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Chapter Three: Biological issues of Fish Passage Design

Objectives and Purpose

The objective of this chapter is to provide a brief overview of the biological factors that affect fish passage design at stream road crossings. The chapter will provide excerpts from research papers, regulations, references and a bibliography. Discussions will address the following questions.

1. When and why do fish move upstream at road stream crossings?
2. What physical conditions constitutes a barrier to the movement of fish ?
3. How does the biology of fish influence the movement of fish and identification of barriers to that movement?
4. Other Passage and Habitat Considerations

Extensive quotes are included in this chapter from two state publications. They can be downloaded from the Web.

1. The Oregon Road Stream Crossing Restoration Guide, Oregon Dept of Fish and Wildlife
2. Fish Passage Design at Road Crossings, a design manual for fish passage at road crossings, Washington Department of Fish and Wildlife, Habitat and Lands Program

Fish Movement in streams

In- stream structures as a minimum must allow for the movement of fish "when fish are moving". Fish move within streams for some of the following reasons.

1. Reproduction: Salmon migrating upstream for spawning
2. Habitat: Juvenile and Adult fish move within the system for food and protection. A stream reach will often have limits of available habitat.
3. Refuge: Fish movement for refuge from environmental factors such as elevated stream temperatures, and high flows . Predation from larger fish will force fish to move for refuge.
4. Life cycle: Each species is unique, They move withing streams as needs change in their particular life cycle. Pacific Lamprey will live in streams for years then migrate to the ocean and later return. The same is true of Salmon. Care should be taken to minimize effects of construction within a stream's ecosystem.
5. Overwintering habitats: Salmon often will move into and out of tributaries and side channels.
6. Genetic programing: Fish move up or down streams looking for a habitat that may no longer be their but historically was available.

Fish passage design: Philosophy, Theory and Practice[1]

"When designing fish passage facilities, the following biological variables are considered:

1. Species of fish present
2. Life stages to be impacted
3. Migration timing of affected species/Life stages.

Fish passage design is normally based on the weakest species or life stage present that requires upstream access and should accommodate the weakest individual within that group. Management objectives and other relevant factors may, however, direct deviations from this standard. For instance, passage needs of undesirable species (i.e.,brook trout in bull trout habitat) may not be accommodated based on other over-riding management objectives. Also , if juveniles, generally the weakest life stage of a species, would use habitat above a culvert for an insignificant portion of the year, ODFW may conclude that only spawning fish (stronger adults) need to be accommodate and that the culvert need not be designed at the higher (juvenile) standard."

Juvenile Fish Passage Through Culverts in Alaska[2]

The report Juvenile Fish Passage Through Culverts in Alaska[3] studied the behavior of juvenile fish at four selected culverts in Alaska. The objective was to determine the behavior of juveniles when attempting to ascend a culvert. It was hypothesized that vertical obstacles or higher velocities of opposing flow may prevent juvenile fish from moving upstream. It was also hypothesized that they would determine and take the path of least resistance to optimize thief chances of successfully ascending a culvert.

Four Culverts were selected for intensive study. In the Beaver Creek culvert, fish used the large corrugations to their advantage when ascending the culverts. The Pass Creek Tributary culvert had corrugations too small for fish to utilize. No- name creek appeared to present no problem for juvenile fish for the water levels at the time of the visit as they swam along the bottom on the centerline of the culvert. In general, observations of fish attempting to move upstream through a culvert revealed that they swam very close to the culvert wall, and in the case of high velocities (Beaver Creek and Pass Creek Tributary) they swam near the surface along the sidewall where velocities are reduced. It is obvious that the juvenile fish are attempting to minimize power output and energy expenditure by taking the path of least resistance.

Although not quantitatively proven, it appears that as long as fish make some headway in their upstream movement they are content. The rationale for this conclusion is that fish do not know what they may encounter upstream, so they attempt to conserve as much power and energy as possible while still moving forward. They generally do so by seeking out the lowest velocities in the cross section. In areas of steep velocity gradients along the wall(where the areal extent of low velocity is limited) , it is clear in our videotapes that fish have problems maintaining their position and preferred orientation. It is apparent from our observations that because of their small size, juvenile fish are hindered by turbulence and that this area needs more study.

Fish Movement and the Road Network[4]

“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 steel head 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 seeing 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 Young1995,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 cycles such as sockeye salmon fry swimming upstream to reach their rearing lake. Coho juveniles have also been noted several studies to migrate upstream in the fall into side water channels and tributaries (Bustard and Narver l975, 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 1979)

Fish Movement in streams

Instream structures should allow for movement of fish "when fish are moving." This is not an exact science. Data is often limited on the flow variations in a stream reach and the ranges of times that fish are moving in those reaches. Fish move within streams for some of the following reasons.

1. Reproduction: Salmon migrating upstream for spawning
2. Habitat: Juvenile and Adult fish move within the system for food protection
3. Refuge: Fish movement for environmental factors such as elevated stream temperatures, flow conditions and predation.
4. Life cycle: Moving upstream to a rearing lake or downstream for fresh water habitat.
5. Overwintering habitat: Coho often will move into tributaries and side channels.
6. Genetic programing: Fish move up or down streams looking for habitat that may no longer be their but historically was available.

When do fish move in the streams? Each drainage and stream will of course have it's own cycles. The chart below is offered as an overview of fish movement in a typical drainage in south western Oregon stream.

FISH MOVEMENT IN STREAMS FOR COOS BAY DISTRICT BLM

COOS BAY DISTRICT BLM

FISH MOVEMENT IN MOUNTAIN STREAMS

COOS ,NORTH FORK COQUILLE AND SOUTHFORK COQUILLE WATERSHEDS

SPECIES	AGE ACTIVITY	JANUARY	FEBUARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	EPTEMBE	OCTOBER	NOVEMBE	DECEMBE
COHO	ZEROS						Move	Down	Stream		Move back into rivers from main trb.		
	1+			Pre	Smolt	Condition							
	SMOLTS					Move	Down	Stream					
	ADULTS										Migrating	Migrating	Migrating
	SPAWNING	Spawning									Spawning	Spawning	Spawning
	HATCHING			Hatching									
WINTER STEELHEAD													
	ZERO						1	1	1		2	2	2
	1+						1	1	1		2	2	2
	2+						1	1	1		2	2	2
	SMOLT					Move	Down	Stream					
	ADULT		Migrating	Migrating									Migrating
	SPAWNING	Spawning	Spawning	Spawning									Spawning
	HATCHING			Hatching	Hatching	Hatching							
CUTTHROAT TROUT	0												
	1						1	1	1		2	2	2
	2						1	1	1		2	2	2
	3						1	1	1		2	2	2
	4						1	1	1		2	2	2
	5						1	1	1		2	2	2
	6						1	1	1		2	2	2
	SMOLT	Move Down	Stream	Move Down	Stream	Move Down	Stream	Move Down	Stream	Move Down	Stream	Move Down	Stream
	ADULT	Move Down	Stream	Move Down	Stream	Move Down	Stream	Move Down	Stream	Move Down	Stream	Move Down	Stream
	SPAWNING	Spawning	Spawning	Spawning	Spawning	Spawning	Spawning	Spawning	Spawning	Spawning	Spawning	Spawning	Spawning
	HATCHING		Hatching	Hatching	Hatching	Hatching	Hatching	Hatching	Hatching	Hatching	Hatching		

NOTE
#1 = Movement down stream.
#2 = Movement back into the river from main stream.

Barriers to Fish Passage

Barriers to fish passage are inventoried as total, partial or temporary. The table below compares barriers and their effects. The biological characteristics of fish determine if a condition in the stream is a barrier. For example each species has different swimming and leaping capabilities. A condition for an adult salmon may be only a temporary or no barrier but the same condition for a trout would make it a total barrier.

Note: Criterion for identifying barriers are not design criterion.

Table : Barriers to fish passage and their potential effects.

Barrier Category	Definition	Potential Impacts
Total Barrier	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 Barrier	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 Barrier	Impassable to all fish some of the times	(1) delay of Movement beyond the barrier for some period of time

Barrier to fish movement at Stream Road Crossings- Physical characteristics

1. Excess drop at culvert outlet or inlet creating jumps - hydraulic jump.
2. High velocity or sudden changes in velocity at the culvert inlet, outlet, or within the culvert barrel
3. Inadequate depth within culvert barrel
4. Turbulence within the culvert
5. Debris accumulation at culvert inlet
6. Lack of resting pools at the culvert inlet, outlet or within the barrel.

Barriers that occur at high stream flows may not be apparent at low stream flow and visa vera.

Photo of Fish trying to enter a perched culvert. Photo downloaded from San Diamas Web Site .

Effects of Fish Barriers

Stream channel crossings by roads has resulted in a serious loses of fish habitat due to improperly designed culverts. Many biologist believe these barriers
have had the greatest effect of all the forest management activities on fish populations. Thousands of culverts have been identified to date that are barriers.

Barriers to fish passage exists in some degrees at most culvert and structure crossings . Barriers also exists in nature in the form waterfalls, debris blockages, beaver dams etc.

What is a barrier and when is it important to remove it? The need for an inventory of man made barriers has to be the first step to developing a recovery program. Once inventoried, agencies can then prioritize the sites and initiate a strategy for repair or replacement.

Total Fish Passage Barrier

A total fish passage barrier is defined as stream crossings because of their design, maintenance, or condition are not allowing for adult salmonid fish passage.

The following blockages would result in conditions that exceed most Adult salmonid fish .

1. Velocities of 10 feet per second or more.
2. More then 12 inches of outlet perching without a pool
3. More than 4 feet of outlet perching with an adequate pool
4. Debris which would concentrate flow
5. Flow depths less than 8 inches unless in simulated natural streambed with conditions similar to the natural channel.

Causes of Full Blockages

1. Bare Culverts: can be a partial blockages under the following conditions
   a. Slopes greater than 4% without back watering
   b. Slopes greater than 6% with back watering ,no jump and non back watered lengths less than 50 feet.
   c. The diam or span is smaller creating excess velocities in pipe..
   d. The culvert is over 200 foot long
   e. The residual pool is less than 2 feet deep or 1.5 times the height of the drop at the outlet whichever is less.
2. Embedded Culverts can be a full blockages under the following conditions.
   a. Embedded material does not a simulated natural channel . There should be evidence of deposition and reworking of smaller materials.
   b. An outlet drop occurs that exceeds the leaping capacity of the fish.
   c. The width of the structure is constricted resulting in high velocities that exceed a fish’s swimming capacity.
3. Bridges and Open Arch Culverts can be a partial blockage
   a. If Debris builds up in the structure causing a constricted flow or high velocity in excess of 15 to 20 feet per second.

Partial Fish Passage Barriers

A partial fish passage blockage is defined as "stream crossings because of their design, maintenance, or condition are not allowing for juvenile salmonid fish passage"[5]. Juvenile salmonid fish require as a minimum:

1. Velocities of 2 feet or less within the structure.
2. Less then 6 inches of outlet perching
3. Little to no inlet Constriction or drop
4. That the structure be free of debris which would concentrate flow
5. Have flow depths greater than 12 inches or have a simulated natural streambed.

Causes of Partial Blockages

1. Bare Culverts: can be a partial blockages under the following conditions
    a. When placed on slopes greater than 0.5% without back watering.
    b. If jump pools at outlet are less then 6 inches in depth .
    c. If diameter or span is significantly less than the stream channel creating a constricted inlet with high velocity sections..
    d. If the culvert length in conjunction with the flow velocities exceed a fish' ability to swim through it.
    e. IF water depths are to shallow for fish to swim through.

2. Embedded Culverts can be a partial blockages when.
    a. rocks within the culvert reform into a smooth channel . There should be evidence of deposition and reworking of smaller materials in an embedded culvert. .
    b. a drop forms at the outlet.
    c. the inlet has a sudden drop or a long shallow run from a bedrock chute..
    d. the culvert width is too narrow compared to the existing stream resulting in high flow velocities, , a constricted entrance or channel scouring at the outlet.

3. Bridges and Open Arch Culverts can be a partial blockage
    a. When debris builds up in the structure causing a constricted flow or high velocity
    b. When the structure is too narrow such that flow is constricted with velocities that exceed the capabilities of the fish.
    c. When the base of the structure is on solid rock such that substrate does not collect and flows become shallow or fast.

Water Velocity and Swimming Speed

Fish swim through many conditions. Those conditions may include high velocity and turbulence in the main flow to quite slow, calm water along the stream edge, around large boulders and wood, or within side channels. The ability of fish to swim in those conditions is a factor of the fishes size, species, and condition. Given those abilities, we are able to approximate if a species is able to swim through a given reach or will be flushed backwards. This information is being used to quantify when the velocity of flow becomes a barrier to fish movement.

To navigate 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 leave a fish exhausted and requires a long period of rest(Webb and Weihs 1983)

Fish use these muscles to achieve three different swimming speeds: sustained, prolonged, and Burst (3-10 seconds). Sustained speed can be maintained for extended periods of time, whereas prolonged and burst speed 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 sustained and prolonged speeds(red muscle) are adequate for most conditions(Bell 1986). Burst speeds may be required to navigate areas with high water velocities such as rapids, narrow sections or reaches with steep gradients."[6]

Given the condition of a fish we are able to calculate if a fish is able to swim through a culvert from a formula developed by Powers and Orsborn (1985)

LSF= (VF -VW) TF x Cf

Where

LSF= Length of culvert that the fish can swim

VF= The speed the fish can swim at either sustained or burst, taken from tables and adjusted for the various sizes of the fish compared to its adult size.

VW= Water velocity a function of the culverts slope,size and the volume of water moving.

TF= Time before the fish becomes exhausted and needs to rest or is swept back. the fatigue time is normally 5 to 15 seconds for burst speed, and 15 seconds to 200 seconds for prolonged speed.

CF= Coefficient of fish condition See table below

Fish Condition	Coefficient of Condition CF
Bright: fresh out of salt water or still a long distance from spawning grounds: spawning colors not yet developed.	1.00
Good: In the river for a short time, spawning colors apparent but not fully developed; still migrating upstream	0.75
Poor : In the river for a long time; full spawning colors developed and fully mature, very close to spawning gourds	0.50

Velocity Barriers - ODFW Guidelines

When fish passage is required by ODFW (in general, wherever fish are present) the following guidelines shall be utilized for preliminary design. Design flows for culvert passage for those months when fish are moving.

Table1: Average Water velocity (fps) at high flow design discharge for

Culvert Length	Salmon and Steelhead	Adult Trout	Juvenile Salmonids
Under 60'	6.0	4	2
60' to 100'	5	4	2
100' to 200'	4	3	see note below
200' to 300'	3	2	see note below
over 300'	2	1	see note below

Note: For juvenile fish ,only designs incorporating streambed simulation solutions will be considered for culverts over 100' in length. “streambed simulation” refers to the situation where substrate and flow conditions mimic th natural streambed above and below the structure.

Velocities requirements noted above may be exceeded within structures with natural beds upon approval by the ODFW Fish Passage Coordinator, Portland. “[7]

Velocity Barriers -WDFW Guidelines

The actual allowable velocity and depth of flow for adult fish depend on the target species and length of culvert and are shown in Table 1 adapted from WAC 220-110-070. These criteria are intended to provide passage conditions for the weakest and smallest individuals of each species.

Table 1. Fish Passage Design Criteria for Culvert Installations

	Adult Trout >6 in. (150 mm)	Adult Pink, Chum Salmon	Adult Chinook, Coho, Sockeye, Steelhead
Culvert Length	Maximum velocity (fps)		
10 - 60 feet	4.0	5.0	6.0
60 - 100 feet	4.0	4.0	5.0
100 - 200 feet	3.0	3.0	4.0
Greater than 200 feet	2.0	2.0	3.0
	Minimum water depth (ft)		
	0.8	0.8	1.0
	Maximum hydraulic drop in fishway (ft)		
	0.8	0.8	1.0

Depth of flow barriers

The depth of water in a drainage structure is critical to fish passage for the following reasons.

1. Partially submerged fish do not maintain 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.

Minimum water depths required during expected fish passage periods.

	Oregon	Washington
Adult Trout	12 inches	8 inches
Adult Pink ,chum salmon		8 inches
Adult Chinook, Coho, Sockeye, Steelhead	1.0 feet	1.0 feet
Trout under 20 inches, kokanee and migrating juvenile salmon and steelhead	8 inches	

Depth of flow- ODFW Guidelines

For embedded (stream simulation) culvert designs, minimum depth at low flow discharge during expected fish passage periods must meet or exceed conditions found in the adjacent natural channel. [8]

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.

Depth of flow- Washington State Guidelines

Low fish passage design flow is used to determine the minimum water depth at any time. The low flow used is the two-year, seven-day low flow as described in WAC 220-110-070.

The depth requirement is a moot issue in culverts designed with natural beds. Culverts designed by the hydraulic option for trout as the default condition as described in the section on Hydraulic Design Option will generally accrete bed material in which a thalweg develops and the depth requirement is also moot. An exception to this is when a culvert becomes pressurized during an extreme flood event, the bed in the culvert scours out. If bed material doesn't immediately recruit, the bare bed condition may persist for some time.

Hydraulic Drop barriers and Jump Height

The goal in new culvert design is to avoid designs that require a jump for fish to enter a culvert. In retrofits designs this often is impossible and jumps are allowed as temporary conditions until a total culvert replacement can occur at a latter date.

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.

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.

The state of Washington has allowed an option for an hydraulic drop at the outlet of the culvert to be used only if all other options are not possible. Table one above gives the maximum drops allowed for various species of fish.

Delay Barriers

"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."[9]

"FISHXING"

Fishxing is a computer program for estimating when an existing culvert is a barrier to fish passage. The program was developed by the Sand Dimas Testing Center and Humboldt State University. The program is is available on the Web as free software. The documentation for it's use is also on the web.

The program allows a user to select a fish species, quantify it's swimming ability and then compare that ability against a culvert's flow characteristics. The program will display by season, and species when a particular culvert is a barrier to fish passage. It also can be used to calculate depth and velocity of flow for all flows through culverts.

The program considers the following

- Species of fish
- Swimming ability of fish
- Condition of fish
- Characteristics of Culvert: Shape, length, size
- Roughness of Culvert
- High Fish passage flow
- Low Fish passage flow

Other Passage and Habitat Considerations - WDFW

“Regardless of successful fish passage, the placement of culverts often result in habitat losses that must be mitigated. These impact are associated with the culvert itself and some may also be associated with channel modification necessary to install or retrofit a culvert for fish passage. There are, for example, habitat losses often associated with steepening a channel to achieve fish passage. Following are habitat considerations that may control the siting, sizing and design of culverts and/or fish passage improvements.

Direct habitat Loss

Salmonid habitats include all areas of the aquatic environment where the fish spawn, grow, feed, and migrate. Culvert installations require some level of construction in the stream channel which replaces native streambed material and diversity with the culvert structure.

Spawning Habitat

Each species of salmon and trout require specific spawning conditions related to the water velocity, depth, substrate size, gradient, accessibility and space. All salmonids require cool, clean water to spawn in. In the stream environment most salmonid spawning will occur in pool tail-outs and runs. Spawning habitat can be lost or degraded by culvert installations in the following ways.

I. Culvert placement in a spawning area replaces the natural gravel used for spawning with a pipe. This is a direct loss of spawning habitat.

II. Culvert construction can require significant channel realignment that eliminates natural meanders, bends and spawning riffles and other diversity in the channel that serve as valuable habitat.

III. Culverts shorten channels leading to increased velocities and bed instability that reduce spawning opportunities and decrease egg survival.

IV. Riffles and gravel bars immediately downstream of the culvert can be scoured if flow velocity is increased through the culvert. Gravel mobilization when eggs are incubating in redds(nests) results in high egg mortality.

V. Any release of sediment into the stream may smother spawning gravel with silt and is considered as a direct habitat impact to that project. In the case of culverts, sediment releases may be due to construction or due to change in hydraulics due to the alignment, siting or design of the culvert. Appropriate mitigation is to prevent the release the sediment in the first place by design and implementation of a good erosion and sediment control plan and by project timing and strict adherence to best management practices.

Rearing Habitat

Juvenile salmonids utilize almost all segments of the stream environment during some stage of their freshwater residence. Habitat usage is highly variable depending upon the species, life stage, and time of year. Pools with large woody debris are especially valuable habitat. Trees on the stream bank provide cover and a source of insects and large woody material which are critical to rearing fish. Culvert construction can negatively impact rearing habitat in the following ways:

1) There is a direct loss of rearing habitat when it is replaced with a pipe.

2) Woody debris at the culvert site is removed to install a culvert. Woody debris provides many benefits to channel structure, function, stability and food production which all contribute to healthy salmonid populations.

3) Riparian vegetation is removed from the stream bank to make way for the culvert installation and is often removed for the entire right-of-way width as a regular maintenance activity.

4) Cutting off of natural bends, meanders, side channels and backwater channels directly eliminates usable habitat. Similarly, any reduction in stream length by a culvert is a reduction in rearing habitat. Most side channels and back water channels are more productive with higher fish usage than the main stream channel, especially during winter flood flows.

5) Culvert placement that lowers the natural water level of pools, ponds, backwaters, or wetlands within or adjacent to the stream can significantly decrease valuable rearing habitat.

Loss of Food Production

Fish, like all other organisms need food in order to survive, grow and reproduce. Juvenile salmonids feed on aquatic invertebrates and terrestrial insects that fall into the water. The food chain in the aquatic environment begins with the primary producers like algae and diatoms (periphyton) which require organic material and sunlight to fuel the photosynthetic process. Benthic invertebrates like mayflies, stoneflies and caddisflies feed on the primary producers. Invertebrates require some of the same conditions as salmonids such as clean water and stable gravel. The inside of a culvert is dark and the absence of sunlight prohibits primary production. Reduction in the number of invertebrates that are a source of food for salmonids can reduce growth rates. It is generally recognized that faster growth rates that produce larger salmonids is a competitive advantage that increases their survival rate at sea.

Removal of riparian vegetation for culvert placement reduces the organic debris like leaves, wood, bark, flowers, fruit etc. that enters the stream and fuels primary production. Terrestrial insects that drop from overhanging vegetation into the water where they are consumed by salmonids are removed from the food base when the vegetation is lost.

Mitigation of direct habitat losses

Mitigation for impacts of loss of cover and pools might include adding diversity and structure such as woody debris to the channel in an appropriate location. Placement of a culvert in a spawning area results in a direct loss of that habitat. Gravel spawning beds are also valuable as invertebrate habitat. Spawning habitat in most Pacific Northwest streams is not limited by the supply of gravel, it is limited by the structure and diversity of channel forms that sort and distribute bed material to create spawning and other habitats. The only effective mitigation in most situations is to avoid loss of the spawning habitat in the first place. In streams that are deficient in spawning gravel, a loss of spawning habitat might be mitigated off site by gravel supplementation. Several techniques might be used.

Gravel merely placed over an existing streambed, whether inside or outside of a culvert, may be an attractive nuisance in that it is attractive to fish for spawning but not stable enough for eggs to survive winter floods. Once the gravel is redistributed by high flows, it can be valuable habitat.

Gravel supplementation should be done to mimic natural gravel deposits or gravel banks. Natural deposits that can be copied are pool tailouts and gravel banks. The downstream end of stable pools and stable riffles might be supplemented with a layer of gravel to mimic tailout deposits. Gravel can be placed upstream of streambed controls installed as part of the fish passage project. A channel constriction made of mounds of gravel will, in the right situation, create a pool and a tailout. Gravel can be supplied to a bankline to mimic a natural eroding gravel bank. The gravel is redistributed most efficiently by high stream flows.

If several feet of washed gravel is placed in steeper culverts there is the potential for low flows to go subsurface and create a barrier. This is especially problematic when there is no input of bedload from upstream to seal the gravels, such as when there is a wetland or pond immediately above the culvert.

Another common reason for placing gravel in culverts is to fill the void created by countersinking the culvert. If the purpose is to prevent an upstream head cut, the material should be sized according to the discussion in the section on Channel Profile.

Water quality

To extend the life span of culverts in acidic water, they are sometimes treated with an asphalt coating. It is unknown what affect this may have on fish or invertebrates in the water. Until it can be shown that these type of treatments are not a risk to fish health they should not be used.

Quality and quantity of road storm water runoff shall be mitigated as determined appropriate by local jurisdiction or the Department of Ecology. In addition, all storm water discharges into a stream must be designed to prevent scour during higher flows.

Upstream and downstream channel impacts

Increased velocity from a culvert can erode downstream banks and thus promulgate the need for bank protection and extended impacts of the culvert. It is recommended that the culvert exit velocity should not exceed the pre-project channel velocity at the outlet location by more than 25% at the same stream flow.

An undersized culvert creates a bed instability upstream. At high flows the culvert creates a backwater and bed material deposits in the channel upstream. With receding flows, the bed and/or banks erode through or around the deposition. The result is either a chronically unstable channel bed or increased bank erosion and the need for bank clearing and protection. It is recommended that the culvert inlet be designed to limit head loss to less than 1.0 foot during a 10-year flood.

The upstream and downstream impacts listed above are normally mitigated by the design process. Typically, the size and elevation of culverts required are such that velocities leaving the culvert are not excessive. Sites with banks or beds susceptible to erosion may require special consideration.

A culvert placed into a stream with an actively migrating channel can result in an acceleration of the channel migration and substantial maintenance effort to keep the channel at the culvert location. Channel migration is a natural geomorphic process though it might be exacerbated by upstream activities; it is part of ecological connectivity.

Additional impacts due to channel head cut and regrade must be considered in the design.

Ecological connectivity

The term connectivity refers to the capacity of a landscape to support the movement of organisms, materials, or energy (cited by Peck, 1998). In terms of culvert design, it is the linkage of organisms and processes between upstream and downstream channel reaches. The health of fish populations ultimately depend on the health of their ecosystems which includes migrations and processes dependent on the connectivity. Biotic linkages might include upstream and/or downstream movement of mammals and birds, non-target fish species, and the upstream flight, and downstream drift of insects. Physical processes include the movement and distribution of debris and sediment and migration of channel patterns.

Some of these functions may be blocked by road fills and culverts that are small relative to the stream corridor These issues are difficult to quantify and generalize but may ultimately be significant to the health of aquatic ecosystems. More development of the concept of ecological connectivity in relation to road culverts is expected and encouraged.

Debris and bed material should be managed by allowing them to pass unhindered through the culvert. When debris is trapped fish passage barriers are created, the debris is not passed to the channel downstream, and a backwater is created upstream that extends the effect of the culvert. Usually the size of the culvert as developed by the design processes described in this manual will be adequate to pass most debris and bed material. There may be special cases where the culvert size should be increased to not capture debris.

Trash racks and multiple parallel culvert pipes racks are generally not acceptable because they trap debris, create barriers to fish migration and increase the risk of culvert failure. In the case of low road profiles, instead of multiple culverts, alternative low clearance culvert structures should be considered.

Debris racks might be a reasonable temporary solution in special cases of existing culverts with high risk of debris plugging and a clear responsibility and committed schedule of future culvert replacement. The debris rack for this situation should be mounted high on the culvert, above the ordinary high water. The rack itself is only functional at high flows when debris is moving. The space below it is left open for flow. Openings within the bar rack should be no smaller than nine inches. A specific monitoring and maintenance plan should be developed for any debris rack and convenient access for these activities must be provided.

Channel maintenance

Other than fish passage, likely the greatest impact posed by culverts to aquatic habitats is the need for channel maintenance created by poor siting of road crossings and culverts. Highways are often placed at the fringe of river flood plains and must therefore cross the alluvial fans of small streams entering the flood plain. As the stream enters the relatively flat flood plain a natural deposition zone is created and the channel is prone to excursions and avulsions across its alluvial fan. Culverts placed in these locations tend to fill with bed material. To keep the culvert from plugging and the road overtopping, periodic and in some cases annual channel dredging becomes necessary. Bed material removal becomes a major impact of channel instability and spawning and rearing habitat losses for some distance upstream and downstream. It is also an ecological connectivity impact to not allow bed material and the channel aggrading process to migrate through the reach.

Mitigation for these channel maintenance impacts include installing a bridge or a culvert large enough that the aggradation and channel evolution processes can continue. A bedload sump might be appropriate in some situations to localize the dredging need and to eliminate at least the upstream impacts of dredging. Relocating the road may be possible and should be considered where feasible.

Construction impacts

Construction impacts might include the release of sediment or pollutants, temporary fish passage barrier during construction, removal of bankline vegetation, blocking of the flow or stranding of fish. These issues are all dealt with in the WAC 220-110-070 by provisions for timing of construction, care of water, erosion and sediment control planning, and revegetation. The construction plans submitted for Hydraulic Project Approval should include, in addition to plans and specifications, a sediment and erosion and control plan covering these items. The provisions of the WAC may be modified for specific projects.

Risk of culvert failure

Structural failure of culverts can cause extensive and massive damage to habitat that persist for a long time. Failures can be a result of inadequate design, poor construction, beaver damming, deterioration of the structure, or extreme natural events. Risks of failure can be minimized by sizing the culvert for passage of extreme events and debris, including appropriate inlet and/or outlet armoring and use of proper backfill and compaction during In some cases fords or alternate road overflow points may be useful. This should be considered at forest roads that are susceptible to debris flows, or at roads that cross alluvial fans. construction[10].

1. Oregon Department of Fish and Wildlife Guidelines and criteria for Stream-Road Crossings, October 23,1997.

2.Juvenile Fish Passage Trough Culverts in Alaska: A field Study by Douglas Kane, Charles Belke, Robert Gieck and Robert McLean., Report Number INE/WERC 00.05,July 2000.

3.Juvenile Fish Passage Trough Culverts in Alaska: A field Study by Douglas Kane, Charles Belke, Robert Gieck and Robert McLean., Report Number INE/WERC 00.05,July 2000.

4.Oregon Road/Stream Crossing Restoration Guide, Spring l999, by Gorge Robison , Albert Mirati and Marganee Allen, June 8,1999.Page 6.

5.Oregon Road/Stream Crossing Restoration Guide, Spring l999, by Gorge Robison , Albert Mirati and Marganee Allen, June 8,1999.Page 27.

6.Oregon Road/Stream Crossing Restoration Guide, Spring l999, by Gorge Robison , Albert Mirati and Marganee Allen, June 8,1999.Page 11.

7.Oregon Department of Fish and Wildlife Guidelines and criteria for Stream-Road Crossings, October 23,1997.page 3,

8.Oregon Department of Fish and Wildlife Guidelines and criteria for Stream-Road Crossings, October 23,1997.page 4,

9.Oregon Department of Fish and Wildlife Guidelines and criteria for Stream-Road Crossings, October 23,1997.page ,

10.Fish Passage Design at Road Crossings. A design manual for fish passage at road crossings, Washington Dept of Fish and Wildlife Habitat and lands Program, Environmental Engineering Divisions, 3 march l999. pages 37 through 44.