Section A
Fish Passage Restoration

Issue: What are the adverse effects of forest road stream crossings on the distribution and movement of fish? How might these effects be further reduced?

Forest Practices Advisory Committee on Salmon and Watersheds

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I. Current Scientific Findings

Overview

Movement of fish throughout a watershed is necessary for a number of life history needs. Upstream and downstream migration of juveniles during low summer flow is often needed so they can find suitable habitat (e.g., to seek cool water refugia). During winter, juveniles may move upstream or into side tributaries and off-channel habitats to escape flood flows. Upstream migration of juveniles has been observed related to the presence and availability of beaver ponds and other fish-rearing habitat. Upstream migration of adults is important for access to spawning grounds.

Loss of fish passage at road crossings and other human-caused barriers has many potential effects, including:

- Loss of access to spawning, rearing, and winter habitat;
- Loss of genetic diversity in an upstream reach for resident fish, as fish can go downstream but not back upstream;
- Loss of range for juvenile fish that may migrate upstream at certain times of the year;
- Loss of nutrients (from the carcasses of anadromous spawning adults) to reaches upstream of passage problems;
- Changes in fish genetics or community assemblages upstream of fish passage impediments (stronger swimming fish species, more hearty gene pools, or only certain life stages can pass upstream while other fish cannot); and
- Loss of resident fish populations in small streams after extreme flood or drought events that evacuate the fish from the reach and prevent their return.

The Botkin Report (1995) and other studies have identified "impediment construction" as a major factor leading to the decline of salmonids in western Oregon.

Discussion

Some of the primary motives fish have to move or migrate are to satisfy basic requirements for reproduction, habitat (i.e., food, cover, thermal regime), and refuge. On an annual basis, upstream migration of adult salmon occurs in many Oregon streams and rivers. 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 upstream movement of reproducing adults and young salmon heading down river to reach ocean feeding grounds are familiar phenomena, other types of fish migration or movement occur but are less obvious. 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 seeking less densely populated areas with better opportunities 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 a 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 strategy is unknown, there is growing evidence that coho juveniles overwintering in these areas have significantly higher survival rates (Bustard and Narver, 1975).

Information about the swimming ability of Pacific Northwest salmonids is not abundant, especially for 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). There is a marked difference in performance between adult and juvenile coho, as well as a demonstration of superior swimming capability of steelhead. The swimming ability of a fish can also be affected by the distance already traveled, turbidity, temperature, oxygen levels, water depth, water velocity, and the general health of the fish.

From this discussion, it is apparent that barriers to movement caused by road crossings 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 time.	1) Delay of movement beyond the barrier for some period of time.

The problem of human-caused barriers to fish passage in the Pacific Northwest appears to be very significant. In the Skagit River basin in Washington State, impassable culverts are responsible for 13 percent of the total decrease in summer rearing habitat on all ownerships (Beechie et al., 1994). This decrease in summer rearing habitat was considered greater than the sum total effects of all other forest management activities combined. Another study reported that as many as 75 percent of culverts in forested watersheds are either outright blockages or impediments to fish passage based upon field surveys done in Washington State (Conroy, 1997).

Of the 532 fish presence surveys conducted on forestlands in Oregon coastal basins during the 1995 survey season, 15 percent (n=79) of the confirmed end of fish use were due to human barriers. Road culverts make up the largest percentage of the barriers (96 percent), with various types of dams comprising the balance. An additional 3 percent of the surveys identified culverts with an upstream population of resident trout, but they were impassable to anadromous fish.

Surveys of county and state highways conducted by the Oregon Department of Fish and Wildlife (ODFW) for the Oregon Department of Transportation (ODOT) have found hundreds of culverts that were assumed to at least partially block fish passage (Al Mirati, personal communication, 1999). The roads surveyed were frequently located low in a drainage system and thus may be impacting passage for a large array of fish species.[1] The state and county road survey found the following number of problem culverts in Oregon:

Coastal Basins – 1,140 crossings
Lower Willamette – 167 crossings
Upper Willamette – 771 crossings
Grande Ronde & Imnaha – 83 crossings
John Day Basin – 260 crossings

The ODFW and Oregon Department of Forestry (ODF) have developed fish passage guidelines to help ensure that any artificial obstructions placed across a stream will not pose a barrier to the movement of adult and juvenile salmonids, both resident and anadromous.

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 must be designed to pass juvenile fish. Since these smaller fish are less capable swimmers, providing conditions that meet their passage needs will also assure that the needs of the adult fish are also met. The design alternatives in the ODF guidelines also eliminate the need for trying to design for specific water velocities 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.

In western Oregon forestlands, passage conditions are most commonly designed to meet the needs of juvenile or adult coho, chinook, steelhead, and rainbow and cutthroat trout. In central and eastern Oregon, structures are most commonly designed to pass juvenile or adult chinook, steelhead, rainbow, cutthroat or bull trout. Obviously, predicting when and where fish will need access is challenging, and coordination with a fisheries biologist is essential for identifying the proper species, age, and time of year to account for in designing the drainage feature. While the ODFW guidelines provide criteria for designing crossings for the adults of different salmonid species, in most cases the crossing will be designed for the passage of all juvenile fish.[2]

[1] The criteria used in the ODFW-ODOT survey included: (1) a slope greater than 1%, and (2) 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 times deeper than the height of the jump. Another condition that put culverts into the problem category were inlet deposits and drops at the inlet which was termed "diving flow."

[2] The ODFW guidelines advise that the culvert should be designed to pass fish for at least 90% of the streamflow 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. ODF guidelines are designed to pass all juvenile fish, and a site-specific plan would be required where this may not be possible.

Table 2: Biological Factors Related to Fish Passage Criteria.

FISH PASSAGE CRITERIA AND RELATED BIOLOGICAL FACTORS	
General Regulatory Criteria	Biological Factors
Water velocity in culvert	Swimming speed
Water depth in culvert	Submergence (sufficient depth for swimming)
Design flow criteria	Delays, dispersion
Height between culvert outlet and water surface	Jumping ability
Timing of in-stream work	Emergence (silting in of redds) Migration - delays or reduction of adult spawners

The most problematic characteristics of culverts that are often readily identifiable in the field include:

- High velocities or sudden changes in velocity at the culvert inlet, outlet, or within the barrel;
- Excessive jumps at the culvert inlet or outlet;
- Shallow water depths within the structure; and
- A lack of resting pools at the culvert inlet, outlet, or within the barrel.

Design considerations for minimizing these adverse effects should include managing water velocities in and around the culvert, preventing drops in and around the culvert, and providing adequate water depth within the culvert. For a comprehensive discussion on these considerations refer to Appendix A.

In terms of fish passage restoration activities on a landscape scale, there are seven basic steps that should be considered:

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

There are several methods being used to survey culvert conditions in Oregon. Two prominent methods are the ODFW culvert survey form and the ODF Road Hazard Survey Protocol (ODF, 1998). The ODFW survey form was used to evaluate culverts on state and county roads. The ODF survey protocol has been used on forest roads. Key measurements from the culvert assessments used in passage evaluations are the culvert slope, outlet drop, and outlet pool dimensions. The information from these key 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.

Partial fish passage blockage refers to stream crossings that are not allowing juvenile salmonid fish passage because of their design, maintenance, or condition. Generally, juvenile salmon passage requires two feet per second or less velocity, outlet perching less than six 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 conditions in the natural channel.

Total fish passage blockage refers to instances in which the design, maintenance, or condition of the stream crossing is such that most (if not all) adult and juvenile salmonids cannot move upstream through the crossing structure. Blockage results where conditions exceed most adult anadromous salmonid swimming capabilities. Generally, this occurs where culvert water velocities exceed 10 feet per second, outlet drops are over 4 feet or over 1 foot without adequate jump pools, or extreme inlet drops or material in the culvert causes barriers. Water depths should be 8 inches or more in the culvert at higher flows or the culvert should have a simulated natural streambed similar to conditions in the natural channel.

There are primarily five ways to improve fish passage at existing crossings without replacing the structure. These methods include adding baffles to the structure, adding sediment or sediment catching devices inside a culvert, backwatering through the crossing by installing downstream weir(s), 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 excess capacity. 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 use of baffle retrofits is for large properly sized concrete culverts that have little slope and no inlet or outlet problems. Baffle maintenance must also be considered, especially in streams where the transport of large substrate or wood occurs. These materials can damage baffles and require future replacement or maintenance.

Recruiting and retaining stream substrate in culverts can also improve passage conditions. Clancy and Reichmuth (1990) introduced a detachable fishway design for a sediment catcher in culverts. 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 that cannot 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 (Clancy and Reichmuth, 1990).

Backwatering through the culvert by using a series of weirs downstream of the culvert can be an effective way of mitigating fish passage at some crossings. 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 also be a channel width or 20 feet downstream to avoid damage from the force 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. As with baffles, the long-term maintenance of weirs must be considered before selecting this strategy.

II. Watershed-Scale Effects

Natural Variability

Over time and space, "natural" fish passage varies due to a range of disturbance and geological factors.   Streams are complicated systems conveying and storing large amounts of water, energy, wood, sediment, and bedload material. The combination of these elements result in an elaborate pattern of flow, water temperature and channel forms (i.e., riffles, pools, runs, glides, and side channels) over both space and time. The natural forces that created these patterns also produce barriers and delays to fish passage at waterfalls, landslides, debris jams, and channel constrictions, and during times of extreme flows and temperatures. Native fish have evolved with these patterns, resulting in behavior and swimming capabilities adapted to the range of natural conditions. Many natural barriers are transitory (e.g., debris dams), and fish can soon reoccupy lost territory or reconnect genetically after a barrier is modified or eliminated.

Human-made barriers such as dams and impassable stream crossings have increased the delays and barriers to fish passage well above natural levels. In some cases, human-made barriers may be in place for periods much longer than a similarly occurring natural barrier. In particular, human-caused barriers may pose the most significant watershed-scale impact to fish with migratory life histories and specialized habitat needs such bull trout. For the species with various life histories such as bull trout or cutthroat trout, fish passage problems may negatively impact some life history forms while not others.

Forest Management

The management of forests has resulted in an overlay of roads across the landscape. Where stream crossings are inadequately designed and maintained, they may prevent fish from meeting their basic requirements for reproduction, habitat, and refuge. Crossings may also produce broader ecosystem effects due to impacts on large wood routing, nutrient cycling, delays to movement, and genetic health of fish populations.

Other forest management activities such as timber harvesting may have altered stream temperatures or caused channel changes that may delay or prevent fish passage. Timber harvesting can increase summer and fall flows, possibly improving some fish passage opportunities. While the extent of fish passage problems related to stream crossing structures has been quantified to some degree, other forest management effects related to fish passage at a watershed-scale level have not been well documented. As described later, systems are in place for forestlands to address many of the fish passage problems over time.

Other Land Uses

All other land-uses also have impacted or disrupted the movement of fish. However, due to different regulatory mechanisms and much less voluntary action, the potential to manage the fish passage problems associated with other land-uses appears less optimistic. Nonforest road crossings often do not fall under the regulatory oversight of the Oregon Removal/Fill Act: only crossings that require more than 50 cubic yards of fill, or exist within streams identified as "Essential Indigenous Anadromous Salmonid Habitat" will have regulatory oversight. Since other land-uses often create barriers lower in a drainage system, the potential negative impacts from these activities may be relatively greater.

III. Objectives of Current Measures and Rules

Oregon Plan Objectives

The Oregon Plan objectives include the elimination of artificial obstructions to fish passage necessary to access key habitat for critical life stages of salmonids:

- Identify all human-created passage impediments to coastal stream segments usable or potentially usable by salmonids, and categorize those segments according to the amount and/or quality of potential habitat by 2010. Establish and maintain a list of "significant" barriers for restoration priority or that block access to more than 600 feet of stream.
- Ensure that human activities in coastal streams currently accessible to salmonids do not block or otherwise segment those streams so as to limit accessibility.
- Remedy 15 percent of the significant human-created impediments to fish passage in coastal streams per biennium.

FPA Objectives

The fish passage objectives of the Forest Practices Act are to allow and maintain upstream and downstream passage for both adult and juvenile fish during conditions when fish movement normally occurs. This objective applies to all stream crossings installed after September 1994. A second objective is to require restoration of fish passage through crossing structures installed prior to 1994 at the time the structure would be replaced under a normal life span. A final objective is to encourage voluntary restoration of passage prior to replacement under a normal life span.

The purpose of the water classification rules is to match the physical characteristics and beneficial uses of a water body to a set of appropriate protection measures. In the current classification system, fish use is a key beneficial use. For the purpose of the classification system, "fish use" means "inhabited at any time of the year by anadromous or game fish species, or fish that are listed under the federal or state endangered species act."

IV. Description of Measures and Rules

The 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. The statutes require that fish passage be provided where anadromous, food or game fish species are present. On state and private lands, the ODF and Division of State Lands (DSL) also regulate fish passage in a manner compatible with ODFW. A Memorandum of Agreement among the agencies has been developed to guide the consistent application of technical requirements to achieve fish passage. On federal lands, the Forest Service and other federal landholders are to comply with ODFW rules and statutes. In areas with endangered fish 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 specify a preference for using bridges but also allow for culverts that simulate natural streambed conditions, nonembedded culverts placed essentially flat, and culverts using baffles or weirs in order of decreasing preference.

ODF has also produced regulatory guidance designed for landowners and operators regarding fish passage that describes crossing alternatives that will likely pass fish under different situations (Robison et al., 1999). 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 percent gradient), and that culverts designed to simulate natural bed conditions be designed for stream widths similar to the natural stream width and be placed at a gradient similar to or somewhat below natural stream gradient. A training document designed to guide fish passage on state and private forestlands has been developed.

DSL regulates the standards for fish passage for structures requiring removal/fill permits. Permits are required for fills in excess of 50 cubic yards of material or for any amount of fill in stream segments designated as “Essential Indigenous Anadromous Salmonid Habitat.” The expedited general authorization approval process, as well as fill and removal permit information for road construction on nonforest lands, is available on the World Wide Web at [http://statelands/dsl.or.us/roadinfo.htm].

There are several other nonregulatory programs regarding fish passage in Oregon. Within the Oregon Plan for Salmon and Watersheds, there are two primary forestry measures that relate to fish passage (ODF 15 and ODF 25). These two voluntary measures target the identification and correction of road-related problems on private industrial forestlands over the next ten years. In addition, Oregon’s Watershed Enhancement Board (OWEB) and ODFW’s Restoration and Enhancement Board provide funding to projects that enhance fish habitat and watershed function, including fish passage improvement projects.

Oregon Plan Measures

The Oregon Plan contains several voluntary measures with the goal of identifying and correcting obstructions and impediments to fish passage. The following is a brief description of these measures that have a direct impact on fish passage:

ODF 1S: *Road Erosion and Risk Project –*
Many forest roads built prior to the development of the Oregon Forest Practices Act or prior to the current BMPs pose increased sediment risk to fish habitat. Industrial forest landowners have agreed to implement a voluntary program to identify risks from roads and to address those risks. This action is making improvements to road elements such as road fills, stream crossings, and drainage and surface problems to improve fish passage and habitat. As part of this measure, a road management guidebook has been developed that includes alternatives for solving identified problems.

ODF 2S: *State Forest Lands Road Erosion and Risk Project –*
This measure, similar to ODF 1S, will identify risks from roads on state-owned lands. This effort will upgrade at least 130 miles of road in each of the next three biennia.

ODF 16S: *Evaluation of Adequacy of Fish Passage Criteria –*
Technical criteria and guidelines for fish passage have been recently established. These criteria and guidelines will be followed by all state agencies when designing or approving projects. However, the criteria and guidelines, while developed using the best available science, have not been validated by monitoring. The objective of this measure is to verify that the criteria and guidelines used for the design of stream crossing structures will allow for the passage of both adult and juvenile fish.

ODF 46S: *Fish Passage Surveys (Weyerhaeuser) –*
The Coos Watershed Association and Weyerhaeuser have completed an analysis of all "major" anadromous fish culverts in the Coos River Watershed. Weyerhaeuser will contract with ODFW to evaluate stream conditions above culverts that are fish passage limiting to establish priority for enhancement.

Measures contained within the Oregon Plan which have some effect on fish passage through monitoring, surveys, and restoration projects include the following:

ODF 5S - North Coast Salmonid Habitat Restoration Project
ODF 6S - Mid-Coast Restoration Project
ODF 10S - Forest Practices Monitoring Program
ODF 13S - Storms of 1996 Monitoring Project
ODF 23S - BMP Compliance Audit Program
ODF 25S - Fish Presence/Absence Surveys and Fish Population Surveys
ODF 32S - Fish Presence Survey
ODF 52S - South Coast Technical Advisory Team

FPA Standards and Rules

The forest practice rules since their inception in 1972, have required "adequate" fish passage. Prior to 1994, this was interpreted to mean passage of adult fish upstream at "Class I" stream crossing. Thus, culverts installed between 1972 and 1994 to provide adult passage may not be providing juvenile passage. During this time, there was also no requirement that passage conditions be maintained following culvert installation. The current standard of protection adopted in 1994 under the forest practice rules for fish passage is to design, construct, and maintain stream crossing structures to allow migration of adult and juvenile fish upstream and downstream during conditions when fish movement normally occurs. Guidance describing structural designs to meet this standard has been developed.

Stream Crossing Structures OAR 629-625-320(2)

"Operators shall design and construct stream crossings (culverts, bridges and fords) to:

(a) Pass a peak flow that at least corresponds to the 50-year return interval. When determining the size of culvert needed to pass a peak flow corresponding to the 50-year return interval, operators shall select a size that is adequate to preclude ponding of water higher than the top of the culvert; and
(b) Allow migration of adult and juvenile fish upstream and downstream during conditions when fish movement in that stream normally occurs."

Road Maintenance OAR 629-625-600(8)

"In order to maintain fish passage through water crossing structures, operators shall:

(a) Maintain conditions at the structures so that passage of adult and juvenile fish is not impaired when fish movement normally occurs. This standard is required only for roads constructed or reconstructed after September 1994, but is encouraged for all other roads; and
(b) As reasonably practical, keep structures cleared of woody debris and deposits of sediment that would impair fish passage.
(c) Other fish passage requirements under the authority of ORS 498.268 and 509.605 that are administered by other state agencies may be applicable to water crossing structures, including those constructed before September 1, 1994."

V. Evaluation of Measures and Rules

Voluntary Measures

The following basic steps to restoring fish passage at road/stream crossings are in place for a large portion of forestland and for state and county highways:

1. Find and prioritize problem road/stream crossings.
2. Get information about the stream and other conditions at the crossings to be restored.
3. Decide if the installation can be repaired, improved, or whether it must be replaced.
4. Decide on a design strategy based on information collected at the site.
5. Prepare a design.

6. Install new road/stream crossing structure.
7. Monitor and maintain the road/stream crossing structure.

The ODF survey protocol is currently being used on forestlands. A substantial portion of the survey effort has been completed on industrial and state-owned forestlands. The current factor limiting accomplishment of the passage restoration objectives is the actual completion of the restoration projects. However, on forestlands, substantial progress is currently being made.

For example, the Oregon Plan Watershed Restoration Inventory reports that 530 culverts were removed, replaced, upgraded or installed for fish passage in 1996-97. In 1998, about 300 culverts were removed, replaced, upgraded, or installed for fish passage, opening 200 miles for fish use. About 80 percent of the effort was by industrial forest landowners. The actual number of structures is likely higher, since between 2 percent and 20 percent of road improvement projects did not provide information on culverts affected.

Stakeholders on forestlands are committed to continuing these types of activities into the future. Industrial forest landowners have estimated spending approximately $13 million a year, or $130 million over the next 10 years, on these projects in the coastal Evolutionary Significant Units (ESUs) alone. State Forest Lands have committed to spending over $2.5 million during the '99-'01 biennium for the restoration of roads and replacement of culverts and other stream crossing structures damaged by the 1996 storm. State Forest Lands are also proposing to spend an additional $2.5 million dollars in each of the next three biennia to improve roads, including stream crossing structures.

How successful these and future activities will be in restoring fish passage is uncertain at this time. Nonetheless, road issues, especially fish passage restoration, are being emphasized statewide and significant accomplishments have been made. Success must be evaluated over time through continued implementation and effectiveness monitoring. These evaluation mechanisms are in place for forestland restoration actions.

Current Rules

Fish use surveys have been completed on approximately 20 percent of all forested streams. In addition to determining the presence of fish, the surveys have provided useful information about: (1) barriers to fish passage, (2) unmapped stream channels, and (3) baseline fish distribution. Where surveys have not been completed, an interim classification system for fish presence is providing a reasonable proxy for actual classification. Issues that have arisen with regard to the classification system include concerns about classifying streams as nonfish use when the absence of fish could be caused by a human-caused passage barrier, and classifying streams when the channel has been recently torrented (especially after the 1996 storms). There is also a desire to get fish presence data available on a GIS-based system to enhance the ability to update and distribute maps.

At the current survey rate, it is expected that the fish presence surveys will be about 80 to 90 percent complete in the next six to eight years at a total cost of $3 to 4 million. There are significant concerns that this level of funding may not be available for these efforts. Some also question whether this is the most productive area to spend limited salmon restoration funds.

The ODF fish passage guidance was released in June 1995 and is updated as new information becomes available (last updated June 1999). While this guidance is based on the most current science available, effectiveness and implementation monitoring must be conducted to verify that these guidelines are achieving the goal of restoring fish passage. The ODF monitoring program is currently conducting a stream crossing compliance pilot study that is discussed below. Significant training about fish passage design was provided by ODF and others to help address some of the issues identified by the pilot study.

Under the new rules, fish passage is required for those stream crossings that have been constructed or reconstructed after September 1994. Culverts installed between 1972 and 1994, while providing adult passage, may not be providing juvenile passage. As older culverts are replaced, they will be required to meet the current standard. If a Type F stream extends up to, but not beyond the culvert outlet, that culvert would have to be designed to pass fish when it is eventually replaced under regular road maintenance. Currently, if it is determined that the upstream reach has the capacity to be a fish bearing stream but is currently a nonfish bearing stream because of a culvert that cannot pass fish, that upstream reach will remain classified as a nonfish bearing stream.

Stream Crossing Study Preliminary Results

The ODF conducted a pilot study in the summer of 1998 to examine compliance with the ODF fish passage guidance. Twenty of the stream crossings monitored were volunteered for assessment ("volunteer sites"). An additional 37 sites were selected in a random stratified manner so that sites with both Type F streams and a newly constructed or reconstructed road were included. The study focused on juvenile fish passage.

Since the 1998 sample is not a random sample, the results presented from these data may not be representative. The 1999 sample will be able to confirm or reject these preliminary findings with statistical validity. Nonetheless, the 1998 data provide the best information available to date and therefore policy decisions are likely to be based in part on the results of this study. The preliminary data indicate that guidelines, education, and outreach need to be emphasized to increase the likelihood that stream crossing structures will meet the ODF guidelines.

Preliminary results are presented in three categories: Written Plans, Implementation of Guidelines, and Juvenile Fish Passage. In the following discussions, results will often be reported separately for "selected" versus "volunteered" sites.

<u>Written Plans:</u> Thirty-three out of 57 sites (58 percent) contained the necessary information to determine which fish passage alternative was being used. It is important that written plans reflect this information for both administrative and monitoring purposes. When the fish passage alternative is not clearly stated (42 percent of the sites), assumptions must be made to determine if the guidelines were properly implemented and if the installation goals were achieved.

Did the written plan contain the recommended information for the particular alternative?
Only eight of 29 of the selected sites (28 percent) and 4 of the volunteered sites (20 percent) contained the minimum amount of recommended information. The technical ODF guidelines provide a list of data that should be included in written plans to allow department personnel to judge the soundness of the installation proposal.

Was the written plan properly implemented?
This is the most basic compliance question that can be answered. Forty percent of the selected sites and 60 percent of the volunteered sites implemented the alternatives described in the written plans (Table 3). Eleven percent of the selected sites and 15 percent of the volunteered sites did not implement the alternatives described in the written plans. The remaining sites fall into one of two categories: unknown and undecided. Unknown alternatives will not be assigned an alternative, because of a lack of information in the written plan. Undecided will be assigned one of three alternatives after further review.

Table 3. Selected Sites That Achieved The Alternatives Described In The Written Plan.

Category	Number of Sites		Percent of Total	
	Selected	Volunteer	Selected	Volunteer
Unknown	8	4	22%	20%
Undecided	10	1	27%	5%
Yes achieved written plan	15	12	40%	60%
No did not achieve written plan	4	3	11%	15%
TOTAL	37	20	100%	100%

Likelihood to Pass Juvenile Fish: There are four assumptions made in determining the likelihood of an installation to pass juvenile fish: (1) bridges and open-bottom arches are likely to pass juvenile fish; (2) culverts installed at or less than 0.5 percent gradient with no outlet drop are likely to pass juvenile fish; (3) stream-simulated culvert strategies are likely to pass juvenile fish; and (4) baffled culverts with no outlet drop are likely to pass juvenile fish. Based on these assumptions, survey results indicate that the selected sites had less likelihood of passing fish than the volunteer sites. Fifty-one percent of the selected sites were likely to pass juvenile fish, while 80 percent of the volunteered sites were likely to provide juvenile fish passage (Table 4). These results indicate that the selected and volunteered sites should not be pooled together. The ODF guidelines provide much greater detail and breadth of scenarios that need to be considered when installing structures, and this is discussed below.

Table 4. Likelihood of Passing Fish by Site Selection Process.

Site Selection Process	Juvenile fish passage	Number of sites (Percent)
Selected	Yes	19 (51%)
Selected	No	18 (49%)
Volunteer	Yes	16 (80%)
Volunteer	No	4 (20%)

Implementation of Guidelines on the Selected Sites: Field data collected at each selected site (excluding the volunteer sites) were compared with the appropriate guidelines. Each installation was evaluated against the specific criterion defined in the ODF alternatives regarding stream and valley characteristics, outlet jump, outlet mitigation, culvert dimensions, and sediment retention.

For the 22 selected sites where the alternative was identified, the installation was rated as "accept" (i.e., the guidelines were properly implemented), "further review" (i.e., borderline instances), or "reject" (i.e., the guidelines were not properly implemented). The standards by which to do this are described in the ODF guidelines (Robison, 1995 and 1997). Results indicate that 36 percent of the installations implemented the guidelines successfully, 36 percent warrant further review, and 28 percent did not implement the guidelines properly (Table 5).

Guideline implementation and the likelihood of the installation to pass juvenile fish can be evaluated together. This evaluation identifies an apparent discrepancy in Table 5. For example, a site may not meet the ODF guidelines yet pass juvenile fish, or visa versa. Of the six sites that did not implement the guidelines, one was likely to pass juvenile fish. This situation was a countersunk culvert (Alternative 4), which based on field data, was actually installed at a gradient lower than recommended for the stream gradient. Under Alternative 4, culverts should not be countersunk such that the stream gradient minus the culvert gradient is greater than 1 percent. However, the culvert was retaining sediment and therefore was assumed likely to pass juvenile fish. The juvenile fish passage rates did not change much from that shown in Table 3, when the unknown alternatives were dropped. Fifty-five percent of the sites are likely to pass juvenile fish, and 45 percent are not likely (Table 5).

Table 5. Proper Implementation Of Stream Crossing Guidelines And Providing For Juvenile Fish Passage (Excludes Volunteer Sites And Sites Where The Alternative Was Unknown).

LIKELIHOOD TO PASS JUVENILE FISH	Determination of Proper Implementation of the ODF Guidelines			
	Accept	Further Review	Reject	Total
Yes	8	3	1	12 (55%)
No	0	5	5	10 (45%)
Total	8 (36%)	8 (36%)	6 (28%)	22

Juvenile Fish Passage Summary

The results indicate that only 40 percent of the selected sites were in compliance with their written plans. Furthermore, only 22 percent contained the minimum amount of information recommended in the guidance. Compliance with the written plan was slightly improved for volunteered sites (60 percent). Fifty-eight percent of all the sites contained enough detail to determine which ODF alternative was being used. These results suggest a need for an increased emphasis on written plan criterion and tools for department personnel to use when determining compliance.

Only 51 percent of the selected sites are likely to pass juvenile fish, while 80 percent of the volunteered sites are likely to pass juvenile fish. The majority of the selected sites either successfully implemented the guidelines (36 percent) or needed further review (36 percent). Twenty-eight percent did not meet the guidelines. With such a small sample size, it is dangerous to apply these numbers to the total population of new installations. However, it does emphasize two important points:

1. ODF is on a fairly steep learning curve at this point with regard to successful implementation of the guidelines. The guidelines are fairly new (two years for the most recent), and the

landowner, operators, and department personnel are still learning how to achieve the fish passage standards. In addition, ODF guidelines are very specific in terms of achieving juvenile fish passage and require rigorous designs not yet seen on other ownerships (e.g., 0.5 percent gradient). Furthermore, when comparing these compliance rates with those reported from other agencies, it is critical to know what criterion the other agencies are using and what monitoring techniques were used. ODF is unaware at this point of any other agency performing such detailed measurements of compliance.

2. While the sample size is extremely low, these results emphasize the need for increased training on the guidelines and the need to incorporate some of the technical guideline criterion into the ODF Guidance Manual.

VI. Possible Additional Measures and/or Rules

Option #1

Objective:
To provide for riparian functions along stream reaches above impassable stream crossing structures that have a high probability of recolonization by salmonids once the structure is replaced/improved.

Description:
If an upstream reach has the capacity to be a fish bearing stream but is currently a nonfish bearing stream because of a stream crossing structure that cannot pass fish, the forest practices rules would be amended or voluntarily applied so that the upstream reach would be classified as a fish bearing stream. The extent of potential fish use upstream of the blockage would be determined using the interim guidance criteria.

Methods/Approaches:
ODF has developed interim guidelines to designate fish use based upon the physical characteristics of a stream. These guidelines were based upon the fish presence survey data and would be used for stream segments above human-caused barriers to designate the Type F reach. The guidelines use either a map or on-the-ground physical characteristics.

1. Voluntary – landowners could agree to implement this approach following the interim fish use guidelines on a voluntary basis. This approach would be easy to implement and track since it would be done on an operation by operation basis.

2. Regulatory – the current stream classification rules would be amended to establish that when fish use ends at a human-caused culvert (or other barrier), then the classification of fish use will be extended above the culvert to a point that would be established following the current interim criteria.

In either case, a process that field-verifies reoccupation in the future and establishes the actual end point of fish use may be desirable and would be included. Such a survey could be conducted a set number of years after the culvert replacement occurs. Also in either case, a process to consider options other than restoring fish passage for very short lengths of stream could be allowed so long as the appropriate length of stream above the culvert was protected as fish bearing as part of the mitigation for loss of habitat.

Benefits:
The most important benefit is that reaches of stream that will be reoccupied by fish once a culvert is replaced will have retained vegetation to facilitate reoccupation and help maintain and restore good fish habitat over time. This option could also remove a disincentive to replace a culvert in a timely manner. It may remove an incentive to harvest a reach above the culvert before culvert replacement. The option eliminates an unfair dichotomy about how streams are classified. Currently, if fish presence surveys have not been conducted above a culvert, than the interim guidelines are applied and the appropriate reach above the culvert is treated as a Type F stream. If fish presence surveys have confirmed the absence of fish above a culvert, than the entire stream above the culvert is treated as a Type N stream.

Costs:
Landowner costs will be increased. Additional harvest restrictions will be imposed for those stream reaches with a classification change from nonfish to a fish bearing stream. Given the relatively large number of culverts that determine the end of fish use, the length of stream affected could be relatively significant. The actual costs will depend upon the stream length and the level of protection required. This option might also create a potential conflict between upstream and downstream neighbors: for example, where a downstream landowner is reluctant to replace the culvert, while the upstream owner is required to provide Type F stream protection.

Resources needed:
Some form of tracking system will be needed to maintain the identity and location of culverts that are the end of fish use. In general, these data are available for completed surveys, but not for channels that have not yet been surveyed. Current stream classification maps could be used for this purpose. The interim classification guidelines should be re-assessed as part of this process and may need to be modified. This assessment would be based upon the additional survey information that has been collected since the original guidelines were developed.

Option #2

Objective:
To facilitate the identification, prioritization, and restoration of existing culverts that currently do not pass fish.

Description:
A large number of stream crossings in Oregon currently do not pass juvenile and adult fish up and downstream. However, on forestland, a protocol for road assessments has been developed, as have criteria for fish passage. When stream crossings are established or replaced on Type F streams, written plans are required and some level of design review service is provided for forestlands. Many landowners are participating with watershed councils to help establish restoration priorities and facilitate grant writing. Recent training efforts have been implemented to

improve the technical understanding of the design criteria. This option is aimed at accelerating culvert replacement above what is currently being done, especially for family forestland owners who often do not have adequate resources to address this issue.

Methods/Approaches:
There are a number of different ways to implement this option. Either a rule-based or voluntary approach could be used. Listed below are specific methods that have been deliberated by the Forest Practices Advisory Committee (FPAC):

1. Require that fish passage be restored for any culvert on a road that is within an active harvest operation within one year after completion of the harvest.
2. Require that landowners inventory fish passage barriers and that such barriers be repaired within a specified time period. The survey could be required over a four-year period and the remediation of fish passage problems completed over a ten-year period. This could be part of an overall road inventory and risk reduction plan. Financial incentives may be needed to fully implement this method.
3. Create a support service within the ODF for road assessment information. There are a number of possible ways of providing a "service" to support road assessment and mitigation. This nonregulatory service would catalog potential fish passage culverts and aid in design standards and in obtaining stewardship grant money, if needed. Information could be forwarded to watershed councils to be incorporated into watershed assessments and action plans.
4. The Conditional OFIC Proposal (in the Forest Roads Issue Paper). Part of this proposal is to address fish passage problems associated with legacy roads and culverts.

Benefits:
Linking fish passage restoration activities to an active harvest operation would accelerate culvert replacement and tie restoration timing and location to activities that produce revenue. Requiring inventories and remediation activities within a specified time period provides for some flexibility for the landowner. Creating a support service will aid in the tracking of culvert work progress and provide assistance to landowners who lack adequate resources, specifically nonindustrial private landowners (NIPLs), also known as family forestland owners. This will also potentially aid in the prioritization of culvert work for watershed councils and allow for the more efficient use of limited resources.

Costs:
Short- and long-term costs will be increased for landowners with some of these approaches. Linking fish passage restoration activities to an active harvest operation may draw resources away from other higher culvert and road priorities. This would require shifting landowner resources from other actions that may have greater benefits to fish. The ODF will need additional resources to build and maintain a support service for road assessment information and the personnel necessary to manage such a service. It is not clear how the data might be used to improve outcomes over current systems.

Resources needed:
New or amended rules and/or financial incentives. A method of tracking the completion of restoration actions tied to operations. A process to track the inventory and repair of barriers. Multi-land use inventories of problem culverts and relative length of habitat above the problem

barrier. Resources to coordinate restoration efforts through ODF, ODFW, or a watershed council. Funding for restoration.

Option #3

Objective:
To provide a more effective and efficient means of classifying streams for "fish use."

Description:
Revise the forest practice rule definition of Type F and Type N streams based upon a physical habitat approach to classify fish use and nonuse streams.

The current water classification scheme is based on the presence or absence of fish. The survey process to determine presence/absence is time-consuming, limited to a short season, and requires significant funding (though costs are relatively low compared to the resources that may or may not be retained based upon the results). Fish presence surveys are becoming more restricted due to the listing of fish under the federal Endangered Species Act (ESA). The surveys also provide useful information to identify barriers to fish passage, identify unmapped stream channels, and create a baseline of fish distribution information. However, surveys can produce unreliable results when fish populations are depressed or there are other environmental factors such as drought or extreme flows.

This survey-based approach potentially reduces the amount of mature forest riparian habitat maintained over time. This can occur where older forest structure along a given stream reach may not be maintained as well as it might under a Type F classification over time because fish were not present at the time the fish survey was conducted.

Methods/Approaches:
ODF has developed interim classification guidelines to designate fish use based upon the physical characteristics of a stream. These guidelines were based upon fish presence survey data and could be used to classify streams that are "fish habitat." The guidelines use either mapped or on-the-ground physical characteristics. The current stream classification rules would be amended to establish that fish habitat streams are any streams that meet the habitat criteria. The habitat criteria may need to be modified and improved based upon more recent and complete survey data. One of the key issues that will need to be addressed is the acceptable margin of error in applying a habitat model. Data indicate that models used to predict fish use in gentle topography have less error than models applied in steep topography. In either case, a policy choice must be made concerning the acceptable predictive error. A more conservative model (error on the side of over-predicting fish habitat) could be used since the rules would also have a process to field survey at the request of the landowner. This option would most likely need to be applied in combination with Option #1 to avoid a range of potential inconsistencies.

Benefits:
This will potentially increase the amount of mature forest habitat available to salmonids over time by allowing the maintenance of such habitat in stream reaches that may have historically

supported salmonid populations. Funds used to conduct the surveys can be allocated to other needs/activities. May reduce classification problems resulting from survey errors or other survey biases. Provides an option if the listing of fish precludes the use of efficient survey methods (electroshocking).

Costs:
Landowner costs will potentially be increased since additional harvest restrictions will be imposed for those stream reaches where there is a stream classification change from nonfish bearing to fish habitat. Conversely, this may also potentially decrease the amount of mature forest habitat available to salmonids over time if the habitat model incorrectly classifies habitat that is used by fish as nonfish habitat. The other values of the surveys such as identifying barriers to fish passage, unmapped stream channels, and creating a baseline of fish distribution information will be lost.

Resources needed:
The interim classification guidelines would need to be reviewed and revised to develop predictive models for fish use. Agreement would be needed about the acceptable error rate. Classification maps would need to be updated. A choice would also need to be made when the classification change would occur and whether ODF, ODFW or the landowner would physically survey the stream or apply the mapped-based approach. The choice might well be different based upon topography or region. Resources are probably adequate to process field survey requests, assuming that demand for this service does not increase substantially. However, some accommodation for scheduling surveys would be necessary due to the limited field season.

Option #4

Objective:
To identify and restore fish passage problems on family forestland owners (5,000 acres or less).

Description:
Create a funding source for family forestland owners or assist family forestland owners in obtaining funds from existing sources to expand the road assessment effort to family forestland owners. This financial assistance would also be used to help family forestland owners replace stream crossings that are not adequately passing fish. The program might be similar to the Forest Resource Trust.

Methods/Approaches:
1. Provide a tax credit for culvert restoration for the next ten-year period which would restore access to "high" priority habitat. The thresholds for high priority habitat would be set based upon factors including size of stream, stream gradient, type of habitat restored, and length of habitat with restored access. The credit would sunset in ten years and replacement would then be at the cost of the landowner.
2. Float a bond issue that would be repaid with Ballot Measure 66 funds to provide a specific account for culvert replacement. This approach would also have a priority system.

3. Establish a combined account for culvert replacement utilizing earmarked Ballot Measure 66 funds, ODFW Restoration and Enhancement funds, new fishing license surcharge, public and landowner contributions, and/or federal funds. This approach would also have a priority system.
4. Establish a capitol investment loan program like the Forest Resource Trust that would provide a low cost loan to family forestland owners for road and culvert repair that would be repaid at the time of a harvest. This approach would also have a priority system.

Benefits:
This would provide a funding mechanism to accelerate culvert replacements on family forestlands. Since family forestlands tend to be lower in a basin and are often located along larger and lower gradient systems favored by coho salmon, access to substantial overwintering coho habitat might be restored.

Costs:
Funding would be needed and may draw resources away from other higher priorities. Ideally, the direct costs to family forestland owners would be minor.

Resources needed:
Possibly legislation, funding sources, and a prioritization system.

Option #5

Objective:
Encourage the use of bridges as the stream crossing design standard of choice.

Methods/Approaches:
Amend the rule guidance to encourage the use of bridges instead of culverts to the maximum extent practicable.

Benefits:
Fish passage would be ensured wherever a bridge would be installed. Bridges have a more limited likelihood of resource damage from catastrophic failure as compared to culverts and fills. Bridges are also are more likely to provide for the downstream movement of large woody debris and sediment.

Costs:
Bridges are very costly to install compared to other options that can also successfully pass fish, though long-term maintenance costs are less. Focusing limited resources on bridges would very likely mean that other efforts to improve fish passage could be significantly reduced.

Resources needed:
Lower cost design and construction options for bridges. Possible financial incentives.

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Appendix A

Water Velocities

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. Migration delays can result in a number of negative impacts on fish (Fish Commission of Oregon, 1969; Groot and Margolis, 1991; Travis and Tilsworth, 1986):

1. **Increased metabolic cost--**Excessive delays in migration cause fish to expend 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 on bodily reserves of fat and protein for migration, further maturation, spawning and redd defense until they die. Body fat reserves of sockeye salmon in the Fraser River were observed to be over 90 percent depleted in females and nearly 90 percent depleted in males at the time of death after spawning. Considering that some salmon species, like those on the Snake River runs, will travel up to 900 miles to reach their spawning grounds, efficient use of stored energy reserves is critical to successful reproduction.
2. **Delay in spawning timing under favorable conditions--**Delayed fish may arrive at holding or spawning areas later than normal thus missing their normal spawning periods, which may be timed with crucial flow and water temperature conditions necessary for egg and fry survival.
3. **Reduced spawner distribution--**The distribution of spawning fish can be adversely 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, resulting in mortality to the progeny of earlier spawning fish.
4. **Increased mortality due to predation--**During a study of the ability of Arctic grayling to pass through a 110-foot long, 5-foot 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 study observed that sport fisherman took a substantial number of fish holding in the pool below the culvert.
5. **Reduced female fecundity--**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. **Reduced juvenile survival--**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 while passage conditions are unsuitable.

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 facilitate upstream movement.

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 the fish will be swept back downstream.

The potential energy due to differences in elevation can result in increased water velocities as water moves down hill. The greater the elevation change between a culvert inlet and the outlet, the more challenging managing water velocity becomes. The velocity profile of a culvert can present a rather homogenous pattern of high water velocities with few zones of slow, calm water. This may lead to the assumption that fish pass through a culvert at their maximum possible speed in order to minimize their exposure to increased water velocity. It has been observed, however, that fish do not always pass through culverts at their maximum possible speed. Behlke et al. (1989) speculate 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.

Fish tend to occupy areas of water that have lower velocities (Powers et al., 1998; and Belhke et al., 1990). In culverts that have obstructions to flow, there tends to be more areas of slower water that fish can occupy and rest between periods when they must negotiate high velocity water. Common areas where low velocity occurs are along the margin of the culvert, immediately downstream of boulders, and along the bottom of the stream. Examination of the *average* velocity of most steep gradient streams shows that natural streams are out of compliance for juvenile fish passage. The reason fish can negotiate these streams is because of these areas of relatively low water velocity dispersed throughout steep gradient streams. One reason wide or embedded culverts are preferable is to provide more opportunities for these low velocity areas. Culverts in which the water is constricted into a narrow flume provide little opportunity for these low velocity rest areas to occur.

Juvenile salmon swimming upstream in culverts have been observed to take advantage of low velocity zones located close to the culvert wall (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. The following are some of the ways in which culverts can become velocity barriers to fish passage:

- Reduce the cross-sectional area of flow
- Reduce roughness
- Increase the gradient (by straightening the stream channel)
- Present 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.

On relatively flat streams (streams from 0-3 percent) 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 percent), the challenge becomes difficult and limited options are available 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 high velocities by making the 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 resting places inside a culvert so that fish can rest or stop inside the culvert in areas with low velocity.

Placing a culvert at a low gradient is one of the best design strategies to provide for fish passage. In essence, the design is simple in that it reduces velocity by reducing potential energy dissipated in the culvert (i.e., change in elevation between the inlet and the outlet). Since culverts typically have very low roughness, it is important to place the 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 percent gradient so careful installation is necessary to create culverts that are very close to level.

Roughness in a culvert causes the potential energy to be expended in other ways than velocity, creating turbulence with areas of reduced velocity. Streambed simulation designs attempt to mimic the natural roughness of a stream channel inside a culvert. Traditionally (i.e., before fish passage was a significant concern) a hydraulically efficient culvert was thought to be one that 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 excess velocity and energy often scours the streambed resulting in an excessive drop at the outlet.

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 nonembedded culvert designs that can meet the maximum allowable velocities are acceptable.

The assignment of risk is used in determining how large a streamflow the culvert is designed to handle during peak flow events. The ODFW guidelines recommend that road/stream crossing accommodate the largest streamflow that would occur in a given hundred-year period (i.e., the

100-year flow) "to the integrity of the structure."[3] The ODF, 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 percent in most cases. However, designing to the integrity of the crossing structure such as ODFW requires would allow for smaller culverts and bridge openings than designing to the top of the culvert. 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, the ODF guidelines require a design for the 50-year peak flood flow and uses the top of the culvert or three feet below the bridge bottom as design criteria. (Likewise, stream crossings that use a streambed simulation design must also be able to pass a 50-year flow and still be able to pass fish.)

Culvert Drops

Salmonids in media images are shown 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.

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.

Drops in water surface 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 block fish passage. Outlet drops are due to excess energy in the culvert being applied to the streambed downstream, causing scour of the streambed. Narrow culverts that concentrate flow and have little roughness create excess velocity 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 and provide adequate water depth inside the culvert.

The culvert inlet can also have a drop if the culvert is sunken relative to the streambed and no material has collected inside the culvert. In this case the fish will be moving through a culvert which typically has less resting areas and they now must use burst speed to move through this inlet 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 inlet drop.

Inlet drop can also occur when a culvert constricts flow at the inlet. This occurs when a wide stream enters a narrow culvert (especially one that has a projecting inlet). In these situations,

[3] "To the integrity of the structure" means that any flow above the 100-year flow will over-top the structure. If the structure were a bridge this would mean to the top of the bridge. If it were a culvert, "the structure" would be to the top of the fill.

water concentrates and 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 the bed drop described above. The use of wide pipe-arch culverts sized to match the active stream width can potentially prevent this kind of inlet drop from occurring.

Drops can occur inside the culvert because of wood and sediment deposition ("clumping"), 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 before installation.

Culverts placed at slopes substantially less than the stream gradient can result in impassable jumps at the culvert outlet. Designs that do not adequately account for the potential for streambed scour below the culvert can also result in excessive outlet jumps. The lack of a resting pool below the outlet can also impede fish passage.

Water Depth

Research concerning conditions for successful upstream migration of adult salmon and trout show that the depth of water in a drainage structure is critical to fish passage for the following reasons (Dane, 1978):

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 depths that are too shallow for fish passage.