas.

Prevent drops in and around culvert

Drops in water surface or between the culvert and stream bred can occur at the inlet, inside, and at the outlet of the culvert. The most common drop seen in old culverts is the outlet drop in which erosion downstream from the outlet has caused the culvert to become perched. Unless the drops are minimal and there is an adequate pool downstream and upstream for resting these drops can inhibit or outright block fish passage.

The culvert inlet can have a drop between the streambed and the culvert bottom if the culvert is sunken relative to the streambed and no material has collected inside the culvert. In this case the fish have just moved through a culvert which typically have less resting areas and now must use burst speed to move through this drop. For juvenile fish this may not be possible. For this reason as well as others, sunken culverts should be embedded so as to prevent this drop. Another inlet drop that can occur is when the culvert constricts flow at the inlet. This occurs when a wide stream enters a narrow culvert (especially one that has a projecting inlet). What occurs here is the water concentrates and the water velocity increases at the inlet causing the water elevation to drop. When there is a flow constriction material tends to scour out and embedded culverts become bare near the inlet creating an additional bed drop described above. It should be noted that the roughness inside a bare culvert is less so there is less energy dissipation so more of it will be converted into velocity further dropping the water surface. The use of wide pipe-arch culverts adequately sized to the stream width is advocated later in this document in part to prevent this kind of inlet drop from occurring.

Drops can occur inside the culvert because of wood and sediment clumping and creating drops or by the culvert settling into the sub-grade creating an uneven slope. To prevent material from clumping together field checks of culverts are critical. To prevent settling steps need to be taken to make sure the

sub-grade is stable (see installation considerations in next section).
Outlet drops are due to excess energy built up in the culvert being applied to the streambed downstream causing scour of the streambed. Narrow culverts that concentrate flow and have little roughness inside them create excess velocity inside the culvert that is dissipated downstream. Designing a culvert that is adequately wide and has adequate roughness should prevent downstream scour. However, additional steps like backwatering from a downstream weir or rip-rapping the downstream end may be desirable to prevent scour downstream.

Provide adequate depth

The requirements for stream water depth were discussed in a previous section. Inside culverts adequate water depth is obtained via backwatering from downstream weir or riffle or in the culvert by weirs or by having adequate roughness (simulated natural streambed) that slows the water and creates variable water depths for fish. The estimated average water depth at various design flows can be estimated using the Manning's equation given above. For embedded culverts, methods that better estimate roughness should be used. In the case of backwatering, special hydraulic equations called backwater equations can be used.

Road/Stream Crossing Restoration Methods

Steps in Restoring Fish Passage in a Basin or Land Ownership

There are seven steps in restoring fish passage at road/stream crossings in a basin or land ownership:

1. Find and prioritize problem road/stream crossings
2. Get information about stream and other conditions at crossings to be restored
3. Decide if installation can be repaired or improved or must be replaced
4. Decide on design strategy based on information collected
5. Prepare a design
6. Install new road/stream crossing structure
7. Monitor and Maintain road/stream crossing structure.

In this section considerable detail will be given on accomplishing each of these steps.

1. Finding and prioritizing problem road/stream crossings

Current Stream Crossing Protocols in relation to information required to prioritize or design road/stream crossing structures

There are several methods being used to survey culvert condition in Oregon. Two prominent methods are the ODFW culvert survey form (Figure 8) and the ODF road hazard survey protocol (ODF, 1998). The ODFW survey form was used to evaluate hundreds of culverts on state and county roads. The ODF survey protocol has been used on thousands of culverts. The information from both these methods (as well as others), by making some elementary assumptions (or by taking a few extra measurements), can be used to estimate if a culvert is partially or totally blocking fish passage or poses a moderate to high risk of catastrophic crossing failure using criteria given below.

The key measurements from the surveys that can go into making criteria are:

1. Culvert Slope,
2. Outlet Drop,
3. Outlet pool dimensions,

Culvert Evaluation Form

Stream____________________________________ Date_________________

Tributary to_______________________ Basin________________________

USGS Quad Map Name:__________________________(Attach Copy of Map)

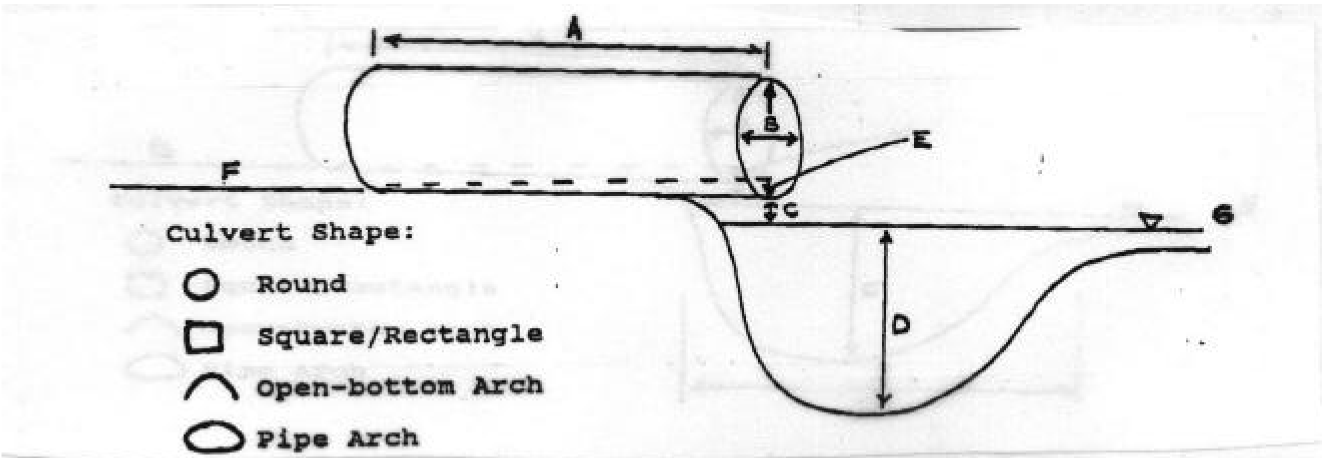
Lat:_______ _______.______ min; Long:_______ ______._______ min

UTM Zone: 10/11; Easting:______________M; Northing:____________M

Twnshp:______N/S Rng: _______E/W Sec.:_________ ¼ of ¼_________

Road Name/Number:_____________________ Road Mile_________________

Evaluator:___________________________ Phone:(____)______________



FACTOR	MEASUREMENT	RECORD IN....
A: Length of culvert		feet (nearest ft)
B: Culvert Height and Width		inches
C: Drop to pool		inches
D: Pool depth below culvert		feet (nearest ft)
E: Culvert slope (drop from horizontal)I		drop in inches or % slope
F: Stream gradient above culvert		% slope
G: Stream gradient below culvert		% slope

IIf culvert slope is not consistent end to end, describe situation under COMMENTS on other side.

Figure 8. ODFW Culvert Survey Form

Culvert Material (circle): Galvanized Steel Tarred Galvanized Steel

Concrete Wood Aluminum Other

(Describe under COMMENTS below)
Describe any internal baffles, weirs or bedload materials: __________

____

____

Who owns/maintains the culvert?______________________________________

Is the culvert in good physical condition?___________________________

____

____

Fish species present above culvert:__________________________________

Fish species present below culvert:__________________________________

Describe upstream adult or juvenile passage problems, if any: _______

____

____

Miles of stream blocked:______ Quality of Habitat Blocked:___________

In your opinion, what improvements are needed?_______________________

____

____

Other comments or observed problems:_________________________________

____

____

____

____

____

Film Roll #____________; Photo #'s___________________________________

Figure 8. ODFW culvert survey form (Continued).

4. Culvert size (diameter and length),
5. Active channel width estimate (see section on information needed for description),
6. Notes on whether culvert has boulders and cobbles in it in a continous embedded fashion (see definition for embedded),
7. Information regarding baffles or weirs including their height and spacing; and
8. Notes on culvert such as damage affecting capacity

Deciding if road/stream crossing partially or completely blocks fish passage

Criteria used in deciding if a culvert had a fish passage "problem" in ODFW- Oregon Department of Transportation state and county road/stream crossing surveys included a slope greater than 1% and an outlet jump greater than one foot if only adult passage was considered and six inches if juvenile passage was also considered. If a jump occurred the pool needed to be 1.5 – 2.0 deeper than the height of the jump. Another concern that put culverts into the problem category were inlet deposits and drops at the inlet which was termed "diving flow."

Using this system the state county road survey found the following number of problem culverts in Oregon:

Coastal Basins – 1140 crossings
Lower Willamette – 167 crossings
Grande Ronde – Imnaha – 83 crossings
Upper Willamette – 771 crossings
John Day basin – 260 crossings

Another system that defines two levels of concern including partial versus complete fish passage blockage as well as looks at flow capacity is presented below.

Defining the term Apartial fish passage blockage≅

For the purposes of these guidelines partial fish passage blockage" is defined as: stream crossings because of their design, maintenance, or condition are not allowing for juvenile salmonid fish passage. Juvenile salmon, for the most part, require two feet per second or less velocity, outlet perching less than 6 inches, and little to no inlet constriction or drop. In addition the culvert should be free from debris that may concentrate flow and increase velocities. Flow depths should be 12 inches or more in the culvert or the culvert should have a simulated natural streambed similar to channel conditions in the natural channel.

In terms of measured crossing dimensions, partial fish passage blockage would occur if the following conditions are ***not*** met.

For bare (non embedded) culverts:

1. Unless backwatered properly the slope should not exceed 0.5%. ABackwatering properly is when

the top downstream control below the culvert is at an elevation at or greater than the inlet bottom at the upstream end of the culvert or advanced open channel backwatering calculations show that backwatering is adequate. Preferably for a bare culvert the elevation of the backwatering structure is greater than the inlet bottom depth by six inches or more.

2. The outlet drop should be no more than 2 foot from the culvert outlet lip to the residual pool water elevation. The residual pool is defined as the pool that would be left over if there was no flowing water simply by the damning effect of the downstream control point. If there is any outlet drop, the residual pool for the downstream jump pool should be 1.5 times deeper that the jump. In fact for culverts that do not use streambed simulation designs, in order to get required water depth, adequate backwatering from the outlet end is needed (Figure 9).

3. To control constricting of flow at the inlet, the culvert diameter or span should be at least 2 the width of the natural bankfull channel. The culvert should be free of large debris blockages or cave in areas that constrict flow and make for high velocity areas. There should be little or no inlet drop such that the flow drop as water enters the inlet should be less than a few inches. The culvert inlet lip should be about level with the channel bed immediately upstream.

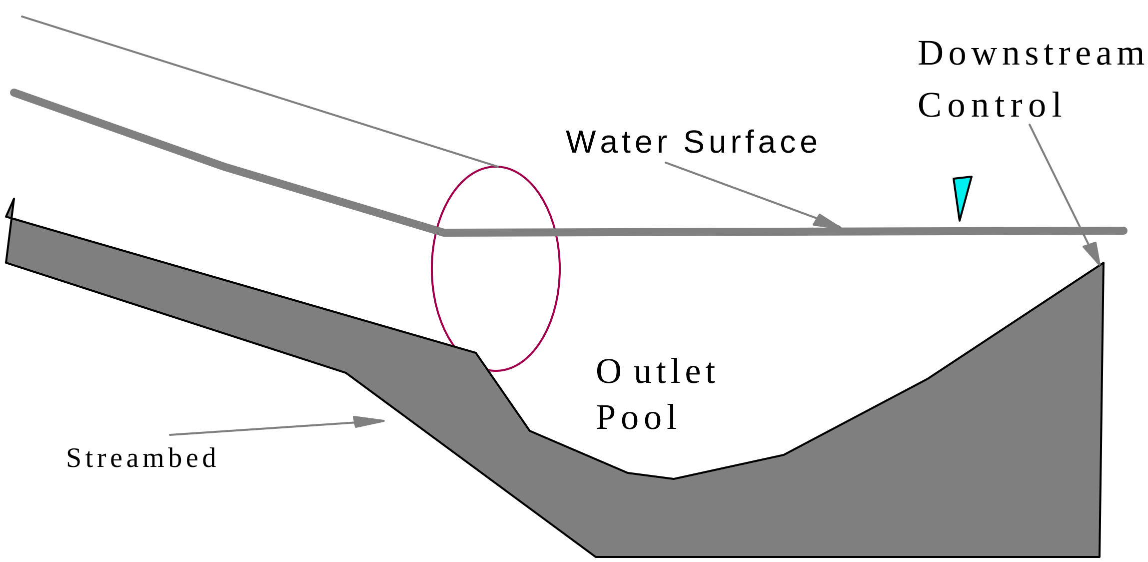


Figure 9. Culvert backwatering from outlet.

4. The culvert should be less than 100 feet long.

5. There is outlet backwatering such that the water depth even at baseflows is 12 inches deep.

For embedded culverts:

1. The culvert should have a variety of material in it forming a simulated natural channel inside the culvert. The material should in most places be a foot or more deep. It is not enough just to have placed material in the culvert but there should be evidence of deposition and reworking of smaller material. If material is lacking use the assumptions for the non-embedded culvert above.

2. There should be no outlet drop.

3. The inlet should have sediment in it at the inlet not a sudden drop. The culvert width should also at least 90% of the average bankfull channel width to prevent channel constriction, channel scour, and drops from occurring at the inlet.

For baffled culverts:
1. Generally speaking, the baffles/weirs should be 0.1-0.15 of the total height of the culvert. The spacing varies with streamflow and culvert gradient but should be set up that one baffle/weir at least at low flow backwaters slow water to the base of the next weir at a minimum depth of eight inches when the pool is residual. If evaluating baffled culverts, it is important to take culvert gradient, weir height, and weir spacing to use in calculations to determine adequacy. More information on calculating weir spacing is in the references given in section 5. In addition, the baffles should be free from debris and sediment in order to function properly.

2. There should be little or no outlet drop (no more than six inches). If the weir is put on the edge of the outlet that drop should be calculated from the residual pool water level to the top of the weir. If there is a small drop the residual pool for the jump pool should be at least 1.5 times as deep as the drop distance.

3. There should be little or no inlet drop and the top weir should backwater into the upstream natural channel.

For Bridges and Open Arch Culverts:
1. Generally speaking a bridge or open arch pose no fish passage problems. An exception is when an bridge/arch is undersized and flowing on bedrock. In these instances the bridge or arch may constrict flow and blow out boulders and cobbles leaving a bedrock chute. For calculation purposes, if the bridge/arch can pass a fifty year flood flow or more this should not be a problem. See step five on sizing culverts and bridges for information on how to do this calculation.

2. Open arches should be free of large debris that may constrict flow and cause high velocity areas inside the arch.

Defining complete fish passage blockage
AComplete fish passage blockage,≅ for this guidance, refers to instances in which the design, maintenance, or condition of the stream crossing is such that even most (if not all) adult salmonids cannot move upstream through the crossing structure. Blockage would result in conditions that exceed most adult anadromous salmonid fish swimming capabilities. Culvert water velocities for fish passage

design flow in excess of 10 feet per second, outlet drops over 4 feet or over 1 foot without adequate jump pools, and extreme inlet drops or material in the culvert that cause severe barriers would cause a blockage. Flow depths should be 8 inches or more in the culvert at higher flows or the culvert should have a simulated natural streambed similar to channel conditions in the natural channel. In terms of measured crossing dimensions, crossing that have passage blockages would also have measurements outside of the following conditions. **These should never be used as guidelines for adult fish passage. The only use for the following characteristics is to differentiate culverts that have partial blockages from those that have complete blockages for assessment work.**

For bare (non embedded) culverts:
1. Culvert slope should not exceed 4% unless there is backwatering or unless the culvert is less than 50 feet long. For short culverts (less than 50 feet) gradients greater than 4% (up to 6%) can be tolerated if not combined with an outlet jump. For backwatering, if downstream control is at an elevation that is equivalent to a point in the pipe with less than 50 feet to go in the inlet the gradient can be up to 6%.

2. The outlet drop should be no more than 4 feet from the culvert outlet lip to the residual pool water elevation. The residual pool is defined as the pool that would be left over if there was no flowing water simply by the damning effect of the downstream control point. If there is outlet drop over 6 inches, the residual pool for the downstream jump pool should be at least 1.5 times the height of the drop or 2 feet deep (whichever is less).

4. The culvert should be less than 200 feet long.

For embedded culverts:
1. The culvert should have a variety of material in it forming a simulated natural channel inside the culvert. The material should in most places be a foot or more deep. It is not enough just to have placed material in the culvert but there should be evidence of deposition and reworking of smaller material. If material is lacking use the assumptions for the non-embedded culvert above.

2. There should be minimal outlet drop

3. The inlet should have tapering streambed material into it not a sudden drop at the inlet. The culvert width should also be at least 1/2 the bankfull channel width to prevent channel constriction and drops from occurring at the inlet.

For baffled culverts:
1. Generally speaking, the baffles/weirs should be 0.1-0.15 of the total height of the culvert. The spacing varies with streamflow and culvert gradient but should be set up that one baffle/weir at least at low flow backwaters slow water to the base of the next weir. If evaluating baffled culverts it is important to take culvert gradient, weir height, and weir spacing to use in calculations to determine adequacy. More information on calculating weir spacing is in Appendix C. In addition, the baffles should be free from debris and sediment in order to function properly. Even if the weirs are not spaced

at optimum this is probably not a fish passage blockage. However, if the culvert baffle(s) are ripped out or improperly functioning, this may pose a blockage problem.

2. The outlet drop should be no more than 4 feet. If the weir is put on the edge of the outlet the drop should be measured from the residual pool water level to the top of the weir. If there is a drop the residual pool for the jump pool should be at least 1.5 times as deep as the drop distance or two feet deep (whichever is less).

3. There should be little or no inlet drop and the top weir should backwater into the upstream natural channel.

For Bridges and Open Arch Culverts:

1. Generally speaking a bridge or open arch pose no fish passage problems. An exception is when a bridge/arch is undersized and flowing on bedrock. In these instances the bridge or arch may constrict flow and blow out boulders and cobbles leaving a bedrock chute. For calculation purposes if the bridge/arch can pass a fifty year flood flow or more this should not be a problem.

2. Open arches should be free of large debris that may constrict flow and cause high velocity areas inside the arch. However to be a total blockage the problem must be severe causing velocities over 15-20 feet per second etcetera.

Determining risk of catastrophic fill failure

Many times stream crossing fills catastrophically fail due to water backing up upstream of the fill due to an undersized or blocked or partially blocked culvert weakens the fill or breaches the fill. At other times, excess water may flow around the fill or over the fill not breaching the fill. According to ODFW guidance an acceptable level of risk of failure is that the fill should remain structurally stable up to a 100 year peak flow by design. ODF in contrast, specifies that culverts and bridges should pass the 50 year peak flow to the top of the culvert (not to structural integrity of the fill) or to 3 feet below the bridge bottom. The ODF design specifications in essence are in most cases at least allowing for structural integrity to a 100 year peak flow event. The reason is that increasing headwater depth above the top, increase flow capacity to a large degree. For instance a 7 foot diameter culvert can pass 262 cfs. If the fill is 20 foot high and the point of structural integrity is up to 14 feet and water is allowed to backup to 14 feet the culvert capacity increases to 525 cfs. If 262 cfs was the 50 year peakflow, 525 cfs is well beyond a 100 year peakflow perhaps as high as a 200-300 year peak flow. Please refer to the culvert and bridge sizing section of step five for more information.

Because both ODFW and ODF (as well as the Forest Service and other Federal Agencies) specify designing crossings to withstand a 100 year peakflow, crossings that do not meet ODF or ODFW current standards are considered to have moderate risk of failure. A culvert can be considered at high risk of failure if the design culvert flow capacity is less than 25% of the 50 year peak flow determined by the ODF method or the determined capacity to maintain structural integrity is less than 25% of the calculated 100 year peak flow. The 25% figure corresponds to a flow capacity that is probably not even capable of passing a 1-2 year peakflow event. In other words a high risk culvert is due to overtop and build pressure if not fail during the next sequence of normal seasonal flooding.

Many times, culverts become blocked with debris, damaged, or partially collapse. In the field, it is important to note the degree of cross-sectional loss of area that is due to these factors. In calculating culvert capacity the amount of flow a culvert can handle is largely dependent on cross-sectional area. To calculate a culvert with reduced cross-sectional area, a culvert with a smaller cross-sectional area can be used in determining the lowered flow capacity. See information in the culvert and bridge peak flow sizing section in step 5.

Crossing Priority Types:

In the previous sections, definitions were given for fish passage blockage and impediment and moderate to high catastrophic fill failure risk. With these definitions in mind a scheme of prioritization can be developed with fish presence, fish passage, and risk of fill failure in mind. As a first cut road/stream crossings can be grouped into the following five types with type 1 having (in general) greater priority and each succeeding type having less priority in sequence order. The current criteria is geared towards coho salmon habitat but could be modified for other regions by changing the target fish species.

Type 1: Culverts that Ablock≅ fish passage (see previous section) to potential coho salmon habitat or have high crossing failure risk to downstream coho salmon habitat within two stream miles downstream. (Note general fish presence/absence can be obtained from ODF or ODFW field offices specific species range can be obtained from ODFW field offices. A system to determine both general fish presence and coho/steelhead presence where specific information is vague is given in section 9.)

Type 2: Culverts that Aimpede≅ fish passage to potential coho habitat or have moderate risk of fill failure that could effect downstream coho salmon habitat within stream miles downstream of crossing.

Type 3: Culverts that block or impede fish passage to potential steelhead or sea run cutthroat trout habitat or have high to moderate risk of fill failure that could effect steelhead or sea run cutthroat habitat within two stream miles downstream of crossing.

Type 4: Culverts that block or impede fish passage of any gamefish (generally resident rainbow or cutthroat trout define upstream extent of fish) or crossings that have a high risk of fill failure that can effect resident fish habitat within two stream miles downstream of the crossing.

Type 5: Culverts on non-fish bearing streams that have a moderate to high risk of failure.

Justification of priority types and their proper use:

The rationale for the priority types is to give a first cut prioritization based on fish present and problems or risks associated with road/stream crossings. There are other schemes such as the Washington state method that takes a quadratic root of several factors (some of which are unmeasurable) (Bates, 1991). There are other inventories that rely totally on professional judgement with no criteria as well. The typing with defined fish passage impediment/blockage and failure risk gives some solid measurable criteria without constraining the field professional with a system that has several unmeasurable parameters.

In general, a priority type one will be lower in the stream system (i.e. the larger downstream portions of watersheds) because coho salmon tend to not use higher gradient habitats that cutthroat and steelhead use. Therefore by using coho as a parameter for the highest priority type should also target the most downstream culverts as well. There will be times when a priority type two is in actuality a higher priority than a priority type one. An example of this could be a small coho salmon stream that has a blocking culvert that blocks off about 1/4 of a stream mile of habitat would be lower priority than a type two culvert that impedes fish passage for potential or actual coho habitat for three tributaries and a main stem section that totals 10 stream miles. In deciding which culverts are highest priority a possible system might be the following:

1. Get required information on all culverts using a survey protocol (see section 7)

2. With the survey information calculate whether the culvert has characteristics that would cause it to be classed as a blockage or impediment to fish passage or a moderate or high failure risk. Also determine what the fish use (or potential fish use) is upstream and downstream (up to two stream miles) from the crossing.

3. With the fish passage, failure risk, and fish use classifications assign each culvert a priority type as defined above.

4. Sort the database based on classification into the five types.

5. Based on information such as the actual potential habitat blocked (in terms of stream miles and quality) to further prioritize crossings within each type. Examine the highest priority ones in each type to see if it can be ranked above some of those in a higher priority type. This step should be done in consultation with the local fish biologist and possibly forest practices forester and other local expertise.

6. After doing all this rank all the culverts examined.

After setting this scheme up, it must be stressed that prioritizing and then targeting crossings for repair and replacement is extremely complex with dozens of technical and social factors to consider. It may be that there is a lower priority culvert that has a landowner that is willing to fix it at his or her cost. Obviously even though this is a lower priority, it still represents an excellent opportunity. However, if a local entity like a watershed council is given a lump sum of money, this scheme can be useful in determining which culverts to fix in what order and can be used as a base to add the other less quantifiable factors concerning crossing priorities to be built upon it.

2. Get information about stream and other conditions at crossings that need improvement

The goal of this step is to get the necessary information in order to make an informed decision during steps three and four when deciding between which design alternative to follow. Much of the information required may have already been obtained during culvert surveys to find and prioritize culverts or other road/stream crossings that are not passing fish or pose other risks to resources. The information required centers on the types of fish present and on the physical characteristics of the stream in and around the crossing as well as the watershed area in order to determine design flows.

Fish Presence Information

Information regarding the presence and distribution of various fish species can be obtained from ODFW or ODF offices. However, on many streams it is unknown whether fish are present or which species is present. One method of coarsely determining fish presence can be found in interim guidance based on stream size and slope and the presence and absence of waterfalls and other migration blockages Table 5. If attempting to ascertain the presence or absence of a fish species specific guidance has been developed on how to survey streams for fish presence/absence ODFW and ODF (1995).

Crossing Physical Characteristics

For all stream crossings

1. Location of stream crossing (should include legal or lat long coordinates as well as descriptive information if helpful)

2. Size of watershed above stream crossing and corresponding 50 or 100 year peak flow calculation (see section on peakflow calculations on the specifics of calculation).

Table 5. Field and map based estimates of fish presence from ODF rule guidance.

Type of Barrier		Physical Survey		Map Analysis
		Salmon & Steelhead	Resident Trout	
Falls & Chutes		8'+	4'+	Any waterfall marked on a map.
		2'+ require a jump pool 1.25 times the fall or chute height.		
Channel Steepness	With Pools	30' or more @ 20%+	20' or more @ 20%+	20%+
	W/O Pools	30' or more @ 12%+	20' or more @ 12%+	
Lack of Livable Space		No pools approximately 12" or more in depth during spring spawning.		60 Acres or Less (Coast 80 Acres or Less (South Coast) 100 Acres or Less (Interior) 300 Acres or Less (Siskiyou) 350 Acres or Less (Blue Mountain and East Cascade)

For fish bearing streams (all fish bearing stream crossings)

1. Profile of existing streambed: When designing culverts simply to pass peak flows, the culvert was assumed full and stream gradient was irrelevant. When considering fish passage, however, stream and culvert gradient becomes an extremely important factor as open channel flow hydraulic characteristics become important. The existing stream profile is the elevational surface of the stream in and around the road crossing. It can be measured with a clinometer (only to the nearest 0.5 to one percent precision). An abney or hand level with staff can improve this precision somewhat. With a tripod level or stadia precision is greatly improved (to 1/10 of a percent). This greater precision can also be achieved with a water leveler or builders level.

Often the existing stream profile is artificial due to an existing culvert installation. Both scour at the outlet and deposition upstream of existing undersized culverts is common. Because of these types of problems it is preferable to profile at least 100 feet upstream and downstream from the existing road/stream crossing. Taking a long profile can be especially important in determining design criteria for sunken/embedded culverts or in doing “flat placed culverts.”

2. Stream bed material (needed for streambed simulation designs): The type of bed material that is in the pre-existing stream bed or in the streambed upstream is critical to know for designs that depend on culvert sinking strategies. The "hydraulic roughness" of the culvert bottom is related to the size of bed material. Hydraulic roughness in turn is related to water velocity and water depth inside the culvert. The sizing of material to embed the culvert with should be similar to the size of material in the adjacent natural stream channel. The various size classes are as follows:

Bedrock..............>13 feet diameter	Bigger than a car or continuous underlayer
Boulders.............>10 inches to 13 feet	Basketball to car size
Large cobble.......>6 in. to 10 inches	Cantaloupe to basketball
Small cobble...... >2.5 inches to 6 inches	Tennis ball to cantaloupe
Coarse gravel......>0.6 inches to 2.5 inches	Marble to tennis ball
Fine gravel.........>.1 in. to 0.6 in.	Ladybug to marble
Sand....................<0.1 in.	Smaller than ladybug, but visible as particle; also gritty as you rub through hands.
Fines..................Not visible as particles	Silt clay muck (not gritty)

While a formal sediment survey is not required, it's important to note the predominant sediment type in the stream and the predominant type in the middle of the stream where water velocities are greater. Since the immediate upstream and downstream areas around an existing culvert may be influenced by scour and deposition around the culvert it is important to take estimates away from these influence zones. The actual determination can be an estimate or can be derived from a cross-section where you pick up and measure systematically or randomly chosen bed particles.

3. Amount of fill material associated with stream: It is also important to estimate the depth of valley fill material. Valley fill refers to layers of unconsolidated gravel, sand, cobble, and other sediment that lie over the top of the bedrock. If little fill is present, then culvert sinking/embedding strategies become impractical because of the difficulty of sinking into bedrock. On the other hand, placing an open arch in a place where there is deep valley fill would require excessive excavation and make an open arch design impractical. If nervous about bedrock when planning on sinking culvert into an existing streambed, it may be wise to take soundings with a metal stake or rebar to check for depth to bedrock. A far too common problem with sunken culverts is that at installation unexpected bedrock is discovered.

4. Active stream width: If there is any chance that a streambed simulation design will be used by sinking or embedding the culvert or if using an open bed design knowing the average active width is critical as the culvert should be wider than the active width of the stream to prevent inlet drop and possible bed scour.

Active width is the stream width that occurs when larger streamflow events occur. The recurrence of these larger streamflow events associated with active flow is about once every one or two years. The locating of active width, while generally based on scientific principles, requires judgement when determining it in the field. In alluvial streams (i.e., in low gradient streams in wider valleys) that have not been incised (i.e., downcut) the active mark is usually where the bank slope moderates from being steep to being more gentle or even flat (Figure 10). Unfortunately, most small streams that are candidates for placement work are either incised or confined by side slopes. With these types of streams clues must be sought on where the active flow mark on the bank occurs. Abrupt changes in vegetation are good clues. Another is the level to which drifted material is deposited on the bank. Changes in rock coloration or intensity of moss or liken growth are also possible indicators. Abrupt changes in texture of the bank material may also be clues. The active width is measured from one side bank mark to the other. Features like large islands that would be dry even under active conditions need to be subtracted out. Active width should be determined for at least 10 cross-sections in the reach that fish passage restoration work is being done. Furthermore, width measurements should be spaced apart one or two channel widths. Data from previous Oregon Department Fish and Wildlife streams surveys may also be used to determine active width (note: active channel width and bankfull channel width are similar).

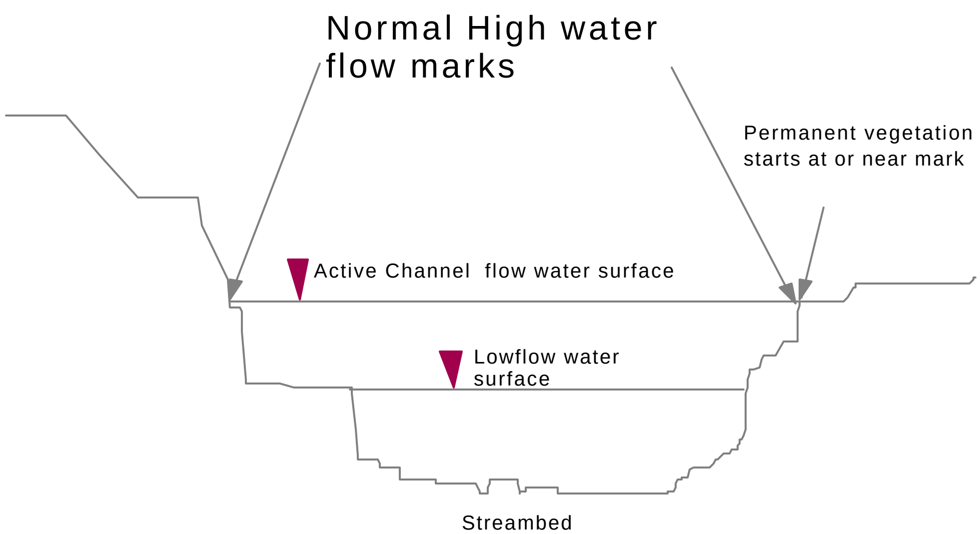


Figure 10. Highwater flow marks and active channel width schematic.

5.   Outlet conditions: it is important to know if there is a current culvert perching problem, this information should be obtainable from the streambed profile. In addition, any information about the streambed material immediately downstream of the culvert is important such as is there a pool scoured to bed rock or did a natural riffle form downstream below the scour pool.

6. Inlet conditions: For some installations a rapid transition from the stream into the culvert can create adverse hydraulic conditions for fish passage. A culvert inlet can project from fill (most common), can square edge into headwall of the fill, or have wing walls to ease the rate of transition. By far the most

common is a projecting inlet, and this can be assumed if not specified. Knowing the type of inlet can help confirm if there was a situation in which sediment would build upstream from the culvert.

3. Deciding between repair vs. replacement vs. abandonment of stream/road crossings

In some cases steps can be taken short of replacement or abandonment of a road crossing to cause it to provide for fish passage or reduce catastrophic failure risk. However, in most cases, in order to meet desired objectives, replacement or abandonment is necessary. Design concerns for replacing crossings is given in the next step. Abandonment is often a more desirable option than people realize especially on forestland. Often times a road is servicing an area that is not due for harvest for decades or can be assessed by another road with little difference in logging haul times, fire, or silvicultural access. Before repairs or replacement is considered, a hard look at the road network should be conducted to see how necessary the road really is.

Fish Passage Mitigation

There are primarily four ways to improve fish passage at an existing crossings without replacing them. The methods include, adding baffles to crossing, adding sediment or sediment catching devices inside a culvert, backwatering through the crossing from the outlet by installing downstream weir(s), or removing debris or modifying the inlet or inlet approach to remove an inlet constriction. Adding baffles to an existing crossing will decrease the peak flow capacity so this option should only be used for culverts that have adequate capacity. In general, this will probably be rare. Another consideration is baffles should only be added when other factors such as outlet drop or inlet constriction are dealt with as well. Materials to use for baffles on existing culverts can be concrete or metal, however, retrofitting metal baffles using bolts may cause the baffle to rip the culvert barrel if the culvert is made of corrugated metal pipe. Probably the most common occurrence when baffles may be added is for large properly sized concrete culverts that have little slope and no inlet or outlet problems or perhaps an outlet drop that can be mitigated.

Another situation that may lead to mitigation is when there is a forest road in a wide valley that is placed at low gradient and the stream itself is low gradient. Often times a downstream weir can be constructed to back water through the culvert and the inadequate size can be dealt with by creating an overflow dip across the road in which the bottom of the dip is about the same elevation as the top of the culvert.

Clary and Reichmuth (1990) introduced a detachable fishway design for a sediment catching in culverts (Figure 11). This particular type of sediment catcher employs angle iron and attaches to the inlet end of the culvert by a hook or T bar so it requires no bolting inside the culvert. Like baffles, sediment catching devices should only be used for culverts that have adequate capacity and do not have other fish passage problems or the other problems can be easily mitigated. Sediment catchers along with placed and naturally deposited streambed material can allow for the creation of a simulated natural channel in the culvert. This option should only be used for culverts that have a width of span similar to that of the natural active channel.

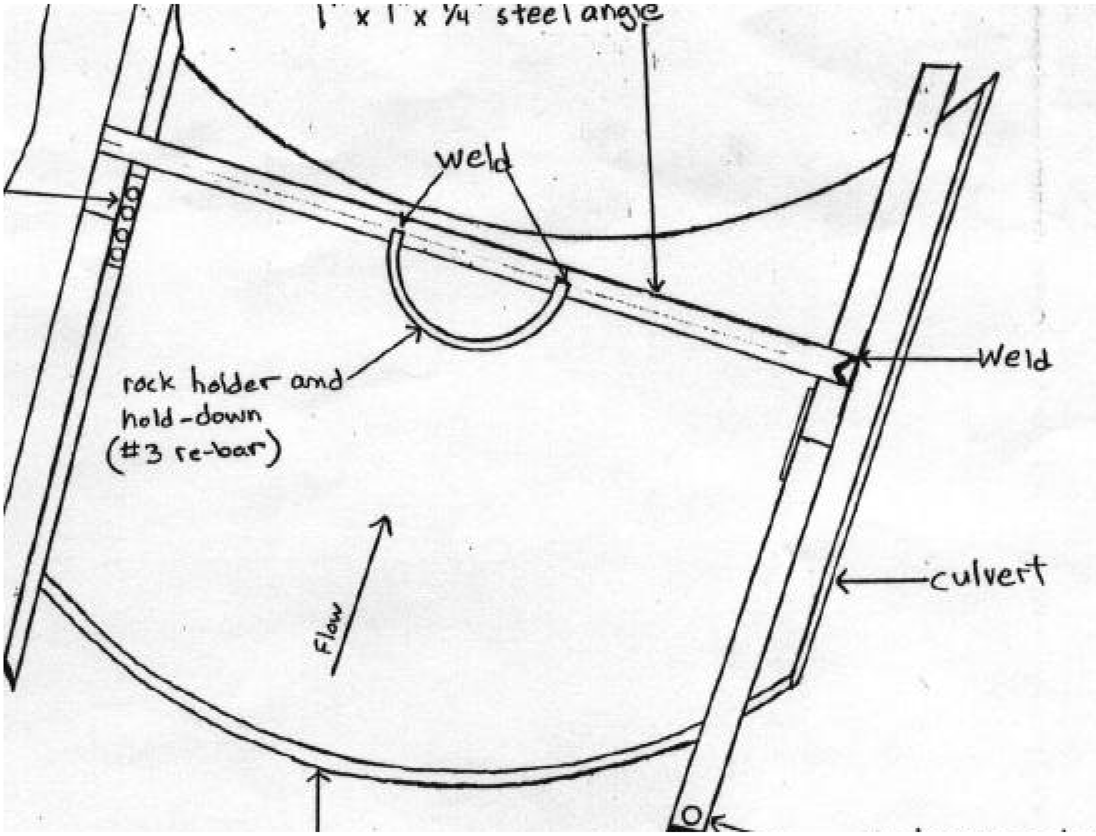


Figure 11. Schematic of sediment catching device (adapted from Clary and Riechmuth, 1990)

The strategy of backwatering water through the culvert by using a series of weirs downstream of the culvert can be an effective way of mitigating fish passage at culverts. However, in a published field survey almost all installations that used this strategy had problems with fish passage (Browning, 1990). If this strategy is used, the weirs downstream of the culvert should have a drop between the weir top and the downstream residual pool of no more than 6 inches. The first weir downstream of the culvert should be a channel width or 20 feet downstream be away from the immediate force that is often at culvert outlets. Subsequent weirs should be placed downstream at an interval of approximately one channel width with each weir designed to take up no more than six inches of drop from the residual pool to the top of the weir.

A final approach to make crossings more passable is to remove obstacles in and around the crossing or re-work the channel on the upstream end to taper towards the inlet rather than have a projecting inlet that is apt to have an inlet drop. Like the other methods, other sources of fish passage problems need to be ruled out or mitigated before employing these options. Obstacles can concentrate flow and create a passage impediment in a culvert that otherwise does provide for fish passage. There are times when culverts are low gradient or even backwatered, but a flow constriction at the inlet end creates a flow constriction which creates a velocity barrier. By tapering the stream banks into the culvert there is a smoother transition without flow constriction.

Repairs to lower the risk of catastrophic failure

There are essentially four major activities that can be done at a crossing (without replacing or abandoning it) to lower the risk of catastrophic failure including tapering the inlet, removing debris or sediment or mitigating future debris accumulation by using a trash rack, and by installing an overflow channel or secondary culvert in the fill. Creating a tapered approach to the inlet causes a condition called a mitered or headwall inlet as opposed to a projecting inlet. By tapering the inlet an increase in flow of about 20% can be gained. Another benefit is a tapered inlet tends to pass through debris better than a projecting inlet.

Removal of debris and sediment from especially around the inlet is really a part of normal culvert maintenance. In addition a Atrash rack≅ can be constructed to catch debris before it clogs the inlet. While this is desirable, often times the trash rack itself may become clogged and begin to reduce flow capacity in and around the fill. There are many designs for these structures and a visit to a culvert supplier will usually give anyone a few options to choose from.

A final way to reduce catastrophic failure risk is to design secondary overflow culvert or road dip. In areas prone to debris torrents the creation of a planned dip with armoring can be extremely useful in conserving the road fill. On low gradient streams in broad valleys the use of a road dip with a culvert not sized to meet any more than a one to two year flood event can be used as a way to reduce fill heights in meadow areas and retain a more natural floodplain system. Road dips should be armored with coarse pit run material underlain by even coarser material. Where practical, the dip should be at about the same height at the top of the culvert to relieve pressure on the fill if the culvert becomes clogged or if water flow goes beyond culvert capacity. If a culvert is placed in such a way that it is providing for fish passage or is in an area where there are no fish, the creation of a well designed road dip in landslide prone areas may be a more effective way to reduce catastrophic fill failure risk than replacing the crossing with a larger capacity structure because debris flow deposits would tend to block even larger capacity structures, but with a dip the stream flow would move over to the dip and be dissipated without losing the fill.

Crossing Abandonment

As mentioned earlier abandonment (even if temporary) is often a preferable option. In many cases tracts of lands are only to need the crossing for short periods of time over long roatation periods. In this case temporary crossings can be used such as temporary rock fills that can be installed and removed during low water. In other cases other roads can access the land just as well. When abandoning a section of road it is important to put the road to bed. This consists of removing cross-drain culverts, water barring, and possibly seeding and planting. In some steep slope situations in could also involve pulling the slope back to reduce the chance of landsliding. When abandoning a section of road it is important to do these activities as the road can become a significant sediment problem because it is no longer maintained.

4. Deciding between various design strategies

Linking design strategies to hydraulics and fish needs

The following criteria is based on field experience, monitoring, hydraulic calculations, and review of the literature.   If called on to prepare a design the crux of the matter is to compare the culvert estimated hydraulic conditions with the swimming capabilities of a design fish for a determined design flow (Figure 12). If the published fish swimming capabilities exceed the culvert conditions then the culvert is deemed fish passable.

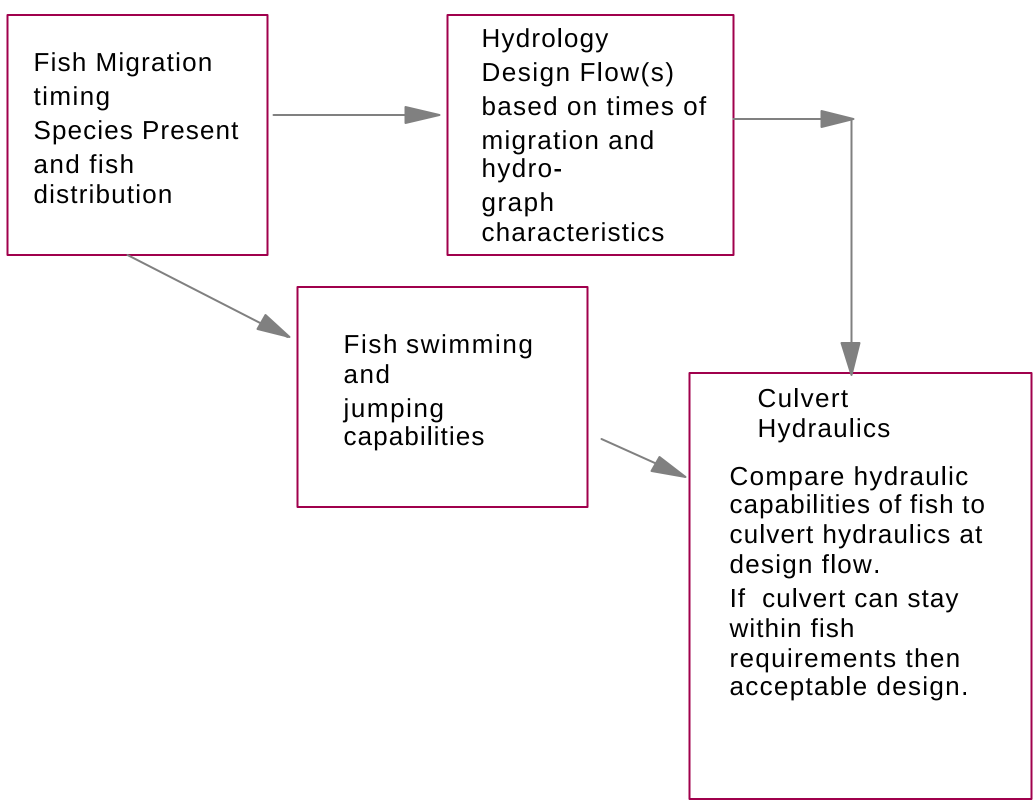


Figure 12. Steps in design process

In calculating the hydraulics for juvenile fish passage for ODF rules (ODF rules require juvenile fish passage where juvenile fish are present) it became apparent that only certain design strategies had a probability for success. For instance, in using the Fish Pass Program (Belhke, et al. 1990) it became apparent that only culverts that were essentially flat (less than 0.5% culvert gradient) could pass juvenile fish for given design flows. Powers et al. (1998) confirmed this issue in a study of juvenile fish passage that showed significant upstream migration inhibition beginning at 0.5% culvert gradient. Because of these findings, a design criteria that culverts must be placed at 0.5% slope or less was developed for culverts that were not designed to have natural bed material or backwatering in them. Advanced hydraulic calculations were not required as the outcome was already known.

In other cases, some design's hydraulic conditions are extremely hard to estimate. For instance, embedded streambed simulation culverts hydraulic conditions are largely based on the degree of roughness. As stated earlier, the roughness influence on velocity changes for given flows and most published values of roughness are for conditions during floods and not for fish design flows. Therefore, a method for determining roughness had to be determined that takes this flow dependence into account (see rationale section for more information). It should also be noted that these equations only give average velocity! White (1996) as well as others including ODF unpublished data illustrate that velocities vary both in cross-section and longitudinally in an embedded culvert creating velocity shadows or hiding places where fish can occupy that are much lower than the average velocity.

Even with some determination of roughness and its effect on velocity, the question of whether the culvert will set up or retain sediment is extremely complex and shear and entrainment equations that are used to make estimates of bed stability are hardly adequate. In this instance, monitoring of existing culverts that were designed to have sediment in them such as occurred with White (1996) and ODF (unpublished data) outlined some of the conditions in which bed material was retained. For the reasons outlined above, hydraulic calculations for specific designs are of little utility for embedded culverts. For this reason, guidelines are given based on mostly on past monitoring results and no design calculations are required for fish design flows.

Hydraulic calculations do have uses in culvert design, especially in determining the degree of backwatering from a downstream weir at given design flows and for determining the conditions inside baffle/weir culverts. In these cases hydraulic methods can and should be employed in design and reviewed before approving designs. Another instance in which these calculations are useful is in determining overall culvert capacity. Culverts that are undersized will tend to concentrate flow and have drops at both the inlet and outlet and will probably not retain or set up material in them. For this reason knowing the peak storm flow of the stream and sizing the culvert appropriately are essential in design. More information on how to properly size culverts is given in step five.

Road/stream crossing designs that will likely allow for fish passage

Often times there are many potential solutions to fish passage problems for a given crossing situation (Figure 13). For instance, on a relatively low stream gradient (i.e. 2-4% stream channel gradient) that has a 50-100 year peak flow in the 100-200 cubic feet per second range several alternatives can work.

For instance, a bridge should allow for natural channel conditions and unobstructed fish passage. A culvert placed flat (for streams up to 2.5% channel gradient) will also in general allow for fish passage especially if backwatered from the outlet side or embedded with natural streambed sediment. A culvert placed at stream gradient with a culvert diameter or span similar to stream active width and backfilled with coarse streambed sediment could also suffice.

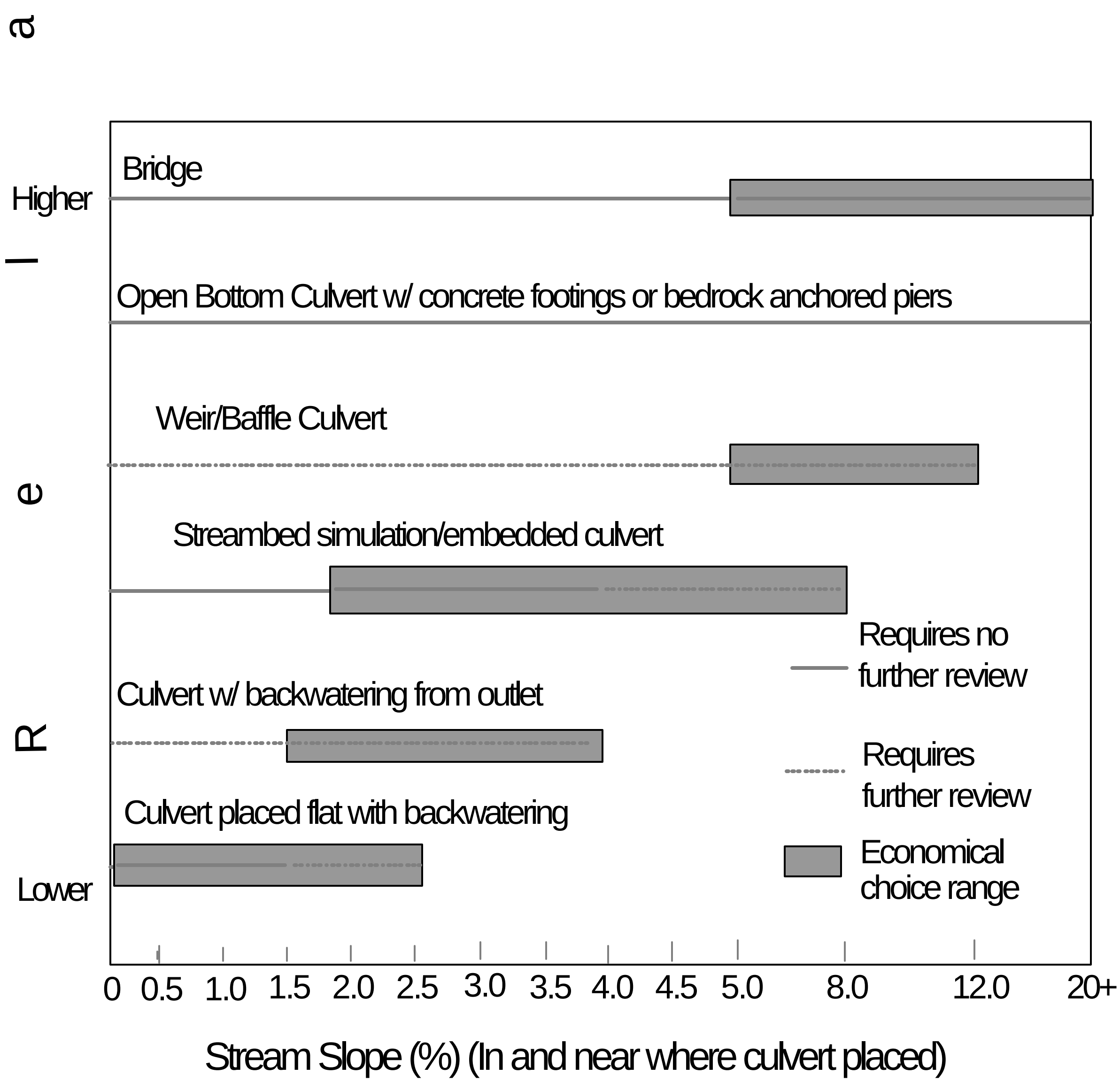


Figure 13. Various stream crossing options in terms of stream slopes where acceptable

However, as stream gradient increases, culverts, unlike bridges tend to have problems if used outside of a given culvert gradient range or under certain streambed conditions. For this reason a bridge is always the preferred solution from an ecological standpoint. However, generally bridges represent the most expensive solution. With thousands of potential culverts needing replacement, the use of bridges everywhere would greatly limit the amount of work being done as only a finite amount of money will be spent to deal with fish passage problems. The following section gives criteria on how to determine which design strategy or strategies will work for a given situation. It is important to take information obtained in step two so that intelligent comparisons of the various alternatives can be made. The order of the alternative design strategies parallels the order given in the ODFW Fish Passage guidelines (Appendix A). It begins with discussing bridges, moves into streambed simulation designs (open arches and sunken and embedded culverts), then to culverts placed flat, and finally to culverts that use weirs to facilitate fish passage.

Along with stream slope, the degree of valley fill material over bedrock is extremely important in deciding between alternatives. For instance, a crossing with a stream slope of 5% gradient can easily be dealt with with a sunken streambed simulation design. However, if bedrock is present, the culvert can no longer be easily buried into the streambed and options like open arch culverts and bridges become more reasonable.

The size of stream is another critical factor along with slope and valley fill depth. Small streams with active channel widths less than 10 feet can be accomodated with culverts at much lower expense than bridges. But as active channel width increases culvert installations become more costly and problematic at some point (where stream active channel width is approaching 15-20 feet) bridges become very desirable.

Having clear objectives as to what instream conditions are desirable can also be a factor in deciding between alternatives. For instance, bridges, open arches, and sunken embedded designs will down cut the upstream section that had sediment backed up from previous culverts. Sometimes a desirable wetland has been created by the culvert or the downstream section is already overloaded with sediment due to other factors. Allowing the channel to down cut may be un-acceptable. In these instances, a baffled culvert can allow the continued existence of the sediment deposit or wetland upstream of the culvert.

In discussing culverts and fish passage there are several key definitions that must be understood. See introductory section on culvert hydraulics if unclear about any of the terms given below. What follows below is discussion of the advantages and disadvantages of each alternative and in which situations each alternative is best suited. Use the information found in step 2 and compare it to the stream characteristics described below to determine which design strategy or strategies are appropriate for a given stream crossing replacement.

Bridges

A bridge is a stream crossing structure that spans the stream and is placed on abutments and/or piers located in or near the stream. Bridges in terms of the natural resource protection should always be the preferred alternative because they allow for a natural flow of sediment and change stream habitat the least. However, when economic considerations and logistics of the particular site are taken into account there are often better economic alternatives than a bridge (Figure 12). Bridges often become the economical as well as the ecological best alternative as stream size increases. When culvert dimensions begin to require multi plate designs in excess of 10 feet in diameter or 15 feet in span the cost of a bridge becomes comparable with that of a culvert. For high gradient streams over 5-8% gradient, especially those flowing over bedrock the only alternatives become a baffled or open bottom culverts, fords, or bridges. In terms of cost, the bridge can become an economical alternative here.

When to use: From an ecological standpoint anytime! However, from a cost standpoint, they become increasingly economical as stream size increases or in steep gradient streams where many of the culvert alternatives won't work.

Advantages: Usually best alternative for fish passage. The channel below the bridge often retains natural state and can be used for rearing and spawning.

Disadvantage: Usually the most costly alternative.

Further Comments: Bridge costs are highly variable as various approaches can be taken. Careful research into the alternative approaches can pay for itself easily in reduced bridge costs. One idea for areas that will need only limited access over time, is to use temporary bridges and then evacuate the crossing and bed the road until the next rotation. This reduces unwanted road traffic and saves money on culvert and bridge costs.
Some alternatives:

1. Log stringer bridges (low cost but costs increasing due to rising log prices and generally short lived)
2. Rail car bridges (In-expensive, come in different lengths, but not load certified)
3. Re-enforced concrete bridge (relatively low cost but limited to 25-30 foot total span because of load capacity concerns)
4. Steel bridges (high cost about $1200-2000 per foot; however, certain designs done by thrifty engineers can cost considerably less)
5. Pre-stressed concrete bridge (high cost, about $1500-2500 per foot of bridge span)

While the fish passage aspects of a bridge design are relatively simple, designing to bear loads is not simple and should be undertaken by a registered engineer.

Open Bottom Culverts

An open arch or open bottom culvert is a metal arch or other material (commonly concrete box culverts with open bottoms) placed on footings with a natural stream bed underneath and fill on top of culvert. The width of footing generally increases as load bearing needs increase. Most footings are from eight inches to one foot wide and are about the same depth. Sometimes footing depth is increased as footings are made deeper to anchor to bedrock. The use of open arch culverts is in favor by many engineers and biologists, but a past survey of fish passage culverts showed that this option, more often than not, had serious undermining threatening the stability of the fill (Browning, 1990). For this reason, it is recommended that this option only be used where the stream is near surficial bedrock as to create stable footings. There are various alternatives that use flanged edges and staking to stabilize the footings or use angle iron to tie in the arch ends without footings but these designs are at best experimental and should be used on a trial basis for lower priority crossings with engineering help. Another design uses weight (load) supporting piers drilled into bedrock and should be considered especially where the bedrock is irregular and depth to bedrock is variable. Open arch installations should be designed by an engineer in consideration of the loads and potential sources of failure in the footings. Specific recommendations regarding these factors is site specific and beyond the scope of this guidance. With all this said, open arches are desirable for fish passage because they have a natural channel bottom (if sized large enough) and provide a natural substrate and conditions similar to a natural channel.

When to use: For streams with grades at or near bedrock at all slopes. The load bearing pier design can be used in places where bedrock is at greater depth. If engineered and designed carefully these structures can be placed on fill. Any structure placed on fill with an open bottom should be designed by an engineer.

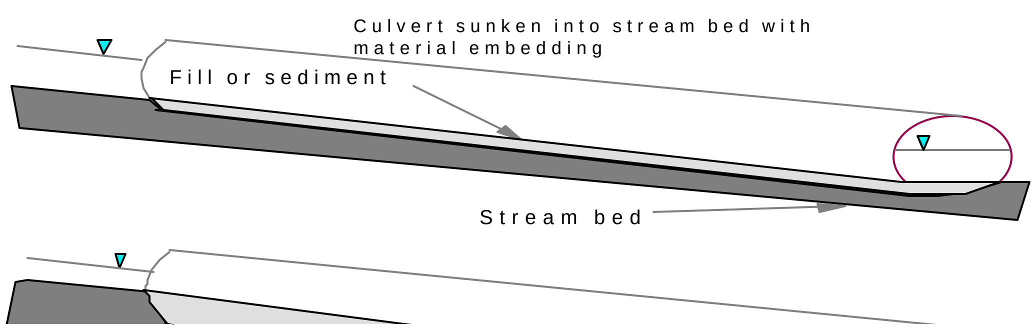
Advantages: Very good fish passage alternative if sized properly.

Disadvantages: Expensive and difficult installation, and not practical when lots of valley fill material is present in natural channel because of difficulty in developing stable footings.

Further comments: The structural stability issues with an open arch are critical and require civil engineering and/or geotechnical expertise. Very important to properly size the culverts or the stream bottom will scour (possibly to bedrock) leaving a chute with difficult fish passage. The width of the open bottom should be at least the active width of the stream channel if being used for fish passage.

Streambed Simulation using sunken and embedded culverts

This design alternative calls for sinking the culvert into the existing streambed at both the inlet and outlet (Figure 14).



When to use: Streams with slopes up to 8% dominated by deep valley fill substrates. If stream and resulting culvert gradient is greater than 4% greater consideration should be given in making sure design works.

Advantages: When properly installed, the culvert grade will be at the same slope as the stream with the same stream sediment characteristics. For a migrating fish this would impose no changes or stress and no delay in upstream migration. From a stream morphology perspective, sediment transport would simply move through the culvert naturally, and there would be no sediment buildup upstream or deprivation downstream. Because the culvert width is similar to the bankful stream width, at the outlet there would be no flow concentration, so there would be no increased scouring or damage at the outlet. This is a relatively simple installation as compared with the others, and the costs relative to bridges and other designs is less.

Disadvantages: Installation as compared to a non-buried culvert, is more difficult. The culvert also has to be oversized to pass the 50 year peakflow, as compared to a non-buried culvert. Must be careful to determine if there is bedrock that would impede proper installation.

Further comments: The first step in this design is to assure that the diameter or span of the culvert is equal to or greater than the active stream width (see how to determine active channel width in step 2). This stream crossing type is usable for culvert gradients up to 8%. It is important that there is adequate stream valley bottom fill available to sink the culvert into. Therefore, this alternative would not work if the stream is predominately bedrock or has extremely large boulders hampering culvert sinking into streambed. Also important is the availability of cobble sized material to build up in the culvert. In most cases, the installer should embed the culvert with cobble - boulder sized material. If the stream bed near the culvert is dominated by sands and fines, there may not be adequate coarse material to make this alternative work without embedding. **For circular culverts, the sinking at inlet and outlet (Figure 15 and 16) must comprise at least 40% of the culvert diameter or 2 feet, whichever is greater. For pipe-arch culverts, a sinking depth of at least 20% of the rise or 18 inches (whichever is greater) is adequate.** For box culverts, 20% of the height or 18 inches (whichever is greater) of burial is adequate, but if the bottom is smooth or concrete, remedial measures may need to be taken to roughen up the bottom so it will collect bed material. The only time embedding may be not be done is when the channel upstream of the channel has been incised by the newly placed culvert and plenty of material is expected to move into the culvert. In these cases, the culvert should be embedded deeper to anticipate the scouring of the upstream reach.

Culvert sinking at the downstream end should be from the downstream riffle or constructed weir (Figure 15). In the past many have attempted to sink the culvert in relation to a downstream scour pool oversteepinging the culvert. Culvert sinking on the upstream end of the culvert should be the difference in elevation between the resulting upstream streambed and the bottom (invert) of the inlet of the culvert (Figure 16).

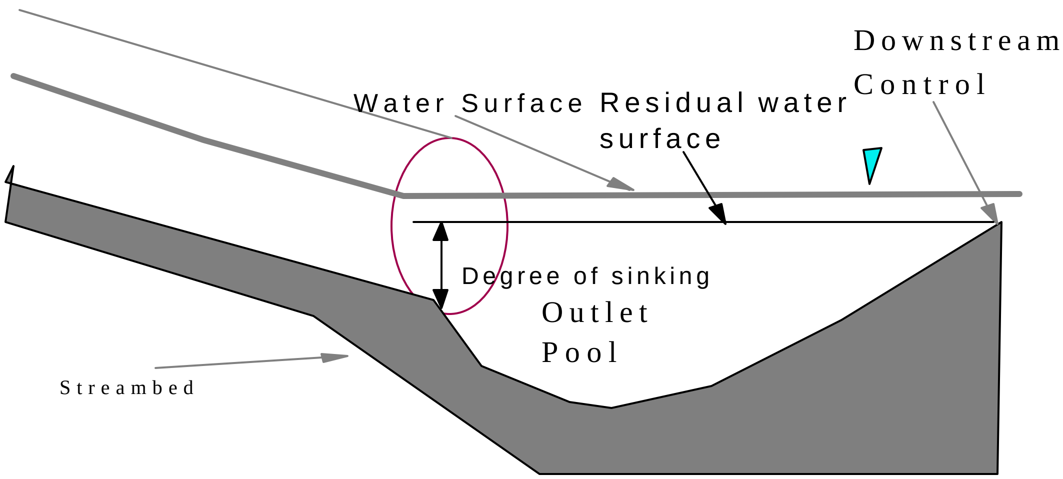


Figure 15. Determining culvert sinking from the downstream end.

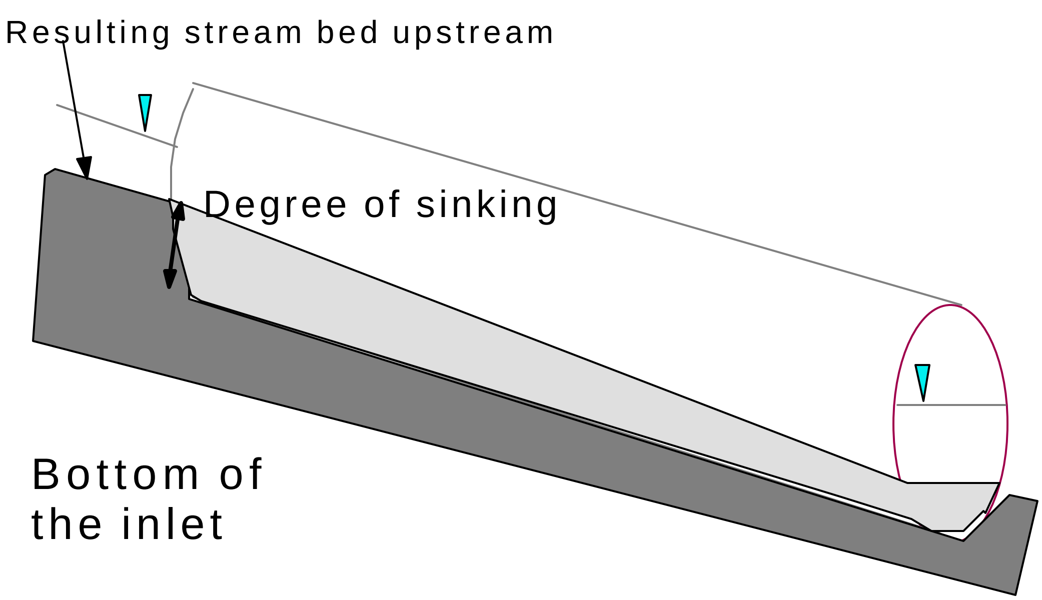


Figure 16. Sinking the culvert at the inlet

In some cases, **sediment catching baffles (see Figure 11) may need to be applied to CMP culverts if inspection over time is showing no material is staying in the culvert.** These measures may include attaching angle iron and rebar to the bottom. Another method is to install a weir in the channel downstream from the culvert to allow the build up of sediment. More careful embedding of the culvert may cause material to stay in the culvert especially if care is used in interlocking the rocks together and using larger rocks to anchor the smaller material.
Generally speaking, because the need to fill circular pipes up to 40%, to get adequate width compared to active stream channel width, this design will be relatively less expensive with pipe arch or squash pipe shaped culverts. To calculate culvert sizing for the 50 year peak flow, methods described in subsequent section need to be used for culverts designed to have sediment in them.

Culverts placed on gradients greater than 4% should be buried at the inlet upstream end to a greater degree than the downstream end. This is called a countersunk streambed simulation strategy (Figure 14). The inlet should be buried into the streambed such that the resulting culvert gradient is about 1.5% less gradient than the existing stream grade. Gradient is lessened to both reduce velocities and aid in retaining sediment in the culvert. The lessening of stream gradient can be more or less than 1.5%, but this requires further review. Generally speaking culvert gradient reduction of up to 3% are acceptable in relatively short steep culvert installations. However, using this installation for streams crossings with stream slopes greater than 8% are to be discouraged. An example of how countersinking would work is for a 50 foot long pipe arch with a five foot rise for a stream with 6% gradient, the outlet should be sunk two feet into the streambed and the inlet should be sunk two feet eight inches into the streambed. This results in a culvert with 4.5% gradient. For the calculation of flow capacity, the basis of flow reduction is based on losing two feet eight inches of the rise at the inlet end. A step by step guide on how to desing with this alternative is given in Appendix E.

Culvert placed essentially flat

Definition: Culvert placed at a gradient of 0.5% or less.

When to use: On low gradient streams up to 2.5% gradient. If working on a stream where the inlet end is to be countersunk to make the culvert flat make sure there is not bedrock in the vicinity of the inlet.

Advantages: Least costly alternative with easy installation.

Disadvantages: Difficult to get fish passage with this design. Generally will allow free passage only for culvert slopes that are below 0.5%.

Further comments: Culverts come in a variety of shapes with both advantages and disadvantages with each. The most common are circular culverts. In addition there are pipe-arch culverts, box shaped culverts, and elliptical culverts. The most common material used in culverts is corrugated metal pipe (CMP). The maximum gradient allowed is for round, elliptical, or pipe-arch culverts with CMP. If dealing with smooth culverts or concrete culverts, even less slope would be allowed because the hydraulic roughness is decreased. **As a practical consideration, these culverts should be installed flat (0% slope) using a tripod level or similar device because even a little slope can cause juvenile fish passage impediments.** There should be outlet backwatering (minimum of 6 inch difference) between downstream weir/riffle and elevation of culvert invert such that water depth is several inches throughout the culvert. The outlet end should be sunk into the streambed six inches or a downstream weir should be constructed to backwater at least six inches deep throughout the culvert.

Depressing the inlet invert into the channel bed can cause degradation of the channel bed upstream with subsequent migration impairment. If the inlet is sunk in too far there is a risk of culvert blockage; that's why it is important to oversize the culvert diameter. In streams with high sediment loads, there could be excessive deposition in the culvert and subsequent blockage and failure. This installation may also cause a migration barrier at the inlet as a high velocity area may be created at the inlet. For this reason it may be desirable to excavate the streambed immediately upstream of the culvert to prevent an inlet drop. It is for these reasons that this alternative is generally reserved for low gradient streams (less than 2.5% gradient). Even at a 1-2% gradient the streambed simulation option is probably preferable and is probably similar in cost. A step by step “cook-book” on how to design with this alternative is given in Appendix E.

Culvert with backwatering at outlet

Definition: Culvert placed at or below stream grade with a downstream control structure(s) like a log or boulder weir that backs up water throughout the culvert to a depth of at least eight inches.

When to use: For streams with up to 4% gradient with the downstream section with little slope and well defined channel in which to install weirs. This design can also be used in concert with other alternatives to improve fish passage.

Advantages: Can be a relatively low cost alternative that works up to stream slopes of 4% and for elevation changes between the upstream and downstream end of up to 2 feet. The resulting pools created downstream can provide valuable rearing habitat and resting habitat for fish migrating upstream.

Disadvantages: Installation of effective weirs to back up water without impeding fish passage themselves can be tricky. Installing stable weirs can be problematic. The degree of backwatering and local hydraulic conditions due to a downstream weir can only be analyzed by using advanced hydraulic methods like those found in programs such as HEC2 and WSPRO. Backwatering will reduce pipe peak flow capacity, changing inlet control to outlet control.

Further comments: The first downstream weir (Figure 17) should be installed at least a couple of channel widths or at least 10 to 15 feet downstream to provide stability. If placed too near the culvert, undesirable side effects may occur. Each weir placed subsequently downstream should be spaced about 2 to one channel width apart and the water surface drop associated with each weir should not be more than a six inches so as to not impair fish passage. The elevation of the top

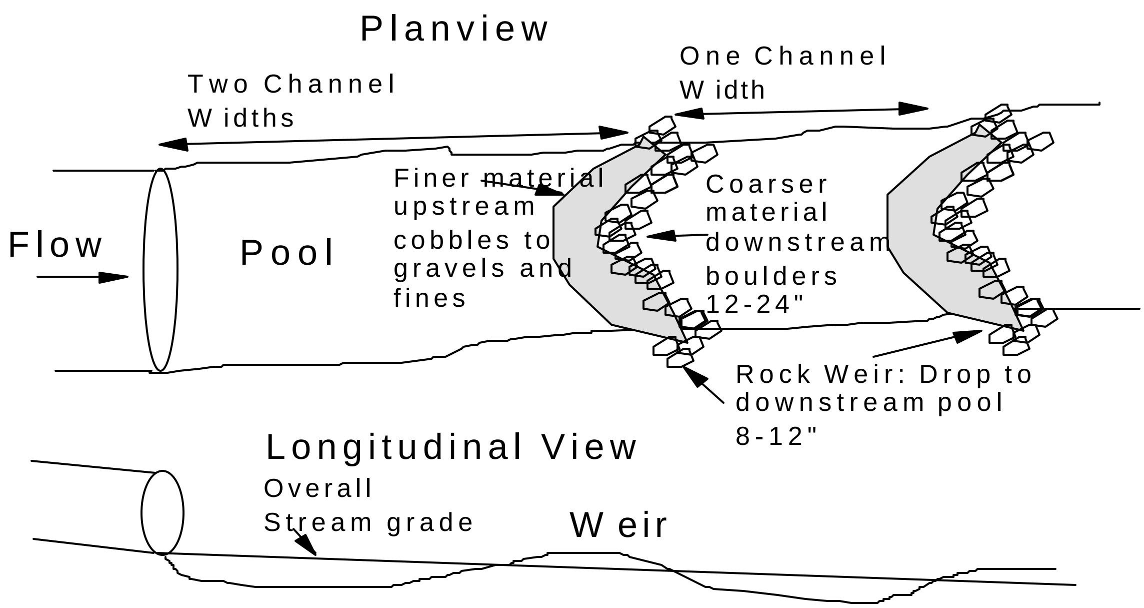


Figure 17. Rock weir schematic

weir (i.e., the one nearest the culvert) should be set at eight inches greater elevation as the elevation of the culvert bottom on the upstream (inlet) end. This method can also be combined with countersinking or culvert burial to increase the range of slopes in which a culvert installation will work without resorting to culvert weirs and baffles. Because of past failures and the multitude of problems that can occur with this design, further review is always required and experienced engineering expertise is recommended in design. When using rock weirs the allowable drop can be increased to a foot.

Weir/Baffle Culverts

Definition: Culvert having various types and configurations of weirs or other flow obstructions installed inside the culvert to either increase roughness or to create a series of pools with drops to increase depths and decrease velocity to aid fish passage (Figure 16).

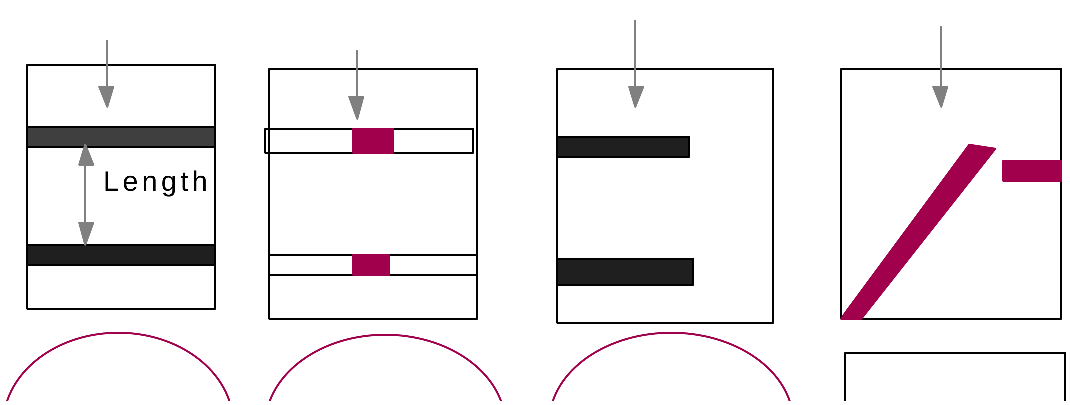
When to use: For streams with gradients up to 12%. Because of cost and maintenance considerations this choice is usually a last resort. In places where there is a desire to preserve a sediment deposit or road fill caused wetland by not installing a structure that allows natural sediment transport of the deposited material upstream of the culvert.

Advantages: Usually requires less oversizing as compared to buried culvert designs. Usually less expensive as compared to bridges or open bottomed culvert structures. Can be installed in valley fill (unlike open bottom culverts unless engineered) or in situations were the stream grade is at or near bedrock (unlike sunken and embedded culverts).

Disadvantages: These types of installations have a legacy of failure. Culverts with baffles are more prone to clog with debris and sediment. If the method of securing the baffles is suspect, the baffles can rip out and damage the culvert, or even cause it to fail. This alternative is usually more expensive than installing a culvert without baffles, even with sinking and embedding. Often times the baffles or weirs disrupt the "boundary layer," which may impair juvenile fish passage. (Note: The boundary layer is the area of flow right above the stream bed where there are reduced velocities.) This design requires considerably more hydraulic engineering savvy than the other methods and requires the use of outside consulting. Installation of steel culverts with pre-fabricated baffles is very unforgiving as any settlement can cause the baffles to pop out of place. Greater care in creating a stable bed and in compacting the haunch areas along the bottom side edges of the culvert must be done. If settlement occurs it can render the weir spacing and height design ineffective.

Further comments: There is a considerable variety of possible configurations in regards to baffled culverts (Figure 18):

1. Weir baffle: Baffle stretches across the stream no notches in baffle.
2. Notch baffle: A weir baffle with a notch in the middle to allow flow to pass through at a lower level.
3. Corner baffle: Baffle placed on one side of culvert with other side without baffle.
4. Offset baffle: One side of the culvert has one baffle pointed diagonally upstream while the other baffle is shorter and perpendicular to flow with a slot in between.



The weirs or baffles can be placed directly upright or can be tilted slightly downstream. They typically are 6-18 inches high, depending on streamflow and culvert size. They can be attached by bolts or welded to metal pipe. They can be made of wood, concrete, or metal plates. In Oregon, a design currently being installed, has a metal plate notched weir tilted downstream with a supporting gusset welded into the metal round or pipe-arch culvert. Preliminary inspection indicates that these baffles or notched weirs are very sturdy and durable and require much less maintenance than other baffle designs. They have been installed at slopes up to 12% and the weirs cost from $300 to $800 each, depending on culvert diameter. Three to 10 or more weirs are required depending on stream flow and culvert slope. This can add to the cost of a culvert from $900 to $8000 or more for this particular type of design. Anecdotal evidence suggests that measures should be taken to protect the area immediately downstream of the outlet from scour creating a jump. Measures include creating a riprapped jump pool below culvert that can resist erosion. Unpublished velocity studies of these weir baffles designs over a range of streamflow conditions show that these designs provide favorable velocity conditions.

There are several rules of thumb and semi-empirical equations on how to determine proper baffle sizing and spacing. In calculating discharge capacity, use the methods given in Section 5 assuming a loss in cross-sectional area due to the weir. For determining fish passage there are several checks that should be preformed including:

1. Depth of flow calculations for low and high design flows (Bates, 1994 and Belkhe et.al. 1990). The low design flow depths must meet Oregon guidelines in Appendix A.

2. Energy dissipation at high design flow by comparing streamflow with pool volumes at High design flow (Washington Design Manual, Bates, 1994, and Belkhe, et.al. 1990).

For many baffled designs there are no empircally developed methods for determing depth of flow calculations or energy dissipation because no experimental calculations have been done for different shapes and configurations of culverts. For instance, the design for baffles slanted 45 degrees downstream described above has different drag characteristics than a weir that is placed perpendicular to flow. All of the past experiments for notched and broad crested weirs used weirs placed perpendicular to flow and not slanted. Therefore whoever does these calculations must apply experimental results from a situation that is different than the current design. This type of exercise requires considerable engineering judgement.   For this and other reasons, these designs should generally be developed by someone with expertise and or experience in hydraulic engineering.

FORDS

Fords should only be considered for low traffic roads that are in general, private, gated and have very infrequent use. Fords are best suited when the stream channel has larger cobble and larger material in general. Low bridges and partial fords can be useful in some instances but only after careful review. In designing a ford, the roads coming into the ford should be tapered (10% grade or less) and hardened using coarse (cobble and coarse gravel sized) material for several hundred yards to allow the shedding of sediment as vehicles approach the ford. Water bars or other drainage should be used to deflect water away from the stream approaches. If a low bridge is to be used the upstream end of the bridge should be tapered to guide material over the top of the bridge instead of against the bridge. The bridge should also be keyed in hard and made of heavy material like concrete so as to not be detached and floated away. If the ford is hardened using cobbles in the stream, filter fabric may need to be used to keep water on the surface so the ford does not become de-watered impeding fish passage.

5. Essentials in preparing designs for grants, permits, and required written plans

Requirements

If designing a new or re-constructed crossing usually a permit or written plan is required. For forestry concerns a notification should be submitted and if the stream is fish bearing a written plan is required. For non forest landuses often times a Division of State Lands (DSL) permit is required. Note there are streamlined permitting processes for road construction and also that if the amount of fill being moved is not large a permit may not be required. It is best to call DSL concerning requirements for given situations. **In emergency situations after large storms where repairs are made to structures to restore access, many of the waiting periods etc… can be waived. However, the need to**

provide for fish passage is not waived. In preparing grants to GWEB and other funding sources information similar to that which would be on a permit or written plan is advisable in order to get approval. It is also advisable to run the design by the regulating authority prior to applying for a grant and perhaps get a written letter of support. This will greatly enhance the chances that the project will get funding.

In Appendix D, guidelines are given for use in helping ODF forest practice foresters in accepting, rejecting or requiring further review of stream crossing installations. Also included is a form that can be used in filling out written plans.

Sizing Bridges/Culverts for replacement

The 50 year peak flow can be described as that stream flow that is only met or exceeded once every 50 years on average based on statistical analysis of past streamflow records. An easy to use straightforward procedure for estimating 50 year peak flows has been developed for use on forest land in Oregon. For agricultural and urban lands, there is no one accepted procedure, but several procedures may be acceptable. The forest land peak flow estimation method should not be used on agricultural or urban lands because the landscape is generally flat as opposed to mountainous and there are significant alterations to the soils and thus the hydrology, particularly on urban land is altered. Acceptable methods for urban/agricultural watersheds can include the rational equation (for watersheds less than 2 square mile), the SCS method, USGS equations, or other methods. Many of these other methods are given in the ODOT hydraulics manual (ODOT, 1990). Often times engineers or engineering firms design crossings in urban settings so the methods and sophistication of the calculation method is greater so more leeway is given on calculation methods. The forest land method given below is still useful even for county and city roads if the basin is small (less than 5-10 sq. miles) and largely forested.

Sizing Method Used by Oregon Department of Forestry

Stream crossing structures are exposed to occasional peak flows that threaten to damage or wash out the structure. Costly repairs or replacements, disruptions to log hauling operations, and damage to fish habitat in downstream portions of the stream can occur when a peak flow exceeds the capacity of a stream crossing structure.

It would be prohibitively expensive to design a culvert or bridge to handle all peak flows, including the largest floods. Instead, stream crossing structures are sized to pass peak flows up to a specified design flow.

This design flow is often described as a peak flow having some recurrence interval. For example, a culvert designed to handle a peak flow that has a 50-year recurrence interval means that the culvert would be overtopped only once every 50 years, on the average. A variety of terms are used to refer to the peak flow having a 50-year recurrence interval. Sometimes it is called the "50-year peak flow" or "the 50-year storm."

Since few forest streams have long-term gaging stations, we usually do not know what the 50-year peak flow is at a proposed stream crossing. However, the 50-year peak flow can be estimated using information gathered from surrounding gaged streams. We have recently analyzed all the available peak flow data for forest streams in Oregon and developed relationships that will allow you to estimate with some confidence the 50- year peak flow for a proposed culvert or bridge installation.

Information about 50-year peak flows throughout Oregon is displayed on a map titled, "Peak Flows for Forest Streams" (Figure 19) A larger scale version of this map is available from ODF in Salem). The values shown on the map indicate the 50-year peak flow in units of cubic feet per second (cfs) per square mile of drainage area.

> *As an example, if a proposed culvert installation is at a location where the map shows the 50-year peak flow to be 200 cfs per square mile and the drainage area upstream of the culvert installation is 0.7 square miles, then the culvert would need to be sized to handle a flow of 140 cfs (200 x 0.7 = 140).*

For the east side of Oregon, the current procedure has divided the eastside into four general runoff regions as follows (Figure 19).

> The Eastern Cascade geographic region has two distinct areas: north of the Warm Springs Indian reservation the 50-year peak flow is 75 cfs per square mile and 25 cfs per square mile south of the reservation.
> The Blue Mountains geographic region also has two distinct areas: approximately northeast of Interstate 84 the 50-year peak flow is 45 cfs per square mile and elsewhere it is 30 cfs per square mile.

However, the runoff in Eastern Oregon is highly variable and in some places local methods or gage comparisons are preferable to using this method. Please contact the author or local offices of ODF if you have any questions about using these values for eastside streams.

For the westside of Oregon, 50-year peak flows are higher than on the eastside and can vary considerably over short distances (Figure 19). Lines are shown on the map indicating areas of common peak flow values, just as contour lines on a topographic map show areas of common elevation. In western Oregon, 50-year peak flows values vary from less than 50 cfs per square mile for an area east of Medford to 600 cfs per square mile for an area east of Brookings. When determining the 50-year peak flow from the map and the location of a proposed culvert or bridge installation lies between two lines on the map, interpolate an appropriate value.

> *For example, if the culvert location lies halfway between the 150 and 200 lines, then the appropriate value to use is 175 cfs per square mile*
> *[(150+200) / 2 = 175]*

The drainage area upstream of a proposed culvert or bridge installation is an important piece of information to know when calculating the 50-year peak flow. Eyeball estimates of drainage area on a map are just not accurate enough. Use a dot grid, planimeter, or digitizer to measure the drainage area. A topographic map should be used and the drainage boundary carefully identified as shown in Figure 18. Note that as you draw in the drainage boundary upstream of the proposed culvert location, the boundary is always at right angles to the elevation contours.

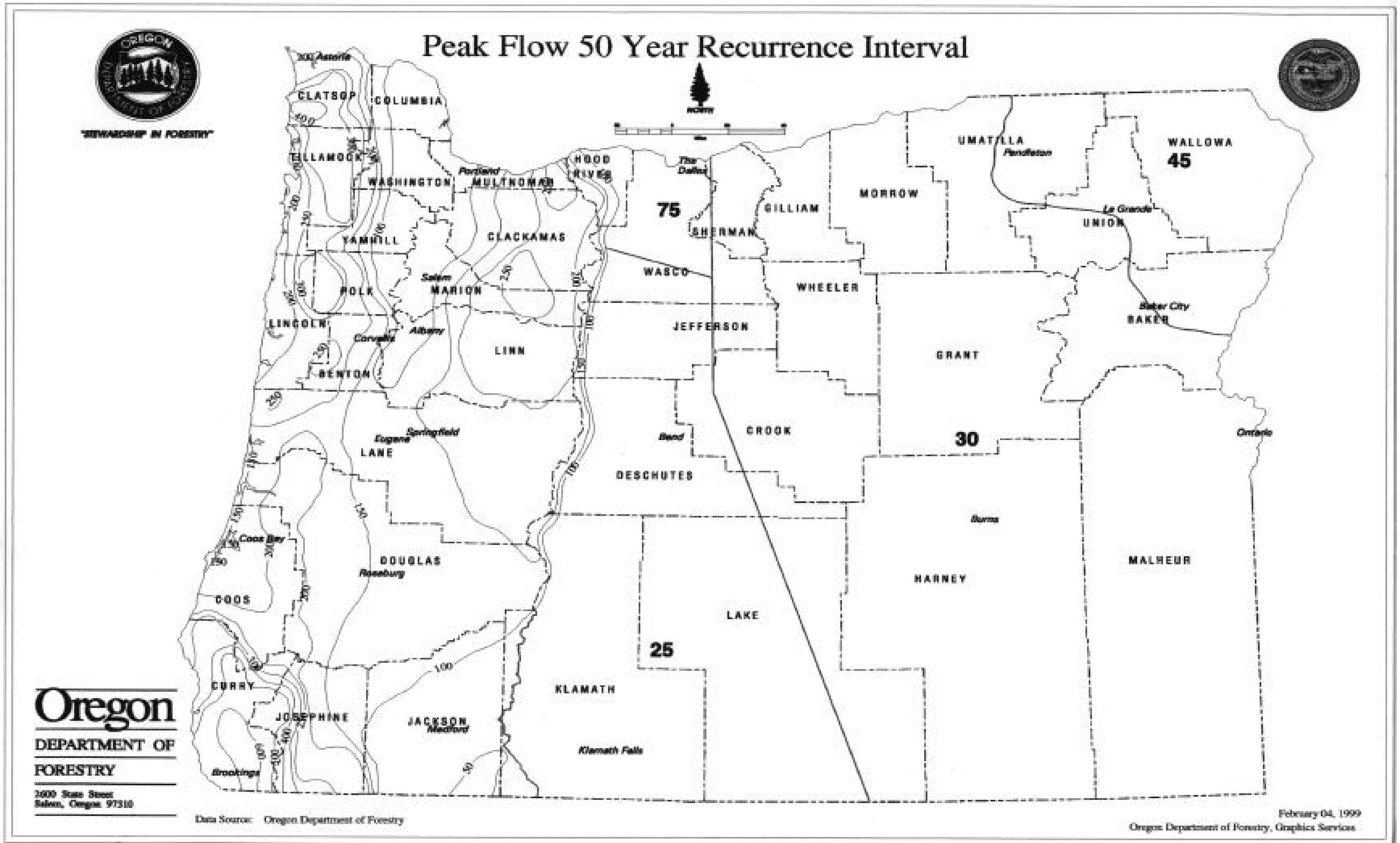


Figure 17. Peak flows for forest streams 50 year recurrence interval for Oregon State.

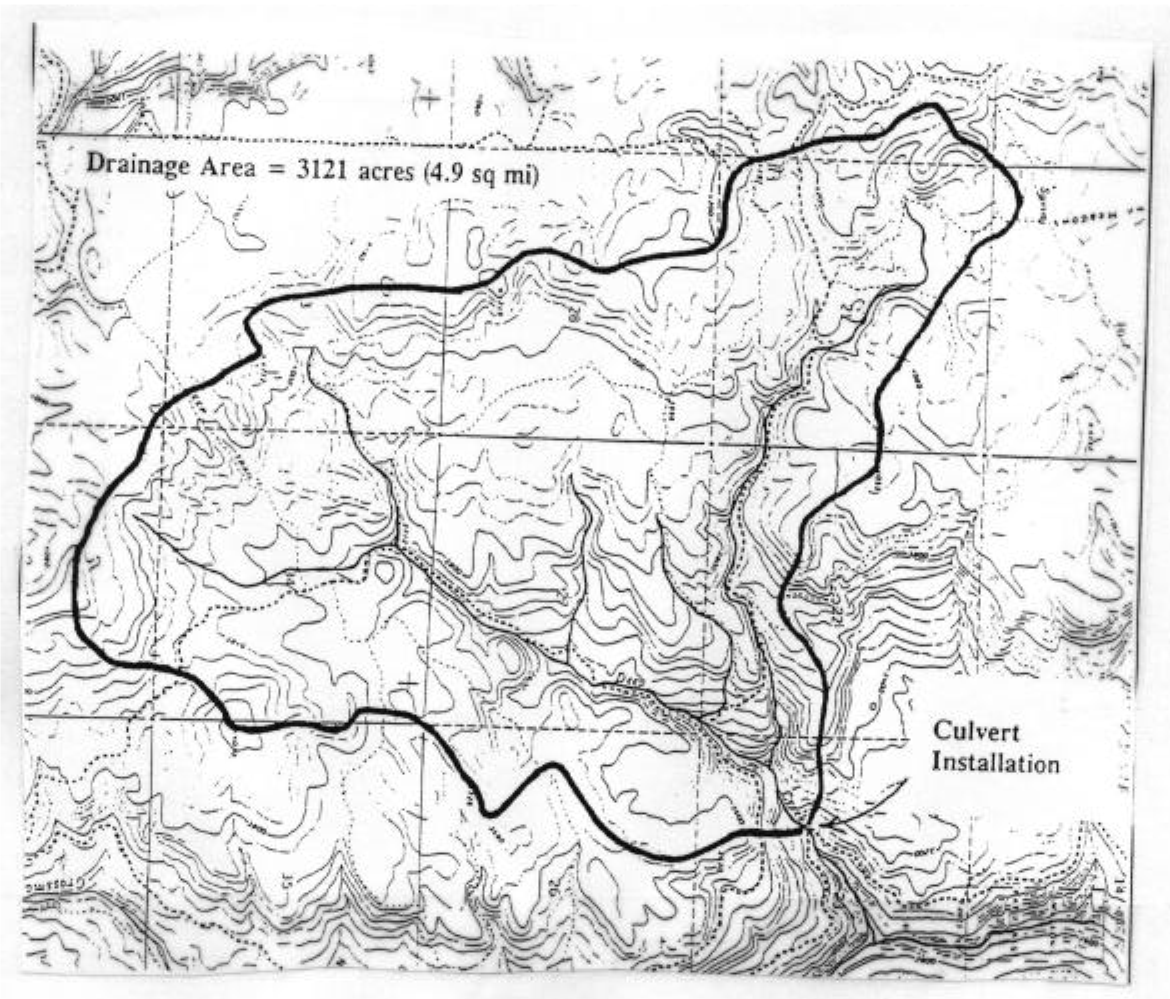


Figure 20. Example of the drainage area outlined upstream of a proposed culvert installation in far northeast Oregon. The drainage area is 4.9 square miles and the 50-year peak flow for this area is 45 cfs per square mile, so the culvert will have to be large enough to handle a flow of 220 cfs (45 x 4.9 =

220). Adapted from landowner reference manual.

Table 6. Flow capacity for circular culverts and pipe-arch culverts.

CIRCULAR CULVERTS			***PIPE-ARCH CULVERTS***		
DIAMETER (inches)	Cross-Section Area Culvert (ft^2)	MAX FLOW in Culvert (cfs)	**SPAN x RISE** (feet and/or inches)	Cross-Section Area Culvert (ft^2)	MAX FLOW in Culvert (cfs)
15	1.2	3.5	22" x 13"	1.6	4.5
18	1.8	5	25" x 16"	2.2	7
21	2.4	8	29" x 18"	2.9	10
24	3.1	11	36" x 22"	4.3	16
27	4	15	43" x 27"	6.4	26
30	4.9	20	50" x 31"	8.5	37
33	5.9	25	58" x 36"	11.4	55
36	7.1	31	65" x 40"	14.2	70
42	9.6	46	72" x 44"	17.3	90
48	12.6	64	6'-1" x 4'-7"	22	130
54	15.9	87	7'-0" x 5'-1"	28	170
60	19.6	113	8'-2" x 5'-9"	38	240
66	23.8	145	9'-6" x 6'-5"	48	340
72	28.3	178	11'-5" x 7'-3"	63	470
78	33.2	219	12'-10" x 8-'4"	85	650
84	38.5	262	15'-4" x 9'-3"	107	930
90	44.2	313			
96	50.3	367			
102	56.7	427			
108	63.6	491			
114	70.9	556			
120	78.5	645			
132	95	840			
144	113.1	1000			

Adapted from the landowners reference manual (1994). The assumptions for this table are projecting

inlet and headwater depth equal to diameter or height of culvert. These assumptions are not relevant for fish passage designs. Therefore, oversizing as described in text needs to be employed.
A grid printed on transparency material can be obtained for use with the 7.5-minute USGS maps (the map scale is 1:24000). To get watershed area, outline the drainage boundary and then place the grid over the area in a random orientation. Count the number of squares and fractions of squares that fall within the drainage boundary. Alternatively, you can count the number of grid intersections that fall within the drainage boundary. Multiply the number of squares or grid intersections by 0.036. This will give you the drainage area in square miles.

> *For example, if the number of squares counted within the drainage boundary was 46, then the drainage area would be 1.7 square miles [46 x 0.036 = 1.7].*

Sizing the culvert:

With the flow determined above, and if the design is a culvert that requires no sinking and does not have baffles, the required culvert size can be determined using Table 6. For example, the stream crossing that has an 140 cfs 50 year peak flow would require a 66" diameter round or 7'-0" x 5'-1" pipe arch. Please note that flow capacity of a culvert is not dependent on its steepness. A culvert installed at a 1 percent gradient has no greater capacity than one installed at an 8 percent gradient.

For culverts that have baffles or are designed to have sediment placed or deposited in them, sizing a culvert is a little more involved. In order to determine the proper culvert size, the culvert cross-sectional area lost due to filling or baffling must be determined and compensated for by choosing a larger culvert size to pass a given flow. Table 7 provides a comparison between percent of culvert rise (for pipe arches) or diameter (for round culverts) that is embedded or baffled and corresponding cross-sectional area loss.

Following the example above, lets say that you have a 3% gradient stream that you plan on using a culvert sunk into the streambed on the inlet and outlet end equally. Let us also assume that we will use a round culvert with 40% of the cross-sectional area slated for fill material. In doing the calculation you would first look to Table 6 and pick a culvert size larger than the 66" diameter that passed 140 cfs as in the above example. Let us assume that perhaps 96" would work. Referring to Table 3, you find that a 40% embedding results in a 37% loss in culvert area. A 96" culvert has 50.3 ft^2 cross-sectional area according to Table 2 and a 37% reduction results in a culvert area 31.7 ft^2. Since the remaining area is greater or equal to the area available to that with a 66" culvert (see Table 6) with no embedding you can assume that the culvert will pass the 50 year peak flow because the capacity equations, are largely based on cross-sectional area.

For sizing the same crossing for a pipe arch culvert, the degree of sinking would only be 20%. You would have to try for a size larger than the 7'-0" x 5'-1" culvert. The next size larger is 8' -2" by 5' - 9" which has a corresponding area of 38 ft^2 (Table 6). A 20% embeding of the rise corresponds to a 20% loss in cross-sectional area which leaves 30.4 ft^2. Since this value is larger than the 28 ft^2 value for the 7'-0" x 5'-1" culvert you can assume that the culvert will pass the 140 cfs peak flow. An important rule of thumb when trying to determine cross-sectional areas of pipe-arch sizes not in Table 6, is that cross-sectional area is closely approximated by the equation:

$$\text{Area (ft}^2\text{)} = \text{Rise (inches)} * \text{Span (inches)} * 0.005472$$

For open bottom culvert sizing the equation for bridge sizing (below can be used). However, for rough field estimates when scoping out various culvert sizes Table 6 can be used to get approximate estimates of what might be involved. A more complete reference on culvert sizing is entitled "Hydraulic design of highway culverts" (Norman et.al., 1985).

Bridge Sizing and Peak Flows

Determining whether or not a proposed bridge installation is capable of handling the 50-year is something you can do with the information provided below. You need the following information to make an evaluation about a proposed bridge installation:

- ! The stream gradient.
- ! A cross-sectional drawing of the bridge and stream channel. The drawing must be drawn to scale (see Figure 21).

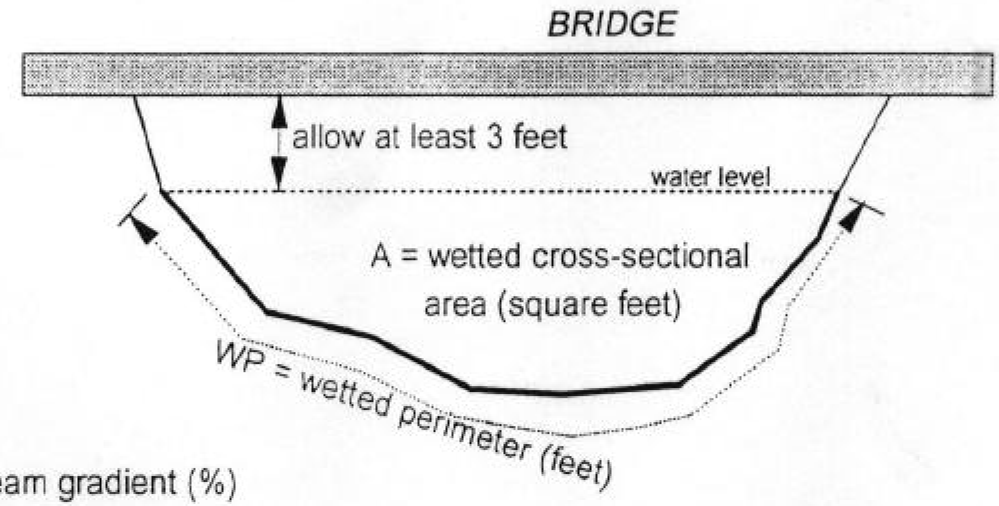
First, on the cross-sectional drawing of the channel and bridge, draw a horizontal line 3 feet beneath the bridge's lower surface (Figure 21). This represents the water level during the 50-year flow. This 3 feet of clearance is needed to pass large woody debris that is floating downstream.

Percent of rise or diameter with baffle or embeddir inside culvert	% Xsec Area Loss Round Culvert	% Xsec Area Loss Pipe Arch Culvert
10	5	8
15	9	14
20	14	20
25	20	26
30	25	33
35	31	39
40	37	45
45	44	51
50	50	57
55	56	63
60	63	69
65	69	74
70	75	79

Table 3. Comparison of percent of culvert diameter or rise with baffles or embedding and corresponding cross-sectional area loss for the culvert.

Flow capacity under bridge =

$$30 * A * (S/100)^{.5} * (A/WP)^{.67}$$



S = stream gradient (%)

EXAMPLE: If the stream gradient is 2 %, the wetted cross-sectional area is 120 square feet, and the wetted perimeter is 30 feet, then the flow capacity would be 1289 cfs.

Figure 21. Cross-section drawing of a bridge and stream channel and the equation to calculate the flow capacity under the bridge. (Adapted from landowner reference manual).

Next, measure the length of channel (in cross section) that would be wetted when the water is at the 50-year flow level. This length is called the wetted perimeter. Write down what this length would be (in feet) in the field. Next, measure the cross-sectional area of water that would exist when the water is at the 50-year flow level. This is called the wetted cross-sectional area. Write down what this area would be (in square feet) in the field.

Finally, calculate the flow capacity of the bridge using the equation:

$$\text{Flow capacity} = 30 \times A \times (S / 100)^{0.5} \times (A / WP)^{0.67}$$

where: A = wetted cross-sectional area (square feet)
S = stream gradient (percent)
WP = wetted perimeter (feet)

The units of the calculated flow capacity are cubic feet per second.

The bridge design is adequate if the flow capacity (derived by the equation) is greater than the 50-year peak flow determined for the site.

Alternative culvert or bridge sizing for a road built across a wide flood plain

Roads built across streams having wide flood plains are often less likely to cause damage to the stream over time if the road fill is designed with a reduced height. Less fill material in the flood plain means that less material is available to be washed downstream during extreme flood events. In order to allow a low fill design, the rules give the operator the option to install a smaller culvert or bridge than would otherwise be required.

A low fill design must contain the following elements to be approved:

- The flood plain of the stream must be at least 3 times the active channel or 100 feet wide at the proposed road crossing.
- The culvert or bridge must be large enough to handle the 1- 2 year peak flow.
- An overflow depression must be constructed in the road fill at a location away from the culvert and at an elevation lower than the top of the culvert or bridge.
- The road surface and downstream edge of the overflow depression must be armored with rock of sufficient size and depth to protect the fill from eroding when a flood flow occurs.

Figure 22 illustrates the features of this optional design for wide flood plains. To get the corresponding peakflow size for the 1-2 year even multiply the 50 year peak flow by 0.40. Therefore a 1000 cfs flow at the 50 year peak corresponds to approximately a 400 cfs flow at the 1-2 year peak.

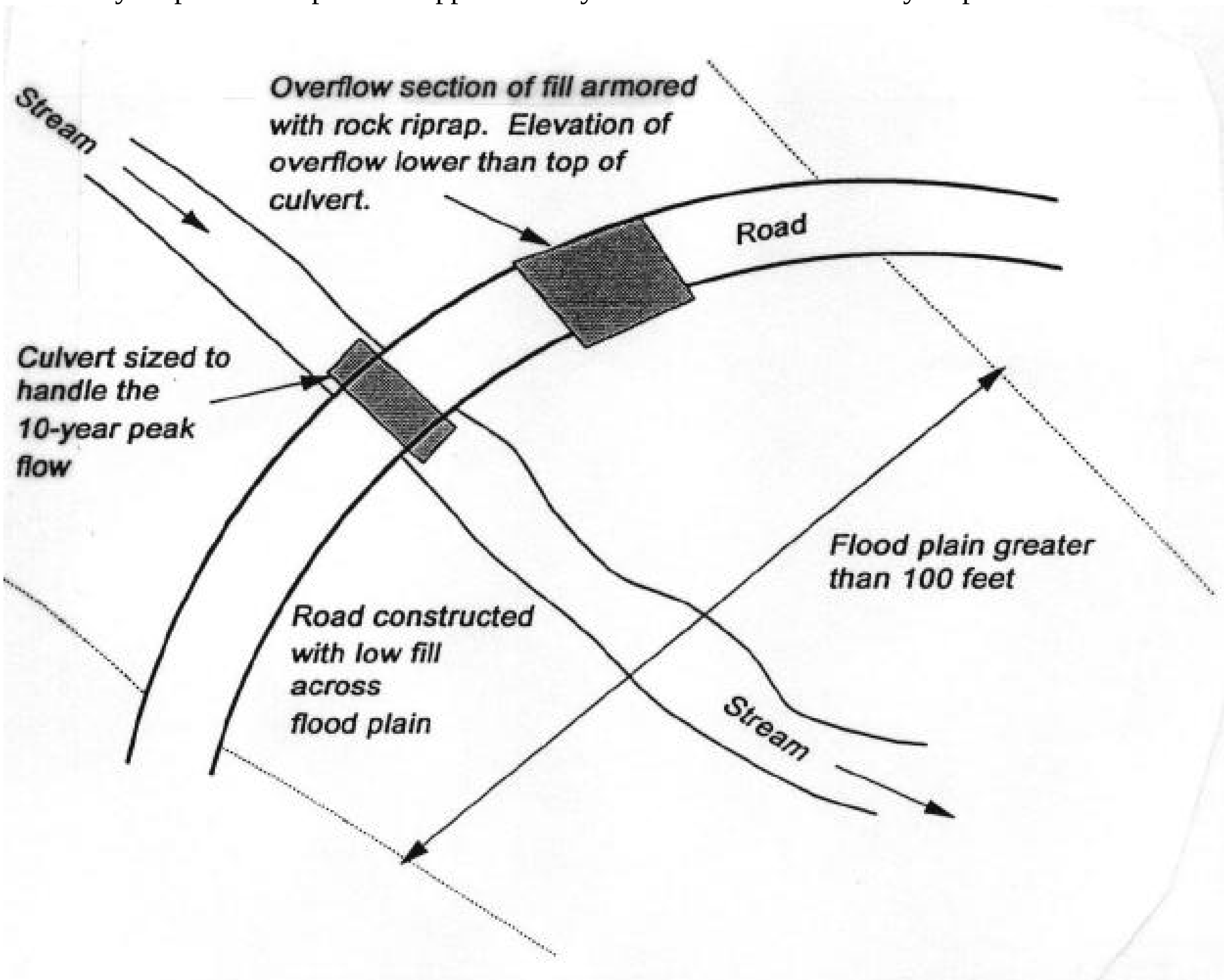


Figure 22. Features for the optional design of constructing a road with low fills and smaller culvert or bridge. (Adapted from landowner reference manual)

6. Installation considerations for road/stream crossings

Some general guidelines regarding working in the stream channel is given in the ODFW fish passage guidelines in Appendix A. AIn water work≅ is defined as that pertaining to work done within the normal high water marks of the stream. Timing along with the amount of work done is also important and a listing of in water work periods for given streams can be found at local ODFW offices or from ODFW's web site at http://www.dfw.state.or.us/hcd/timing/timing.html. The basic premise behind the timing and guidelines is to reduce sediment impacts by working during the lowest flow periods (or periods when key fish species are not in the system or spawning or have eggs in the stream) and by mitigating impacts by de-watering and isolating the stream from the construction activity as much as possible. Another idea (in addition to ODFW guidelines given in Appendix A) is the use of hay bales downstream to slow down the streamflow and allow for deposition and filtration of the streamwater near the source of sedimentation. Working in such a way that does not minimize sediment impacts not only is outside the spirit of restoration but may also be the cause of fines and expensive clean up efforts.

When installing culverts another consideration is to create a stable bed of gravel to lay the culvert on and compact the bed prior to installing the culvert. After laying the culvert in the bed should be laid down around the culvert in lifts and each successive layer should be compacted. Guidelines for lift thickness are given in culvert specification books. Creating a stable bed helps prevent settling of the culvert, while the use of lifts stabilizes the culvert giving it equal pressures to prevent crumpling. A culvert requires side pressures to be able to handle vehicle loads. This is particularly important for pipe arch culverts.

The sides of the fills on each side of the culvert should be no more that 1.5/1 (horizontal distance/vertical distance). If attempting to create steeper sides the use of concrete, gunnite or carefully placed boulders must be used. In determining length of culvert the issue of side slope angle must be considered.

During installation with the equipment on hand is a good time to install overflow dips (Figure 20) and or grade reversals in the road in case the culvert clogs. With these types of structures in the road the water can be diverted without washing out the fill or the road. In western Oregon generally seeding the area disturbed is not required, however, in eastern Oregon grass seeding may be desirable to reduce erosion in and around the installation site.

7. Maintenance and monitoring of installations

There are several formal monitoring efforts regarding fish passage in Oregon and in neighboring states. For instance, the Oregon Department of Forestry is monitoring the compliance level of stream/road crossing installations to guidelines similar to these. Washington state is monitoring several culverts and determining fish movement in and around culverts. However, a more fundamental monitoring concern is to assure that the installations are functioning as planned and to determine if any maintenance needs to occur to keep the installation functioning as planned. What follows are several key questions to look at with recently installed culverts. These questions, address concerns based on field experience that most often need remedial action. The factors are:

1. Outlet drop – Did the culvert develop an outlet drop of more than six inches? If yes, actions might include riprapping the outlet or installing or repairing a downstream control structure.

2. Inlet drop – Did the culvert develop a drop in bed or constriction to flow that causes the water level to drop suddenly at upstream end of the culvert? If yes, actions might include re-shaping the stream upstream of the culvert if there is a constriction. It could also involve putting material or a sediment catching device in the culvert if the culvert was meant to be embedded but the material washed out at the inlet.

3. Embedding – Is the culvert retaining material as designed? If no, larger material may have to be added or a sediment catching device may need to be added.

4. Trash at inlet or inside culvert – Is there material inside or lodged at the inlet of the culvert? If yes, the material needs to be removed. If a constant problem and an expensive or important crossing a trash rack could be installed.

5. Culvert filling – Is the culvert more than 50% full of sediment? If yes, you may consider cleaning some of it out or opening up the outlet side more to allow material to move through. Oftentimes this temporarily occurs in reaches that were aggraded upstream of an undersized culvert and with the new culvert the aggraded material moves in quickly. Overtime this material may cycle out.

6. Culvert damage – Did rip rap from the sides dent the culvert significantly? If yes, this could be a serious problem because to the amount the culvert is dented, there is a reduction in flow capacity.

Rationale behind recommendations

Background on culvert/bridge sizing method

The peak flow forest streams map used in this training guide is based on gage data from small forest streams. Both conventional gage data and crest gage data was used as a source of information. In developing the Department of Forestry's method, recurrence interval values (i.e. T year peak flows) were estimated using the Log Pearson III distribution in accordance with Bulletin 17 B guidelines. Gage information consisted of a small population of long-term gages with a larger number of short-term gages. For all gages the 10-year annual peak flow was determined. For the long-term gages the 50-year annual peak flow was determined. A ratio between the 50-year and 10-year peak flows was then developed. This ratio was applied to the short-term gage data to extend it out to a 50-year value. All gage data was then plotted as points on a map of Oregon. From the point data, the iso lines of common peak flow were drawn producing the peak flow for forest streams map.

The map and method was reviewed by Dr. Marvin Pyles and George Taylor from Oregon State University. In recent discussions, Chip Andrus indicated that the drawing of iso lines was generally straightforward for most the state. However, in the Central and Northern Cascades gage data was highly variable. Here, the iso lines were drawn to reflect median values and therefore the method under-predicted peak flows in some areas.

Other methods that are commonly used to estimate peak flows for small forested watersheds are known to not match well with gage data. The U.S. Geological Survey methods will under-predicted peak flows in small forest watersheds because the equation was developed using data from both large and small watersheds. Small watersheds have heightened peak flows compared to large watersheds (when expressed as cfs per square mile of drainage area) and the equation does not account very well for this. The Campbell method does not suffer from this problem but in comparisons with gage data the method tends to under-predict peak flows along the South Coast, in areas east of Tillamook, and in the Siletz River area. It tends to over predict peaks in Columbia county and in parts of Eastern Oregon. The SCS method is known to grossly over-predict peak flows for all areas of the state because it assumes overland flow.

Because of the problems associated with other methods , the map method should be the primary method used for road crossing design in small forested basins (i.e. basins less than 10 square miles). The only exception to its use should be when gage data is available and directly applicable for predicting peak flows for a given installation.

Another consideration is that the ODF peak flow map method (when used in concert with the culvert sizing criteria in this guide) is really (in most cases) not a 50 year design for integrity of stream crossing fills. The method's criteria sizes culverts so that the flow at the 50 year peak is right at the top of the culvert (not a the top of the fill or at a point of fill stability). In this regards, this design criteria is conservative allowing for leeway in case partial culvert plugging or other problems occur. To understand how conservative this design can be, a seven foot diameter round culvert with a 20 foot fill height would pass a calculated 50 year flow of 262 cubic feet per second (cfs). However, if water was allowed to build on the road fill up to 14 feet the flow capacity would change to 525 cfs. This would be well over the 100 year flood if the 50 year flood is 262 cfs. Another conservative assumption is the ODF method assumes a projecting inlet as opposed to a mitered inlet or headwall inlet. A change in inlet design from projecting to headwall can change flow capacity from 262 cfs to 310 cfs which is about a 100 year flow. After saying this, it should be stated that there are many low fills with projecting inlets that would have only marginal increases in flow capacity.

In order to estimate the 100 year peak flow based on ODF 50 year maps, a simple ratio between the 100 year and 50 year peak can be calculated and multiplied by the determined 50 year peak value. The ratio can be determined from frequency distributions or actual gage data compilations. In using gage compilations the range in the 100/50 ratio is from 1.07-1.23 for Coastal Oregon streams using USGS peak flow compilations. The smaller streams tend to have the higher ratio so a recommended ratio would be 1.2 if converting to 100 year flows from 50 year flows. For Cascade and Valley streams the ratios inspected tend to be similar. Using this method, if the peakflow determined from the ODF method is 100 cfs the 100 year peakflow estimate would be 120 cfs.

Background on hydraulics of embedded culverts

As mentioned earlier most compilations of Mannings N values for roughness are derived during high flows and Mannings N generally increases as streamflow decreases in natural streams. For this reason a method had to be developed that could estimate the effect of roughness on mean velocity for lower flows. Fortunately, a series of flume studies have been conducted and the results of several are given in Thorne and Zevenbergen (1985).

Equations used to calculate mean velocity inside embedded culverts were chosen based on the relative "submergence." Relative submergence (also called relative roughness) is the depth of flow of water compared to the height and size of the boulders or cobbles present. If relative submergence was less than 1.2 Bathurst's large scale roughness equation was used. If relative submergence was between 1.2 and 4 then Bathurst's intermediate equation was used. Finally, if relative submergence was greater than 4 then Hey's small scale roughness equation was used. The equations all appear in Thorne and Zevenbergen (1985). Some algebraic manipulation had to be done to use them to solve for mean velocity directly.

These equations were then combined with culvert geometry relations into a spreadsheet to examine the various velocities and other hydraulic characteristics that occur inside a culvert during various streamflows. The equations based on empirical data from flume studies confirm the idea that Manning's N does indeed increase as flow decreases (Figure 23).

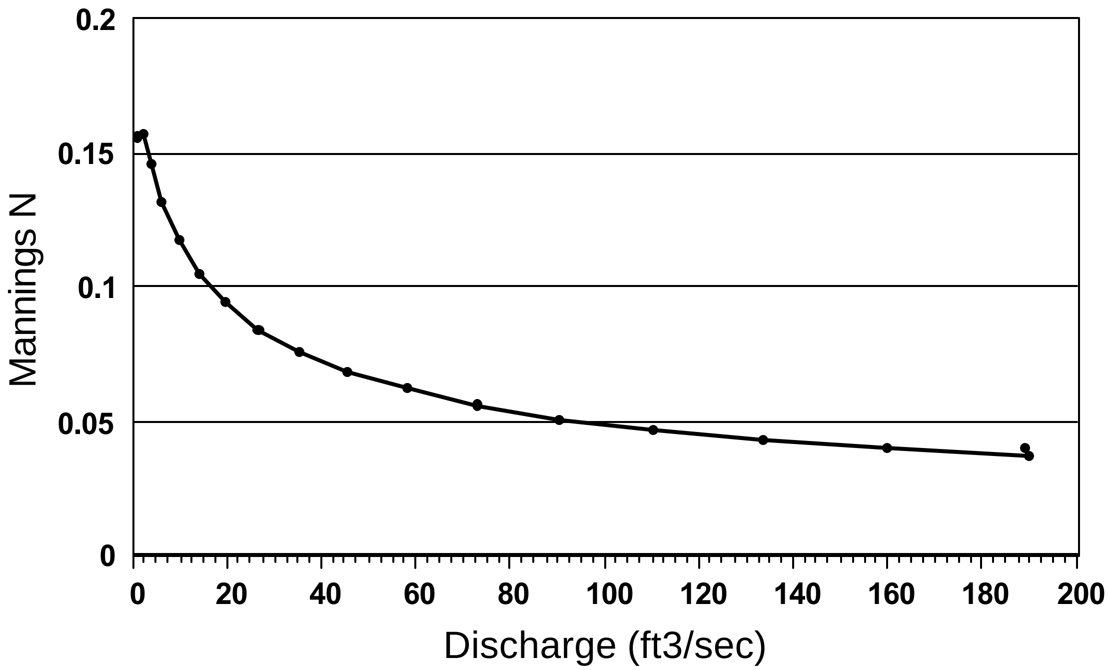


Figure 23. Variation of Mannings N with Flow for 10 foot diameter culvert with dmax 15 inches and stream slope 6%.

In addition, calculations indicated that in order to get favorable average velocities inside the culvert larger embedding material needs to be used as slope increases (Figures 24 and 25). In this example, a 10 foot diameter round culvert half full of material with a maximum diameter of 15 inches with other smaller material mixed in had average velocities below two feet per second for flow up to 15 cfs for a culvert with a slope of 6% (Figure 25). This was very similar in performance to a culvert with six inch material that had a slope of 3% (Figure 24). In fact, the culvert estimates had average velocities less than 4 feet per second even to flows as high a 45 cfs. Since the occupied (where fish occupy) area velocity should be much less in a roughened channel of this nature, there is probably favorable velocity conditions even for juveniles. This 45 cfs flow corresponds to a flow that is approximately 20% of the 50 year flow for 10 foot culvert half full of sediment which should easily be greater than a 10 percent exeedence flow and also give minimal migration delays at this flow level.

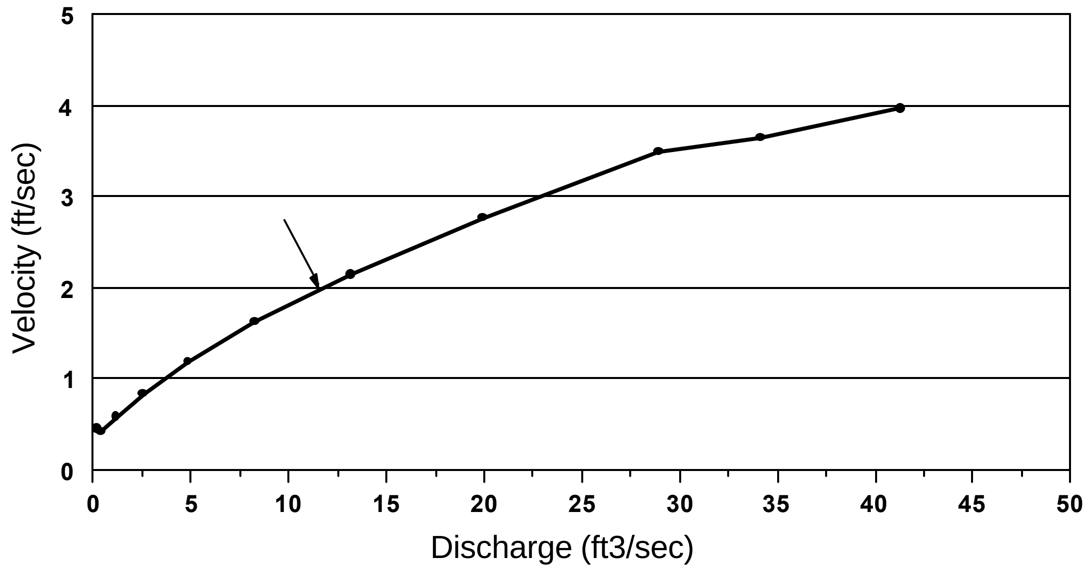


Figure 24. Variation of average velocity with flow for 10 foot diameter culvert with dmax 6 inches and slope 3%.

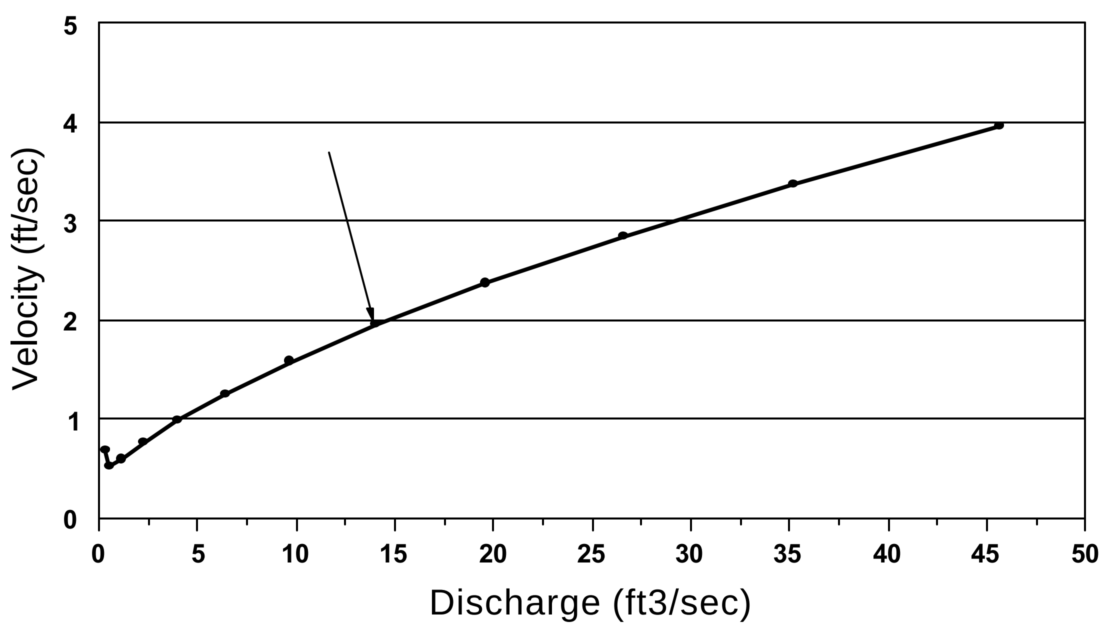


Figure 25. Variation of average velocity with flow for a 10 foot diameter culvert with dmax 15 inches and slope 6%

It appears that the material size gradation needed to render favorable hydraulics is greater than the sizing needed to maintain bed stability as determined from U.S. Army Corp of Engineers (1994) methods for sizing riprap in artificial channels. The results from the culvert survey in Oregon (White, 1996) seem to also show material being retained in actual culverts that is somewhat smaller than that needed to get favorable hydraulics in these equations. From Figures 24 and 25, it appears that material that is a gradation that has a largest diameter particles around 15 inches would appear to be both stable and produce favorable hydraulics in culverts of up to six percent. For culverts of less gradient embedding material can be smaller.

Another indicator of favorable fish passage hydraulics is to have overall flow values be "sub-critical (that is a Froude Number less than one). According to the equations from Thorne and Zeberhagen it appears that on average sub-critical flow predominates in flows up to 60 cfs for a 6% gradient culvert with a 10 foot diameter half full of sediment (Figure 26). This corresponds to approximately 25% of the 50 year flow capacity for this culvert type.

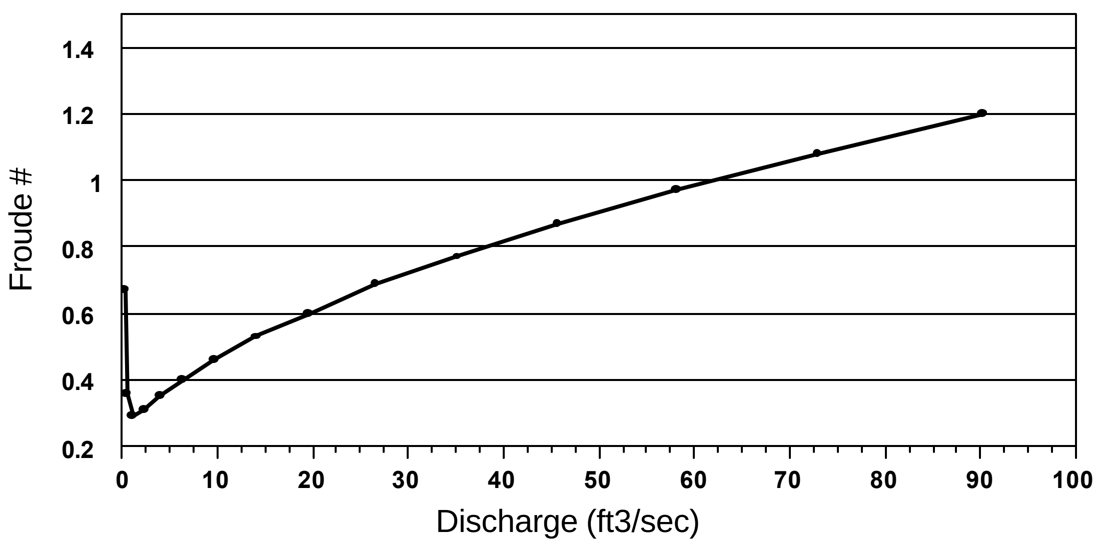


Figure 26. Variation of Froude # with flow for a 10 foot diameter culvert with dmax of 15 inches and a slope of 6%.

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Appendixes

Appendix A – ODFW Fish Passage Guidelines

Appendix B – ODFW Fish Passage Statutes

Appendix C – Interagency MOA

Appendix D – Proposed ODF Rule Guidance Regarding Fish Passage

Appendix E – Step by Step Guide for Culverts placed flat and for sunken embedded culverts.