WILD SALMON CENTER

Culvert Installation in Salmon Streams

WHITE PAPER

Road crossing on the Samarga River, Primorski Krai (A. Semenchenko)

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Forest Road Construction and Culvert Installations in Salmon Streams: Best Management Practices and Lessons for the Samarga Watershed

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Introduction:

This document is intended to:

- describe best management practices (BMPs) for culverts and other road crossing installations in salmon streams, especially those in forested regions;
- emphasize the most effective standards for preserving fish passage capacity;
- give examples of government-mandated practices in the U.S and Canada as references;
- make recommendations for the conditions of the Samarga Watershed in Primorskii Krai;
- present resources and references in the appendix for further technical guidance.

In fish-bearing watersheds, road crossings pose serious obstacles to fish passage and migration, and can prevent migratory fish from reaching their habitat. This question has been studied intensively in the United States and Canada, especially in regions with anadromous salmon populations. In the Pacific Northwest, thousands of miles of roads – mostly in forested areas – cross streams and rivers. Many road crossing structures pose serious obstacles to salmon and trout passage, because of poor design and maintenance of the culverts designed to preserve stream flows. The study of fish passage through culverts has yielded a vast literature of studies and recommendations from the fisheries, transportation, and forestry sectors, with standard guidelines issued by government agencies, environmental groups and private firms. Most of this research is oriented toward adult anadromous fish, but both resident fish and juvenile anadromous fish migrate in search of habitat or as part of life cycle histories. The goal of fish passage is to support year-round upstream and downstream migration of all fish species in all life history phases.

Summarizing the best management practices to preserve fish populations requires simplification, but yields a primer on the most effective techniques for minimizing impacts on fish populations. Where this document is insufficient, references should provide guidance for further research.

The dominant factors influencing fish passage through culverts are:

- excessive water velocity at the downstream end, causing erosion and a vertical barrier
- channel constriction resulting in a hydraulic jump at the upstream end of the culvert
- vertical barriers to fish passage, due to culvert outfall height
- velocity of water through a length of culvert, in relation to fish swimming capabilities
- lack of hydraulic roughness in the culvert
- depth of water in the culvert structure at high, moderate and low flows
- icing and debris problems
- design flows in relation to hydrological trends and seasonal time of fish passage
- size, species and age of fish passing through the culvert structure.

Of these factors, water velocity and vertical barriers are the most severe obstacles. Because water velocity is subject to engineering decisions such as culvert diameter, slope, and the installation of baffles, weirs and resting pools, it can be viewed as the cumulative effect of many separate design elements. Vertical barriers to fish passage are likewise reflective of a collection of engineering decisions on slope, fill material and erosion control, and the correct assessment of high and low water levels.

All assessments of fish passage abilities are highly dependent on the fish species and age class, geomorphology and stream characteristics of a particular region, and should be made only after careful consideration of hydraulic, engineering and biological factors. In areas with exceptional ecological value, utmost care should be taken to reduce risk to fish populations. Means of mitigating risk include relocating a planned road crossing, using alternatives to culverts, and installing weirs and low dams to keep water levels at the appropriate heights. In all cases, attempts should be made to make stream crossing structures "transparent" to watershed processes when they are installed. In other words, the channel and floodplain will function as they did prior to the stream crossing installation. This is a standard higher than that required by U.S. or Canadian law, but preserving the ability of all fish to migrate up- and downstream necessitates these efforts.

Ultimately, a sound design should maintain the stream's ecological functions: (Klochak 2002)

<u>Fish passage</u>: passage of native fishes at all life stages at appropriate times and flows in the appropriate direction

<u>Hydrology</u>: allowance for appropriate range of flows suitable for the watershed and the specific location of the crossing. Flow conditions should be maintained upstream, downstream and within the crossing structure.

<u>Sediment transport and deposition</u>: transport of sediment downstream for storage in a natural manner conducive to maintaining natural habitat conditions in the watershed, both above and below the road crossing structure

<u>Large woody debris transport and storage</u>: transport and storage of woody debris of the size and type appropriate for the watershed and location. Transport capacity is a function of stream flow, stream size, and vegetation type.

<u>Habitat connectivity</u>: maintaining habitat connectivity at the crossing location, including connections for wetland areas, connection of off-channel habitats with floodplains, and connections to sources of woody debris and other organic inputs

<u>Tidal influence</u>: full natural extent of tidal influence, including inundation, natural salinity levels, woody debris transport, and sediment import and export to areas on the landward side of tidal channel crossings

<u>Floodplain processes</u>: processes include ability to create and maintain off-channel and side-channel habitats including channels, wetlands and other open-water habitats. They also include connections to the hyporheic zone and connections to sources of large woody debris, other organic materials, and nutrients.

Summary of Best Management Practices:

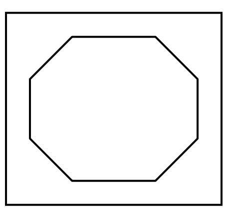
A standard introduction to the intricacies of "Fish Passage Through Culverts" is provided by Calvin Baker, a fish biologist, and Frank Votapka, a civil engineer, in a 1990 document for the US Department of Agriculture–Forest Service and the Department of Transportation. They conclude:

> Ideally, a culvert installation should not change the conditions that existed prior to that installation. This means that the cross-sectional area should not be restricted by the culvert, the slope should not change, and the roughness coefficients should remain the same. (Baker and Votapka, 1990)

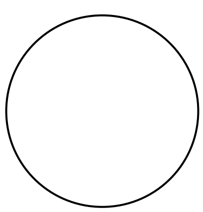
Baker and Votapka summarize the existing research, broken down into biological, engineering and hydraulic components. This document follows the general form of their article, but emphasizes engineering and hydraulic considerations. It is assumed that the reader will know the migratory patterns of salmonid species in his or her region. Except when noted, all citations and illustrations are from Baker and Votapka.

Circular culverts made of corrugated metal, concrete or wood are chosen in the first place for stream crossings because they are cheaper than competing technologies. Regrettably, the most common designs cause the most fish passage problems. The circular, corrugated metal pipe is the stereotypical design of a culvert, but concrete box culverts, pipe arches, or bottomless arches are used in many sites where fish passage is a concern. The appeal of these designs is the flat bottom, which reduces velocity and can be bedded with the natural substrate so that it functions like the streambed.

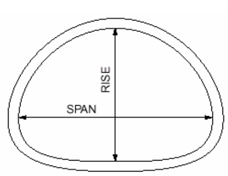
Figure 1: Culvert Shape and Characteristics



Box (square)
- Wide bottom area, large backwater influence
- Can be placed side-by-side
- Simple baffle design and construction
- Smooth bottom increases velocity; can be remedied if installed several feet below stream grade



Circular
- Greater water depth at low discharges, improving access at low flow
- Influence of baffles on culvert hydraulics is reduced
- Inexpensive material, widely available
- Pipe corrugations may reduce flow rates and provide resting areas for small or juvenile fish

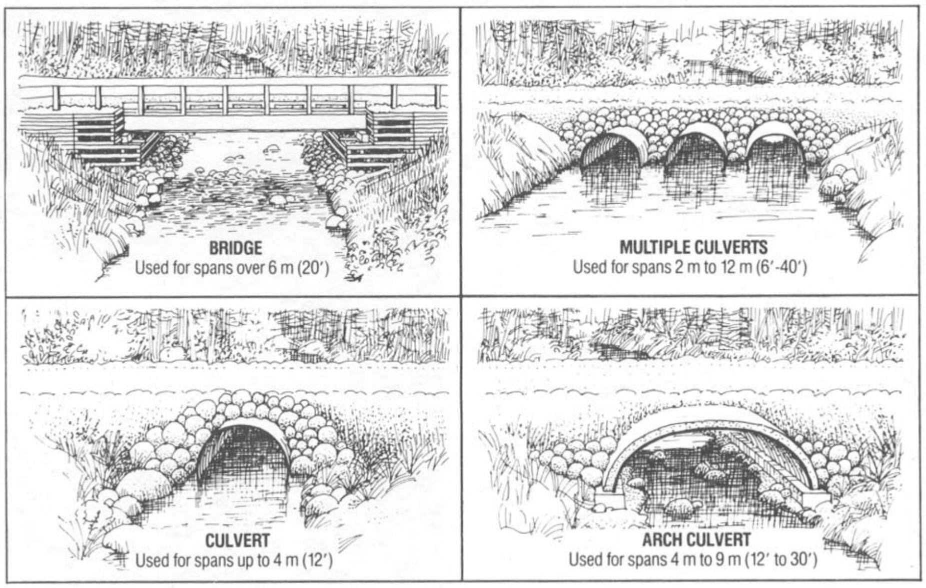


Pipe Arch
- Wide bottom area, large backwater influence
- Low profile, advantageous for situations in which headroom is limited or upstream water stage must be minimized
- Bottom can easily be covered by streambed gravel

Bottomless Arch (shown upside-down prior to installation)
- Permits stream substrate to be retained within the culvert, approximates conditions within natural channel
- Most desirable, but requires substantial initial disturbance to streambeds due to excavation for culvert footings

The Ministry of Natural Resources of Ontario, Canada depicts some water crossings of various lengths with road crossing structures that may be appropriate. While the illustrations on the following page are not definitive recommendations, they do demonstrate how streams of different sizes may require different crossing techniques. The multiple culvert design indicated here is no longer recommended for channels requiring fish passage, due to the heightened risk of debris plugging the inlet pipes.

Figure 2: Water Crossing Structures (Ministry of Natural Resources, Ontario)



Culvert Engineering Guidelines

Regardless of the shape of a culvert, there are important engineering criteria for siting and installation that hold true for all installations:

- There should be no sudden increase or decrease in the natural stream gradient or water velocity for at least 100 feet (30 m) above or below the crossing location.
- Ideally, a stream should have 100 ft (30 m) of straight alignment above and below the culvert.
- Remaining consistent with the natural stream gradient is highly valued by almost all management practices. However, some guidelines recommend installing culverts at *less than natural grades* because fish can negotiate steeper gradients in natural streambeds than they can in culverts. These guidelines are relevant for montane streams, but not for alluvial plains. In streams, a culvert installed in a natural 5% (3º) grade is too steep for most fish, but a culvert installed at 3% (2º) with an 8% (5º) grade upstream due to a headcut could allow fish passage. Installing a culvert at less than natural gradient should be done only after careful hydrologic, engineering and biological analysis. Suggested gradients in Baker and Votapka include:
    - At or near zero
    - 3% (2º) less than stream grade
    - flat grade
    - 0.5% (0.3º)
    - <5% (<3º) with baffles
    - 0% (0º) preferred, <5% (<3º) allowed with baffles

More recent documentation advises reducing gradients even further. The Alaska Department of Fish & Game study of the Tongass National Forest discovered that 66% of culverts in streams with anadromous fish, and 85% of culverts in streams with resident fish populations, were inadequate for fish passage. Velocity was the most common fish passage obstacle, and slight changes in culvert slope (0.5-1%) (0.3º - 1º) would have enabled fish passage in many of those inadequate culvert installations. (Flanders and Cariello, 2000)

- To extend the life of metal culverts, coatings can be applied to the inside and outside of the culvert. These bituminous compounds (often asphalt) can extend the life of the culvert, but they also will increase water velocity. In some cases, the corrugations are completely smoothed over. These detract from fish passage capabilities, especially for small or juvenile fish.

Controlling Sediment Discharges

Release of sediment into a stream has serious and damaging consequences on both individual fish and habitat suitability. Sediment smothers spawning beds and eggs, leads to increased disease and mortality in salmonids, and harms other organisms in the stream.

The most effective way to control sediment is to thoroughly dewater an installation site by pumping water around the site, install the culvert in a dry condition, and stabilize the site using erosion control best management practices, before diverting the stream back into its bed. During dry or low-flow periods, it may be possible to do installations when fish are not migrating and streams are most accessible to construction crews. There are many documents and guidelines with specifics on mitigating sediment from in-stream construction.

In installations for which material is selected to serve as a bed within a culvert, the material must be as silt-free as possible. If natural streambed material is used, the gravel should be washed, hosed down with the silt trapped or removed, and installed before the stream is diverted back through the culvert.

General Culvert Installation Guidelines

Improper installation of culverts can restrict fish passage in a variety of ways, illustrated here by Evans and Johnston (1980). While this illustration depicts a corrugated metal pipe, the implications are the same for other culvert materials and designs.

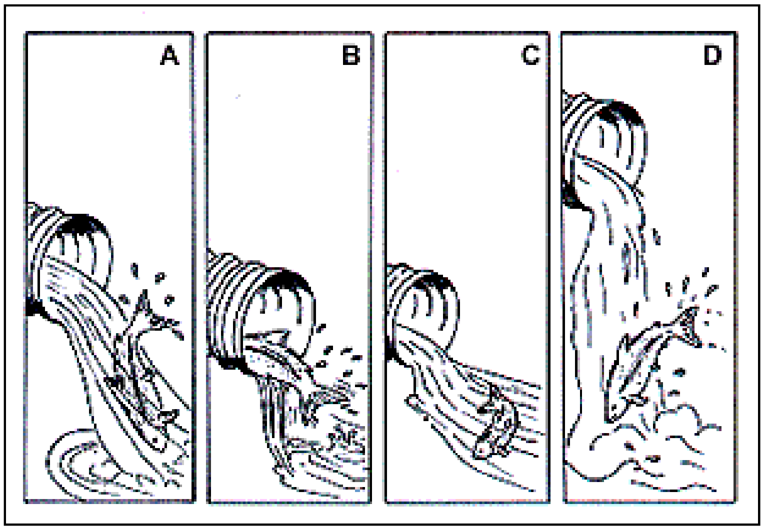


Figure 3 Improper culverts block fish passage in a variety of ways: (A) water velocity too great for fish to swim upstream; (B) water in culvert too shallow, (C) no resting pool below culvert, and (D) jump too high. Evans and Johnston, 1980.

Baker and Votapka summarize some principal lessons in culvert installation. Their lessons are principally applicable for confined, montane stream systems. They may not be appropriate for road crossings and culverts in floodplains, wetlands, estuarine channels or other sites.

<u>Siting and Scheduling of Construction:</u>

1. More consideration should be given to location of the stream crossing, rather than simply following the roadway alignment. Structures should be placed where the streambed is straightest and gradients are acceptably low. A stream should not be redirected out of its natural course solely for the convenience of the road builder. Additionally, the number of crossings should be minimized to the extent possible, and forest practices that don't require crossings (aerial logging) should be considered instead of stream crossing in difficult terrain. One of the most effective, and least costly, means of reducing impacts on stream morphology and ecology is to design a road system to require as few stream crossings as possible.
2. Construction of a crossing should be conducted when stream flows are lowest, and ground conditions best suited to minimize sedimentation and erosion. In many regions, this will be dry periods during winter, when the ground is frozen and streams are at their lowest levels.
3. All rehabilitative work within the stream channel should be complete before the stream is diverted through the culvert, including fish passage mitigation efforts such as resting pools.

Materials and Design:

4. Wherever fish passage is required for a stream crossing, bridges, bottomless arches, or partially buried pipe arches are preferable to round pipes. This is especially true for culverts 100 feet (30 m) long or longer, in areas with threatened species, or if gradients are steeper than 4% (2º).
5. Water velocities in smooth bottom culverts are 2-3 times those of corrugated metal pipes when all other factors are equal. For that reason, corrugations or baffles are preferred to smooth surface pipes if metal materials are used.
6. In areas of high streambed erosion or acidic soils, the design life of corrugated metal culverts is less than 20 years. Designers should plan for the life-cycle of a particular crossing and build highest-quality culverts in areas with these characteristics..
7. Culvert baffles, which are designed to create a pocket of low velocity water within a culvert, are not a panacea for design problems. They are generally not recommended in lieu of larger pipes, reduced pipe gradients or other more expensive corrective measures. Baffles fail far earlier than culverts themselves, and significantly reduce the hydraulic efficiency of a culvert. When used, they are best suited for box culverts or unburied pipe arches.
8. Debris accumulation is a hidden danger for culvert design. There are three options to handle debris: upstream management (through mechanisms which may harm fish); culverts wide enough to pass debris; or installation of a bridge instead of a culvert, in areas where debris loads are high or fisheries values are so high that sediment or wash-out risks cannot be taken.
9. One of the most difficult phenomena to address is the build-up of ice in channels or culverts, called *aufeis*. In colder regions ice can completely fill culverts, resulting in spillover. Aufeis does not usually occur during periods of fish passage, but can endanger culvert installations.

Hydraulics:

10. Culvert diameters must be adequate to pass the maximum expected design flows, as well as debris or other materials. The culvert should be designed to pass a 50-year flood at a static head and a 100-year flood with a headwater depth. For fish passage, a larger pipe with lower flow speeds is always preferable to a narrower pipe.

11. Culverts should be designed and installed to keep the velocity of water passing through the pipe equal to the predicted stream velocity at design flows. Outlet velocities should be maintained at speeds no higher than the maximum velocity of the natural stream, and can cause streambed scouring and bank erosion. Bank protection measures or energy dissipaters should be used to prevent downstream damages or "perching" (see below).

Fish Passage:

12. Migrating fish can generally tolerate some delays in migration. However, if culverts are poorly designed, and accessible for passage at only infrequent times, fish may suffer. Common practice is to design culverts so that flow conditions are unsuitable for fish passage during the 5% of the year when flows are at their highest. This does not usually interfere with migrations.
13. Tailwater control measures should be used to ensure that the culvert outlet is always submerged for easy access for fish. It may be necessary to build several small downstream dams or weirs to raise the water level to the appropriate elevation. If tailwater measures are not installed, "perching" can occur when the outlet of a culvert is too far above the stream level. This is a serious vertical obstacle to fish passage, as illustrated in Figure 2 (D) on page 4.

14. When culverts are installed in streams with high gradients, the designers should provide for resting pools and bank protection at least 100 meters above and below the culvert installation.
15. An outlet pool with tailwater control should be constructed at the downstream end of a culvert for streams that serve critical fish habitat. This pool should be twice as long and wide as the culvert itself, and the bottom elevation of the pool should be at least two feet below the invert elevation of the culvert outlet.

On the following page, Evans and Johnston illustrate the difference between well-designed and poor culverts for fish passage. These illustrations document how fairly simple changes in culvert engineering and installation can mean life or death for migrating salmonids.

Note the critical differences between Figures 4 and 5. In Figure 4, a culvert installation makes no concessions to fish passage. There are steep gradients and high water velocities through the culvert, and water depth is too shallow or variable within the culvert to allow fish passage. The designers have installed neither a weir nor gabion to create a resting pool at the culvert outlet, and migrating fish will be buffeted by the current with no areas to regain strength during their passage upstream.

In Figure 5, water depth, velocity and gradient are carefully moderated to allow fish to pass upstream. The use of a concrete weir or gabion at the outlet of the culvert creates a pool of still water in which fish can rest and gather strength before continuing. The weir also dissipates the energy of the outflow from the culvert, and reduces the risk of downstream scouring. Within the culvert, the gradient is nearly flat (0% or 0º) and water depth is kept sufficient for mature fish to pass safely. A resting pool at the inlet to the culvert is deep and long enough to allow fish to gather strength yet again to continue their migration.

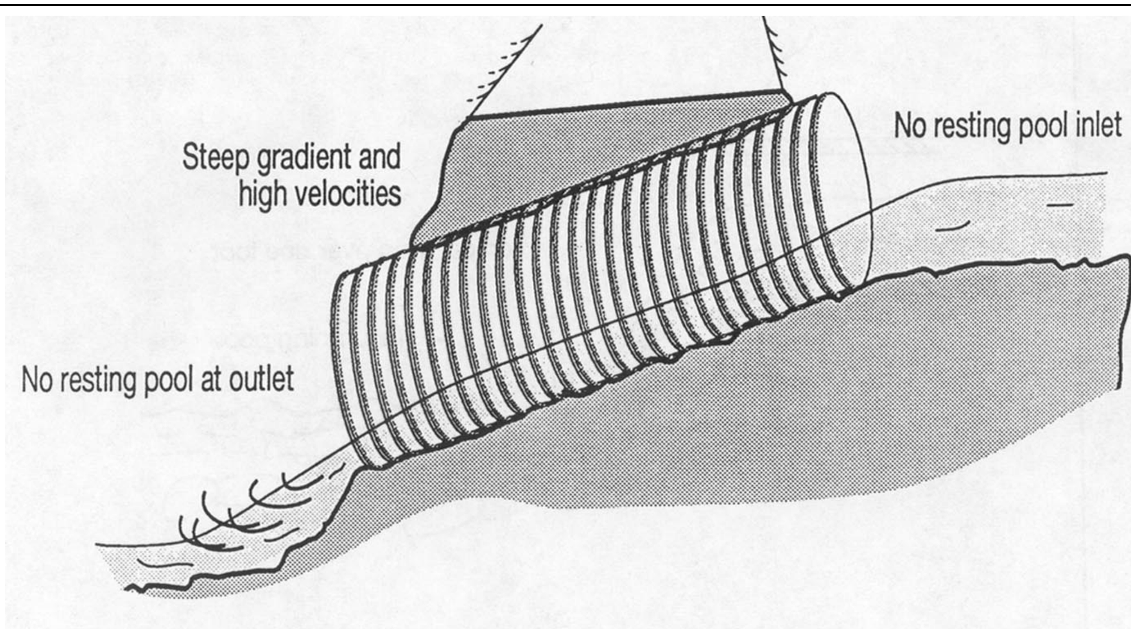


Figure 4 Installation unsuitable for fish passage. Evans and Johnston, 1980.

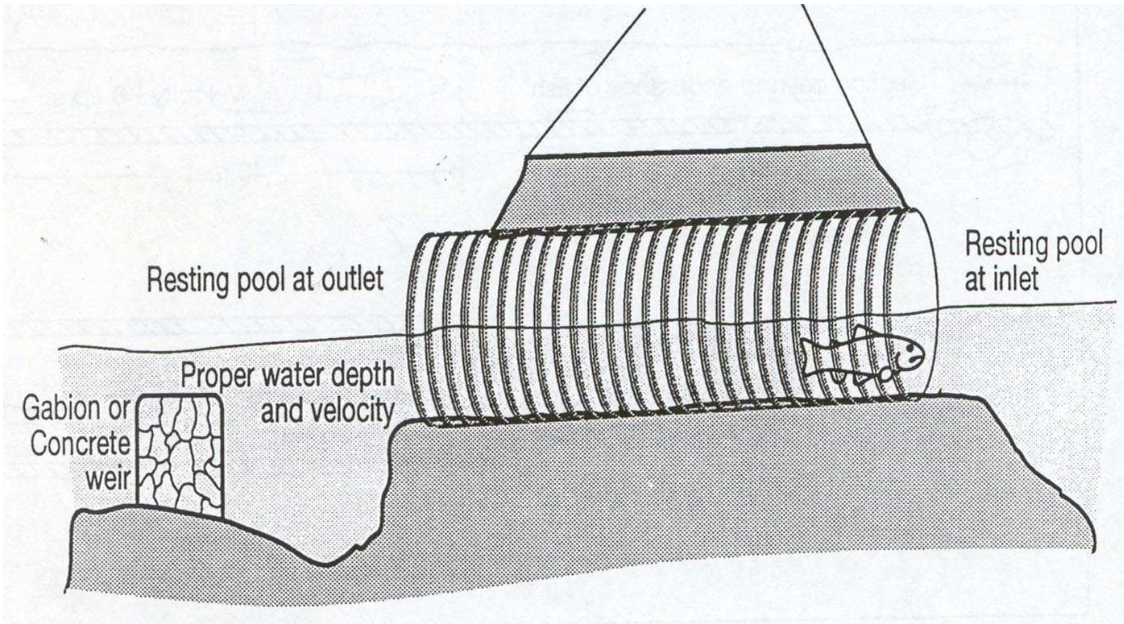


Figure 5 Installation suitable for fish passage. Evans and Johnston, 1980.

When possible, it may be advisable to create a no-slope design for culverts. These are among the simplest, least complex and most fish-friendly culvert designs for a new construction, and are suitable under the following conditions:

- New and replacement culvert installations
- Simple installations; low to moderate natural channel gradient or culvert length
- Passage required for all species
- No special design expertise or survey information required

Pieces of information needed for the no-slope option are:

- the average natural channel bed width
- the natural channel slope
- the elevation of the natural channel bed at the culvert outlet
- an evaluation of potential headcut impacts as the upstream channel regrades

The Washington Department of Fish and Wildlife recommends these designs in low flow/ low velocity streambeds. Culverts in no-slope installations are usually slightly larger in diameter than those used in hydraulic designs. The diameter must be at least 1.25 times the width of the stream channel.

The following illustration shows a no-slope design. Upstream, the culvert is countersunk 40% into the channel. The outlet of the culvert is countersunk by only 20%. This allows the stream to re-create its own natural flow rates and often even the channel substrate within the culvert. (Washington Department of Fish and Wildlife, 2001)

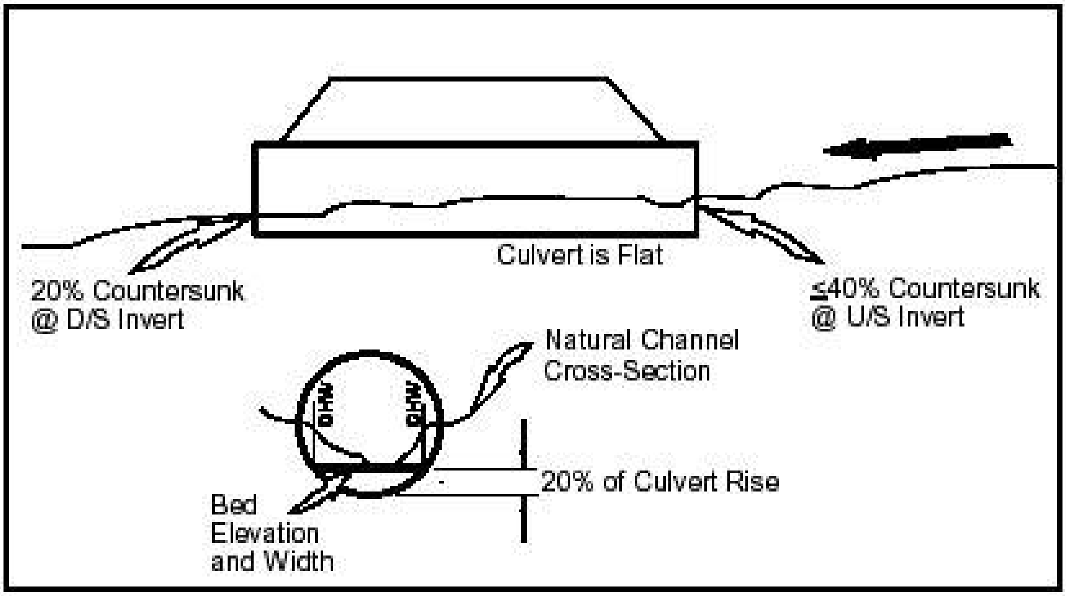


Figure 6: No Slope Culvert Design. Washington Department of Fish and Wildlife, 1999.

Any culvert design that can be installed at close to zero slope is preferable when addressing the passage concerns of different species of fish and different life cycle stages. Juvenile salmonids of all species and some species of adult fish (coho, for example) lack the swimming strength of other species. Because no-slope culvert construction is the most fish-friendly, it is an appealing design option in regions with a variety of migratory fish species or age ranges. When installing a hydraulic culvert with a gradient, however, calculations must be made of the swimming abilities of a target fish species and age class. This introduces the need to match a particular culvert design precisely with the fish populations of a river basin.

Governmental Standards on Culverts and Fish Passages:

In recognition of the crucial elements of culvert design that affect fish survival during their migrations, state and provincial governments in the United States and Canada have each issued guidelines for culvert installation in fish-bearing rivers and streams. Oregon, Washington and British Columbia's guidelines are the most relevant for anadromous salmonids, although none of their guidelines are completely suited for conditions in the Russian Far East. However, they do provide a demonstration of the *types* of criteria that regulatory agencies study most intensively, insofar as they can affect fish passage and the health of fish populations.

The state of Washington guidelines for culverts in forest roads are illustrative of the approach taken by regulatory agencies in the U.S. and Canada, and are used here as an example. In this case, the guidelines are adopted jointly by the Department of Fish and Wildlife, Department of Natural

Resources, and an inter-agency agreement on Timber, Fish and Wildlife. The principles that govern the Washington guidelines are as follows:

WAC 222-24-010 Policy (2)
To protect water quality and riparian habitat, roads must be constructed and maintained in a manner that will prevent potential or actual damage to public resources. This will be accomplished by constructing and maintaining roads so as not to result in the delivery of sediment and surface water to any typed water in amounts, at times or by means, that preclude achieving desired fish habitat and water quality by:
* Providing for fish passage at all life stages […];
* Preventing mass wasting;
* Limiting delivery of sediment and surface runoff to all typed waters;
and
* Avoiding capture and redirection of surface or ground water. This includes retaining streams in their natural drainages and routing subsurface flow captured by roads and road ditches back onto the forest floor;
* Divert most road runoff to the forest floor;
* Provide for the passage of some woody debris
* Protect stream bank stability;
* Minimize the construction of new roads;
* Assure that there is no net loss of wetland function.

Washington State guidelines to meet these goals are specific and straightforward. Among the most relevant are the following.

- All permanent culverts installed in forest roads must be designed to pass a 100-year flood event with consideration for the expected amount of debris
- Culverts must have sufficient erosion control measures to withstand a 100-year flood
- No permanent culverts will be installed that are smaller than 24 inches (61 cm) for anadromous fish streams or wetlands where anadromous fish are present.
- The alignment and slope of culverts will parallel the natural flow of streams wherever possible.
- Where fish life is present, the bottom of the culvert must be at or below the natural streambed at the inlet and outlet.
- Culverts must be either open-bottomed, or have the bottoms covered with gravel and installed at least six inches (15 cm) below the natural streambed.
- Closed-bottom culverts must not slope more than 0.5% (0.3º); open-bottom culverts shall not slope more than the natural slope of the streambed. Any closed-bottom culvert set at existing stream gradients between 0.5% (0.3º) and 3% (2º), shall be designed with baffles for water velocity control.
- Culverts must terminate in materials that will not readily erode.
- If water is diverted from its natural channel, it must be returned via a culvert, flume, or spillway. The discharge points for returning water to its natural streambed must be protected from erosion.
- Streambeds must be cleared of debris for 50 ft (15 m) upstream from the culvert inlet.
- Entrances to culverts must have catch basins and headwalls to minimize erosion or fill failure.
- Culverts shall be set to retain normal stream water depth through the length of the culvert.

The Washington State guidelines are typical of those enacted by state and provincial governments in salmonid regions in Western North America. While Oregon, British Columbia and other governments offer nuanced differences for criteria such as distances from a culvert that the stream must be cleared of debris, the general themes remain the same regardless of the governing agencies. For example, British Columbia regulations state that, “Fish stream crossing structures should retain the pre-installation stream conditions to the extent possible,” and specifically advise bridges or open-bottom culverts for fish passage. (British Columbia Ministry of Forests, 2000).

While the themes may remain similar, implementation of the regulations and maintenance of road crossings and culverts varies across regions. In regions with vast forest road systems and insufficient staffing, culverts may deteriorate and fail. Failures are commonly due to erosion and mass failure at the point of the culvert construction, buildup of debris at the culvert passages, or stream wash-out below the culvert.

In Washington State, the inter-agency commission on Timber, Fish and Wildlife conducted studies between 1992-1995 to determine the “Effectiveness of Forest Road and Timber Harvest Best Management Practices with Respect to Sediment-Related Water Quality Impacts.” (Rashin *et al*, 1993, 1994). Their evaluation was specifically intended to determine whether state BMPs were effective at minimizing the impacts of erosion and sedimentation. They included several components on forest road construction, including stream crossing and culvert installation, as their higher-priority BMPs. The other BMPs evaluated by Rashin *et al* included timber harvest BMPs and haul road maintenance.

In the study design of these reports, Rashin *et al* examined study sites in six of the nine physiographic regions of Washington State, and evaluated each site’s Slope Hazard Classification.

Table 1: Washington State Slope Hazard Classifications (Rashin *et al*, 1993, 1994)

BMP Category	Low	Moderate	High
Harvesting BMPs	0-19% slope 0-11º slope	20-40% slope 12-22º slope	>40% slope >22º slope
New Road Construction & Road Maintenance BMPs	0-19% slope 0-11º slope	20-50% slope 12-27º slope	>50% slope >27º slope

Most of the streams examined in these studies were relatively small streams, Types 3, 4, or 5 under Washington State’s forest practices classification system. In all cases, they evaluated localized effects of logging and road construction activities during the first two-three years following application of state-mandated BMPs.

The Washington State studies reveal that practices for installing stream crossings at new road construction were ineffective or only partially effective at preventing chronic sediment delivery to streams. Road drainage BMPs, specifically relief culverts, were found effective at over half of the new forest road sites. Effectiveness was measured on the basis of erosion and sediment delivery, physical disturbance of stream channels, and the condition of aquatic habitat and riparian communities. While stream crossing and culvert BMPs were only partially successful in Washington, BMPs for maintaining active haul roads for timber harvests and maintaining streamside buffer zones were generally effective. Other timber harvest and forest road crossing BMPs had mixed results, depending largely on the slope hazard characteristics of the site.

Samarga River Characteristics and Culvert Suitability

In many respects, the Samarga watershed in Primorskii Krai shares the same characteristics of the salmon-bearing watersheds of the Western states and provinces of the United States and Canada. However, due to its extraordinary biodiversity and ecosystem resources the Samarga offers distinct challenges to forest road and timber harvest management. (Semenchenko, 2001)

1. The Samarga watershed has never been logged and large sections consist of pristine forest untouched by roads or permanent settlement. This differs from Oregon, Washington and British Columbia, where most forests are second-growth and show impacts of past logging.
2. The Samarga features exceptionally vulnerable and endangered species, including the world's largest and healthiest populations of anadromous Sakhalin taimen. The river and its tributaries are also home to large, healthy populations of wild pink salmon, masu salmon, chum salmon, white-spotted char and Dolly Varden. Other rare and unique species include white-breasted bear, Blackiston's fish owl, Japanese yew, Fori rhododendron, and Amur tiger.
3. Plans for the logging of fir and spruce forests involve new road construction across pristine areas, many of them characterized by steeply inclined streambeds and valleys. The hydrographic network of the Samarga basin is very complex, with many tributaries ranging in length from 2 km to 70 km. The total watershed area is 7820 km^2.
4. The most economically valuable timber in the watershed–Ayan spruce and Khingan fir–are large trees (16-26 m at maturity) that grow along river channels, at an elevation of 200-500 m. Because the trees are growing alongside the river, logging could easily result in sedimentation and stream bank erosion. Many erosion control safeguards must be in place to prevent serious habitat degradation associated with timber harvesting, new road construction and log hauling, in addition to culvert design and maintenance.
5. The Samarga watershed is characterized by monsoon-influenced rains and high stream flows in summer and autumn (late June through mid-October), during which the peak runs of pink and other salmon occur. Studies show that fish migration upstream toward spawning grounds is positively associated with warming temperatures (between 7º and 16º Celsius) and rising water levels. Thus, any construction that interferes with the water levels could seriously affect the salmonid populations.
6. Indigenous Udeghe people rely on healthy fish runs and non-timber forest products for subsistence, and would be seriously harmed by watershed and forest degradation.

Examples of current practices for river crossings and culverts in the Russian Far East can be found in recent logging operations in Primorskii Krai on the Bolshaya Ussurka river basin, on a tributary to the mighty Amur River. In Figure 7 on the following page, a large span of wood and iron girders crosses the Ussurka in its upper reaches. Despite the bridge's impressive span and solid construction, there are potential problems due to the middle pier posing a logjam hazard that would divert flow towards the abutments and may cause erosion.

Figure 7: Bolshaya Ussurka river crossing, Primorskii Krai. Semenchenko, 2002.

In the following photo conditions are far worse. These types of dilapidated crossings are seen in the upper tributaries and narrow streams. Log bridges are suspended from bank to bank, about two log diameters above the water level. These techniques fail because debris and sediment pile up, or the banks erode during storms, and soon the fish passage ability is gone.

Figure 8: Stream crossing, upper Bolshaya Ussurka basin. Semenchenko, 2002.

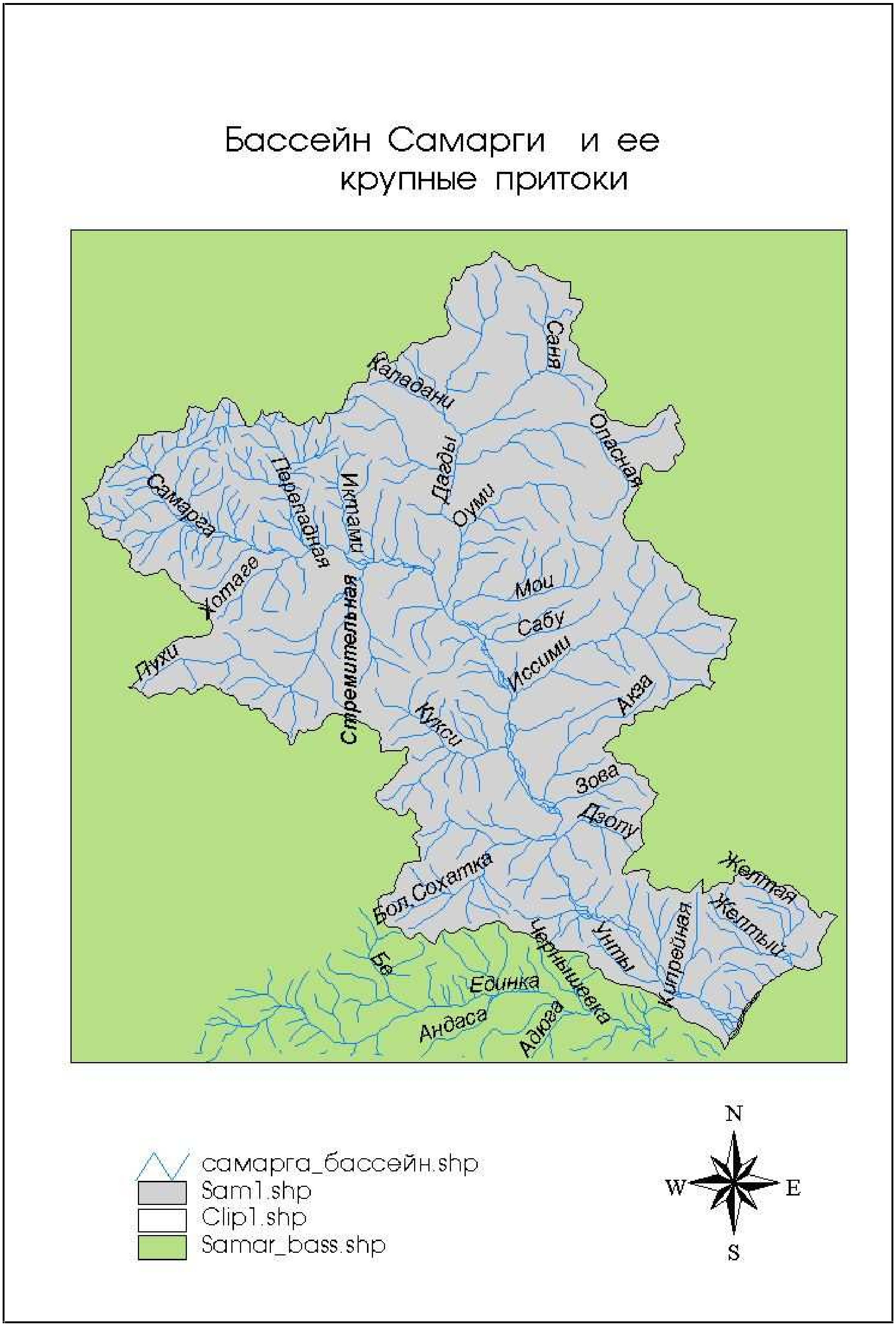


Figure 9: Samarga Watershed and Its Large Tributaries. Semenchenko 2001.

The unique ecological features of the Samarga River and the vulnerability of particular species demands that all forest activities be conducted with the highest possible standards of environmental management. Logging and other extractive activities must be conducted with scrupulous attention to ecosystem and fisheries health.

Under the Russian Federal Forest Code, most of the Samarga watershed is categorized as Group 3 forest, which is open to commercial logging operations. There are three Groups, of which Group 1 is the most protected. However, certain Group categorizations within a forest area are subject to heightened levels of protection, among which are:

1. Streamside buffer areas, with precise specifications to be determined by scientific assessments by the staff of the Ministry of Natural Resources at the Oblast' or Krai level;
2. Spawning areas for commercially important fish stocks; and
3. Traditional use areas for indigenous peoples. (Russian Federation Federal Act No. 22-FZ. Chapter 9, Sections 55-58. Adopted by the State Duma on January 22, 1997)

Russian law also provides special protections in the Far East for particular regions. According to the 1993 Rules of Forest Harvest of the Far East, in areas with slope greater than 30º, only limited forest uses are permitted. This restriction holds regardless of the Group designation of a particular forest. Other restrictions vary on the basis on regional implementation of the Federal code, and certain areas (Kamchatka, Magadan, and the Okhotsk District of Khabarovskii Krai) have more stringent restrictions. The Federal code specifies that:

> Expressly protected parcels of forests with a restricted regime of forest use (bank and soil-protection forest sectors along the shores of bodies of water, slopes of gullies and gorges, edges of forests on the borders of treeless territories, the haunts and habitats of rare and endangered species of wild animals, plants, etc.) may be identified within the forests of the aforesaid groups. (Section 55)

This is promising as it grants to the regional-level representatives of the Ministry of Natural Resources a high degree of autonomy in determining which forest areas receive special protection. Based on the criteria described above in the various legal documents, many areas within the Samarga should be held to the highest possible standards of environmental protection. Movements to improve the status of environmental protection based on the above criteria are well underway, and should be able to make a strong case for heightened standards of environmental management during any proposed logging operation. To date, the process to declare the Samarga watershed an area of traditional use has not succeeded, but environmental protection groups and Udeghe representatives may press for additional protections on those grounds.

Recommendations that apply specifically to the Samarga, in addition to the general recommendations above for forest road and culvert construction, include:

1. New roads for timber access must be oriented to cross streams at sites that are straight for at least 30 meters both upstream and downstream of the crossing. Structures must be placed to insure that natural meanders are not cut off, which could result in higher stream velocities or accelerated head cutting, streambed scouring, or erosion.
2. Construction of river crossings must be performed under the driest conditions possible. In Primorskii Krai this is midwinter. Russian law mandates that logging be carried out solely during winter (depending on the regulations at the Oblast' or Krai level) but violations are widespread. All logging activities – from road construction, to harvesting, to hauling – involve

risks of erosion and sedimentation, especially during wet periods. For those reasons, construction, harvest and hauling should be done only when the ground is frozen solid and there is little risk of sudden melt-off or erosion.

3. Streamside buffer zones (riparian management zones) must be established and respected, with distances depending on the ecological value of the stream, the slope hazard, and the altitude at which vegetation changes from wetland to upland plant community. Road construction and timber harvest should be designed to preserve stream bank integrity, water temperature (through shading), a representative ratio of deciduous to coniferous trees, and wildlife habitat.
4. Because the Samarga salmonids migrate during high stream flow periods, the general recommendations to design culverts that are inaccessible to fish passage during the 5% of the year when stream flows are highest may not be applicable (see page 5, # 6).
5. For streams with high gradients, resting pools and bank protection must be installed for at least 100 meters above and below the culvert installation. Gabions or concrete weirs should be installed below the culvert to prevent downstream erosion and create resting pools.
6. In places where fish passage is most important, bridges, bottomless arches, or partially buried pipe arch culverts are strongly preferred to round, corrugated metal pipes. This is especially true for culverts longer than 30 meters, or with stream gradients $\geq 4\%$ ($\geq 2.5°$).
7. Log-hauling roads should be constructed with adequate road drainage, skid trail erosion BMPs and other erosion control measures. (See Burroughs, E.R. Jr.; King, J.G. *Reduction of soil erosion of forest roads*. USDA Forest Service General Technical Report INT-264.)
8. Any river or stream in which anadromous Sakhalin taimen exist should be deemed off-limits to all logging and new road construction. The last healthy stocks of these ancient fish should be preserved for future generations. If for any reason a road crossing is necessary, it must be permitted only after extensive environmental review by qualified specialists with the authority of the relevant agencies. For any such crossing, bridges or pipe arch culverts–not closed-bottom culverts–must be used.
9. River systems on which Udeghe communities rely for subsistence fishing and non-timber forest products should be logged only after revenue-sharing and resource management plans are formulated with the resident communities.

Appendix One: Resources for Further Study:

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http://www.concrete-pipe.org/manual/START.pdf

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Baker, Calvin O. and Votapka, Frank E. *Fish Passage Through Culverts.* US Department of Agriculture–Forest Service Technology and Development Center, prepared for US Department of Transportation Federal Highway Administration. Report No. FHWA-FL-90-006. 1990.

British Columbia Ministry of Forests. Forest Practices Code Guidelines on Fish-Stream Crossing. March 2002. http://www.for.gov.bc.ca/tasb/legsregs/fpc/FPCGUIDE/Fish%20Stream%20Crossing/FSCGdBk.pdf

Burroughs, E.R. Jr.; King, J.G. *Reduction of soil erosion of forest roads.* US Department of Agriculture–Forest Service. General Technical Report INT-264. 1989.

Evans, Willis; Johnston, F. Beryl. *Fish Migration and Fish Passage: A practical guide to solving fish passage problems.* US Department of Agriculture–Forest Service. 1972, revised 1980.

FishXing Software and Learning Systems for Fish Passage Through Culverts. http://www.stream.fs.fed.us/fishxing/. Computer software (Windows 95/98/2000/NT) designed to simulate the ability of fish populations to traverse culverts around pipelines, roads, etc. CD-ROM also includes video simulations, multi-media lectures, and standard references in Adobe PDF including Baker and Votapka (1990), above. Available from USDA Forest Service, San Dimas Technology and Development Center, 444 E. Bonita Avenue, San Dimas, CA 91773. Annotated bibliography for culvert crossings current to November 1999 (in MS Word, Adobe PDF, HTML) available at website.

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Ministry of Natural Resources, Ontario, Canada. *Environmental Guidelines for Access Roads and Water Crossings.* Publications Ontario. 1990, 1995.

International Erosion Control Association (IECA). International body that offers resources on training and seminars, member directory with expert guidance, and listings of products and services. 2002. http://ieca.org.

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Meehan, William R. *Influence of Forest and Rangeland Management on Salmonid Fishes and Their Habitats.* American Fisheries Society. Special Publication 19. 1991.

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Rashin, Ed; Bell, Johanna; Clishe, Casey. *Effectiveness of Forest Road and Timber Harvest Best Management Practices With Respect to Sediment-Related Water Quality Impacts.* Interim Reports No. 1 and 2. Washington Department of Ecology, Environmental Investigations and Laboratory Services Program. Ecology Publications No. 94-27 and 94-67. June 1993 and May 1994.

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U.S. Forest Service. Region 10: Tongass National Forest. Tongass Monitoring and Evaluation 2001 Report. May 2002. http://www.fs.fed.us/r10/tongass/management%20news/tlmp/monitoring/2001monitor.html

Washington Department of Fish and Wildlife. *Fish Passage Design at Road Culverts: A Design Manual for Fish Passage at Road Crossings.* Habitat and Lands Program, Environmental Engineering Division. March 3, 1999. http://www.wa.gov/wdfw/hab/engineer/cm/fpdrc.pdf

Washington Department of Fish and Wildlife. *Fish Passage Barrier and Surface Water Diversion Screening Assessment and Prioritization Manual.* August 2000. Website includes prioritization and assessment spreadsheet available in MS Excel and Quattro Pro. http://www.wa.gov/wdfw/hab/engineer/fishbarr.htm.

Washington Department of Natural Resources. Forest Practices Guidelines. "Water Crossing Structures." 2001. http://www.wa.gov/dnr/htdocs/fp/fpb/fprules2001/wac222-24.pdf.

Wiest, Richard L. *A Landowner's Guide to Building Forest Access Roads.* US Department of Agriculture–Forest Service, Northeastern Area. July 1998. http://www.na.fs.fed.us/spfo/pubs/stewardship/accessroads/accessroads.htm