



## National Marine Fisheries Service Southwest Region



# GUIDELINES FOR SALMONID PASSAGE AT STREAM CROSSINGS

## 1.0 INTRODUCTION

This document provides guidelines for design of stream crossings to aid upstream and downstream passage of migrating salmonids. It is intended to facilitate the design of a new generation of stream crossings, and assist the recovery of threatened and endangered salmon species. These guidelines are offered by the National Marine Fisheries Service, Southwest Region (NMFS-SWR), as a result of its responsibility to prescribe fishways under the Endangered Species Act, the Magnuson-Stevens Act, the Federal Power Act, and the Fish and Wildlife Coordination Act. The guidelines apply to all public and private roads, trails, and railroads within the range of anadromous salmonids in California.

Stream crossing design specifications are based on the previous works of other resource agencies along the U.S. West Coast. They embody the best information on this subject at the time of distribution. Meanwhile, there is mounting evidence that impassable road crossings are taking a more significant toll on endangered and threatened fish than previously thought. New studies are revealing evidence of the pervasive nature of the problem, as well as potential solutions. Therefore, this document is appropriate for use until revised, based on additional scientific information, as it becomes available.

The guidelines are general in nature. There may be cases where site constraints or unusual circumstances dictate a modification or waiver of one or more of these design elements. Conversely, where there is an opportunity to protect salmonids, additional site-specific criteria may be appropriate. Variances will be considered by the NMFS on a project-by-project basis. When variances from the technical guidelines are proposed, the applicant must state the specific nature of the proposed variance, along with sufficient biological and/or hydrologic rationale to support appropriate alternatives. Understanding the spatial significance of a stream crossing in relation to salmonid habitat within a watershed will be an important consideration in variance decisions.

Protocols for fish-barrier assessment and site prioritization are under development by the California Department of Fish and Game (CDFG). These will be available in updated versions of the *California Salmonid Stream Habitat Restoration Manual*. Most streams in California also support important populations of non-salmonid fishes, amphibians, reptiles, macroinvertebrates, insects, and other organisms important to the aquatic food web. Some of these may also be threatened or endangered species and require "ecological connectivity" that dictate other design criteria not covered in this document. Therefore, the project applicant should check with the local Fish and Game office, the U.S. Fish and Wildlife Service (USFWS), and/or tribal biologists to ensure other species are fully considered.

The California Department of Transportation Highway Design Manual defines a culvert as "A closed conduit which allows water to pass under a highway," and in general, has a single span of less than 20 feet or multiple spans totaling less than 20 feet. For the purpose of fish passage, the distinction between bridge, culvert or low water crossing is not as important as the effect the structure has on the form and function of the stream. To this end, these criteria conceptually apply to bridges and low water crossings, as well as culverts.

## **2.0 PREFERRED ALTERNATIVES AND CROSSINGS**

The following alternatives and structure types should be considered in order of preference:

1. *Nothing* - Road realignment to avoid crossing the stream
2. *Bridge* - spanning the stream to allow for long term dynamic channel stability
3. *Streambed simulation strategies* - bottomless arch, embedded culvert design, or ford
4. *Non-embedded culvert* - this is often referred to as a hydraulic design, associated with more traditional culvert design approaches limited to low slopes for fish passage
5. *Baffled culvert, or structure designed with a fishway* - for steeper slopes

If a segment of stream channel where a crossing is proposed is in an active salmonid spawning area then only full span bridges or streambed simulations are acceptable.

## **3.0 DESIGNING NEW AND REPLACEMENT CULVERTS**

The guidelines below are adapted from culvert design criteria published by many federal and state organizations including the California Department of Fish and Game (CDFG, 2001). It is intended to apply to new and replacement culverts where fish passage is legally mandated or important.

### **3.1 Active Channel Design Method**

The Active Channel Design method is a simplified design that is intended to size a culvert sufficiently large and embedded deep enough into the channel to allow the natural movement of bedload and formation of a stable bed inside the culvert. Determination of the high and low fish

passage design flows, water velocity, and water depth is not required for this method since the stream hydraulic characteristics within the culvert are intended to mimic the stream conditions upstream and downstream of the crossing. This design method is usually not suitable for stream channels that are greater than 3% in natural slope or for culvert lengths greater than 100 feet. Structures for this design method are typical round, oval, or squashed pipes made of metal or reinforced concrete.

- Culvert Width - The minimum culvert width shall be equal to, or greater than, 1.5 times the active channel width.
- Culvert Slope - The culvert shall be placed level (0% slope).
- Embedment - The bottom of the culvert shall be buried into the streambed not less than 20% of the culvert height at the outlet and not more than 40% of the culvert height at the inlet.

### **3.2 Stream Simulation Design Method**

The Stream Simulation Design method is a design process that is intended to mimic the natural stream processes within a culvert. Fish passage, sediment transport, flood and debris conveyance within the culvert are intended to function as they would in a natural channel. Determination of the high and low fish passage design flows, water velocity, and water depth is not required for this option since the stream hydraulic characteristics within the culvert are designed to mimic the stream conditions upstream and downstream of the crossing. The structures for this design method are typically open bottomed arches or boxes but could have buried floors in some cases. These culverts contain a streambed mixture that is similar to the adjacent stream channel. Stream simulation culverts require a greater level of information on hydrology and geomorphology (topography of the stream channel) and a higher level of engineering expertise than the Active Channel Design method.

- Culvert Width - The minimum culvert width shall be equal to, or greater than, the bankfull channel width. The minimum culvert width shall not be less than 6 feet.
- Culvert Slope - The culvert slope shall approximate the slope of the stream through the reach in which it is being placed. The maximum slope shall not exceed 6%.
- Embedment - The bottom of the culvert shall be buried into the streambed not less than 30% and not more than 50% of the culvert height. For bottomless culverts the footings or foundation should be designed for the largest anticipated scour depth.

### **3.3 Hydraulic Design Method**

The Hydraulic Design method is a design process that matches the hydraulic performance of a culvert with the swimming abilities of a target species and age class of fish. This method targets distinct species of fish and therefore does not account for ecosystem requirements of non-target species. There are significant errors associated with estimation of hydrology and fish swimming speeds that are resolved by making conservative assumptions in the design process. Determination of the high and low fish passage design flows, water velocity, and water depth are required for this option.

The Hydraulic Design method requires hydrologic data analysis, open channel flow hydraulic calculations and information on the swimming ability and behavior of the target group of fish. This design method can be applied to the design of new and replacement culverts and can be used to evaluate the effectiveness of retrofits of existing culverts.

- \$ Culvert Width - The minimum culvert width shall be 3 feet.
- \$ Culvert Slope - The culvert slope shall not exceed the slope of the stream through the reach in which it is being placed. If embedment of the culvert is not possible, the maximum slope shall not exceed 0.5%.
- \$ Embedment - Where physically possible, the bottom of the culvert shall be buried into the streambed a minimum of 20% of the height of the culvert below the elevation of the tailwater control point downstream of the culvert. The minimum embedment should be at least 1 foot. Where physical conditions preclude embedment, the hydraulic drop at the outlet of a culvert shall not exceed the limits specified above.

**Hydrology for Fish Passage under the Hydraulic Design Method**

- \$ **High Fish Passage Design Flow** - The high design flow for adult fish passage is used to determine the maximum water velocity within the culvert. Where flow duration data is available or can be synthesized the high fish passage design flow for adult salmonids should be the 1% annual exceedance. If flow duration data or methods necessary to compute them are not available then 50% of the 2 year flood recurrence interval flow may be used as an alternative. Another alternative is to use the discharge occupied by the cross-sectional area of the active stream channel. This requires detailed cross section information for the stream reach and hydraulic modeling. For upstream juvenile salmonid passage the high design flow should be the 10% annual exceedance flow.
- \$ **Low Fish Passage Design Flow** - The low design flow for fish passage is used to determine the minimum depth of water within a culvert. Where flow duration data is available or can be synthesized the 50% annual exceedance flow or 3 cfs, whichever is greater, should be used for adults and the 95% annual exceedance flow or 1 cfs, whichever is greater, should be used for juveniles.

**Maximum Average Water Velocities in the Culvert at the High Fish Passage Design Flow -**

Average velocity refers to the calculated average of velocity within the barrel of the culvert. Juveniles require 1 fps or less for upstream passage for any length culvert at their High Fish Passage Design Flow. For adult salmonids use the following table to determine the maximum velocity allowed.

Culvert Length (ft)	Velocity (fps) - Adult Salmonids
<60	6
60-100	5
100-200	4
200-300	3
>300	2

**Minimum Water Depth at the Low Fish Passage Design Flow** - For non-embedded culverts, minimum water depth shall be twelve 12 inches for adult steelhead and salmon, and six 6 inches for juvenile salmon.

**Juvenile Upstream Passage** - Hydraulic design for juvenile upstream passage should be based on representative flows in which juveniles typically migrate. Recent research (NMFS, 2001, in progress) indicates that providing for juvenile salmon up to the 10% annual exceedance flow will cover the majority of flows in which juveniles have been observed moving upstream. The maximum average water velocity at this flow should not exceed 1 fps. In some cases over short distances 2 fps may be allowed.

**Maximum Hydraulic Drop** - Hydraulic drops between the water surface in the culvert and the water surface in the adjacent channel should be avoided for all cases. This includes the culvert inlet and outlet. Where a hydraulic drop is unavoidable, its magnitude should be evaluated for both high design flow and low design flow and shall not exceed 1 foot for adults or 6 inches for juveniles. If a hydraulic drop occurs at the culvert outlet, a jump pool of at least 2 feet in depth should be provided.

### **3.4 Structural Design and Flood Capacity**

All culvert stream crossings, regardless of the design option used, shall be designed to withstand the 100-year peak flood flow without structural damage to the crossing. The analysis of the structural integrity of the crossing shall take into consideration the debris loading likely to be encountered during flooding. Stream crossings or culverts located in areas where there is significant risk of inlet plugging by flood borne debris should be designed to pass the 100-year peak flood without exceeding the top of the culvert inlet (Headwater-to-Diameter Ratio less than one). This is to ensure a low risk of channel degradation, stream diversion, and failure over the life span of the crossing. Hydraulic capacity must be compensated for expected deposition in the culvert bottom.

### **3.5 Other Hydraulic Considerations**

Besides the upper and lower flow limit, other hydraulic effects need to be considered, particularly when installing a culvert:

- Water surface elevations in the stream reach must exhibit gradual flow transitions, both upstream and downstream. Abrupt changes in water surface and velocities must be avoided, with no hydraulic jumps, turbulence, or drawdown at the entrance. A continuous low flow channel must be maintained throughout the entire stream reach.
- In addition, especially in retrofits, hydraulic controls may be necessary to provide resting pools, concentrate low flows, prevent erosion of stream bed or banks, and allow passage of bedload material.

- Culverts and other structures should be aligned with the stream, with no abrupt changes in flow direction upstream or downstream of the crossing. This can often be accommodated by changes in road alignment or slight elongation of the culvert. Where elongation would be excessive, this must be weighed against better crossing alignment and/or modified transition sections upstream and downstream of the crossing. In crossings that are unusually long compared to streambed width, natural sinuosity of the stream will be lost and sediment transport problems may occur even if the slopes remain constant. Such problems should be anticipated and mitigated in the project design.

#### **4.0 RETROFITTING CULVERTS**

For future planning and budgeting at the state and local government levels, redesign and replacement of substandard stream crossings will contribute substantially to the recovery of salmon stocks throughout the state. Unfortunately, current practices do little to address the problem: road crossing corrections are usually made by some modest level of incremental, low cost “improvement” rather than re-design and replacement. These usually involve bank or structure stabilization work, but frequently fail to address fish passage. Furthermore, bank stabilization using hard point techniques frequently denigrates the habitat quality and natural features of a stream. Nevertheless, many existing stream crossings can be made better for fish passage by cost-effective means. The extent of the needed fish passage improvement work depends on the severity of fisheries impacts, the remaining life of the structure, and the status of salmonid stocks in a particular stream or watershed.

For work at any stream crossing, site constraints need to be taken into consideration when selecting options. Some typical site constraints are ease of structure maintenance, construction windows, site access, equipment, and material needs and availability. The decision to replace or improve a crossing should fully consider actions that will result in the greatest net benefit for fish passage. If a particular stream crossing causes substantial fish passage problems which hinder the conservation and recovery of salmon in a watershed, complete redesign and replacement is warranted. *Consolidation and/or decommissioning of roads can sometimes be the most cost-effective option.* Consultations with NMFS or CDFG biologists can help in selecting priorities and alternatives.

Where existing culverts are being modified or retrofitted to improve fish passage, the Hydraulic Design method criteria should be the design objective for the improvements. However, it is acknowledged that the conditions that cause an existing culvert to impair fish passage may also limit the remedies for fish passage improvement. Therefore, short of culvert replacement, the Hydraulic Design method criteria should be the goal for improvement but not necessarily the required design threshold.

Fish passage through existing non-embedded culverts may be improved through the use of gradient control weirs upstream or downstream of the culvert, interior baffles or weirs, or in some cases, fish ladders. However, these measures are not a substituted for good fish passage design

for new or replacement culverts. The following guidelines should be used:

- **Hydraulic Controls** - Hydraulic controls in the channel upstream and/or downstream of a culvert can be used to provide a continuous low flow path through culvert and stream reach. They can be used to facilitate fish passage by establishing the following desirable conditions: Control depth and water velocity within culvert, concentrate low flows, provide resting pools upstream and downstream of culvert and prevent erosion of bed and banks. A change in water surface elevation of up to one foot is acceptable for adult passage conditions, provided water depth and velocity in the culvert meet other hydraulic guidelines. A jump pool must be provided that is *at least* 1.5 times the jump height, or a minimum of two feet deep, whichever is deeper.
- **Baffles** - Baffles may provide incremental fish passage improvement in culverts with excess hydraulic capacity that can not be made passable by other means. Baffles may increase clogging and debris accumulation within the culvert and require special design considerations specific to the baffle type. Culverts that are too long or too high in gradient require resting pools, or other forms of velocity refuge spaced at increments along the culvert length.
- **Fishways** - Fishways are generally not recommended, but may be useful for some situations where excessive drops occur at the culvert outlet. Fishways require specialized site-specific design for each installation. A NMFS or CDFG fish passage specialist should be consulted.
- **Multiple Culverts** - Retrofitting multiple barrel culverts with baffles in one of the barrels may be sufficient as long as low flow channel continuity is maintained and the culvert is reachable by fish at low stream flow.

## 5.0 OTHER GENERAL RECOMMENDATIONS

Trash racks and livestock fences should not be used near the culvert inlet. Accumulated debris may lead to severely restricted fish passage, and potential injuries to fish. Where fencing cannot be avoided, it should be removed during adult salmon upstream migration periods. Otherwise, a minimum of 9 inches clear spacing should be provided between pickets, up to the high flow water surface. Timely clearing of debris is also important, even if flow is getting around the fencing. Cattle fences that rise with increasing flow are highly recommended.

Natural or artificial supplemental lighting should be provided in new and replacement culverts that are over 150 feet in length. Where supplemental lighting is required the spacing between light sources shall not exceed 75 feet.

The NMFS and the CDFG set in-stream work windows in each watershed. Work in the active stream channel should be avoided during the times of year salmonids are present. Temporary crossings, placed in salmonid streams for water diversion during construction activities, should meet all of the guidelines in this document. However, if it can be shown that the location of a

temporary crossing in the stream network is not a fish passage concern at the time of the project, then the construction activity only needs to minimize erosion, sediment delivery, and impact to surrounding riparian vegetation.

Culverts shall only be installed in a de-watered site, with a sediment control and flow routing plan acceptable to NMFS or CDFG. The work area shall be fully restored upon completion of construction with a mix of native, locally adapted, riparian vegetation. Use of species that grow extensive root networks quickly should be emphasized. Sterile, non-native hybrids may be used for erosion control in the short term if planted in conjunction with native species.

Construction disturbance to the area should be minimized and the activity should not adversely impact fish migration or spawning. If salmon are likely to be present, fish clearing or salvage operations should be conducted by qualified personnel prior to construction. If these fish are listed as threatened or endangered under the federal or state Endangered Species Act, consult directly with NMFS and CDFG biologists to gain authorization for these activities. Care should be taken to ensure fish are not chased up under banks or logs that will be removed or dislocated by construction. Return any stranded fish to a suitable location in a nearby live stream by a method that does not require handling of the fish.

If pumps are used to temporarily divert a stream to facilitate construction, an acceptable fish screen must be used to prevent entrainment or impingement of small fish. Contact NMFS or CDFG hydraulic engineering staff for appropriate fish screen specifications. Unacceptable wastewater associated with project activities shall be disposed of off-site in a location that will not drain directly into any stream channel.

## **6.0 POST-CONSTRUCTION EVALUATION AND LONG TERM MAINTENANCE AND ASSESSMENT**

Post-construction evaluation is important to assure the intended results are accomplished, and that mistakes are not repeated elsewhere. There are three parts to this evaluation:

- 1) Verify the culvert is installed in accordance with proper design and construction procedures.
- 2) Measure hydraulic conditions to assure that the stream meets these guidelines.
- 3) Perform biological assessment to confirm the hydraulic conditions are resulting in successful passage.

NMFS and/or CDFG technical staff may assist in developing an evaluation plan to fit site-specific conditions and species. The goal is to generate feedback about which techniques are working well, and which require modification in the future. These evaluations are not intended to cause extensive retrofits of any given project unless the as-built installation does not reasonably conform to the design guidelines, or an obvious fish passage problem continues to exist. Over time, the



NMFS anticipates that the second and third elements of these evaluations will be abbreviated as clear trends in the data emerge.

Any physical structure will continue to serve its intended use only if it is properly maintained. During the storm season, timely inspection and removal of debris is necessary for culverts to continue to move water, fish, sediment, and debris. In addition, all culverts should be inspected at least once annually to assure proper functioning. Summary reports should be completed annually for each crossing evaluated. An annual report should be compiled for all stream crossings and submitted to the resource agencies. A less frequent reporting schedule may be agreed upon for proven stream crossings. Any stream crossing failures or deficiencies discovered should be reported in the annual cycle and corrected promptly.

## 8.0 DEFINITIONS

These definitions apply to terms used in this document. Meanings may differ when used in another context and are not legal unless otherwise noted. Definitions were shortened, paraphrased or adapted to fit regional conditions and for ease of understanding.

**Active Channel:** A waterway of perceptible extent that periodically or continuously contains moving water. It has definite bed and banks which serve to confine the water and includes stream channels, secondary channels, and braided channels. It is often determined by the "ordinary high water mark" which means that line on the shore established by the fluctuations of water and indicated by physical characteristics such as clear, natural line impressed on the bank, shelving, changes in the character of soil, destruction of terrestrial vegetation, the presence of litter and debris, or other appropriate means that consider the characteristics of the surrounding areas.

**Bankfull:** The point on a streambank at which overflow into the floodplain begins. The floodplain is a relatively flat area adjacent to the channel constructed by the stream and overflowed by the stream at a recurrence interval of about one to two years. If the floodplain is absent or poorly defined, other indicators may identify bankfull. These include the height of depositional features, a change in vegetation, slope or topographic breaks along the bank, a change in the particle size of bank material, undercuts in the bank, and stain lines or the lower extent of lichens and moss on boulders. Field determination of bankfull should be calibrated to known stream flows or to regional relationships between bankfull flow and watershed drainage area.

**Bedload:** Sand, silt, and gravel, or soil and rock debris rolled along the bottom of a stream by the moving water. The particles of this material have a density or grain size which prevents movement far above or for a long distance out of contact with the streambed under natural flow conditions.

**Fish Passage:** The ability of both adult and juvenile fish to move both up and down stream.

**Flood Frequency:** The frequency with which a flood of a given discharge has the probability of recurring. For example, a "100-year" frequency flood refers to a flood discharge of a magnitude

likely to occur on the average of once every 100 years or, more properly, has a one-percent chance of being exceeded in any year. Although calculation of possible recurrence is often based on historical records, there is no guarantee that a "100-year" flood will occur at all within the 100-year period or that it will not recur several times.

**Flood Prone Zone:** Spatially, this area generally corresponds to the modern floodplain, but can also include river terraces subject to significant bank erosion. For delineation, see definition for floodplain.

**Floodplain:** The area adjacent to the stream constructed by the river in the present climate and inundated during periods of high flow.

**Flow Duration Curve:** A cumulative frequency curve that shows the percentage of time that specified discharges are equaled or exceeded. Flow duration curves are usually based on daily streamflow and describe the flow characteristics of a stream throughout a range of discharges without regard to the sequence of occurrence. If years of data are plotted the annual exceedance flows can be determined.

**Ordinary High Water Mark:** The mark along the bank or shore up to which the presence and action of the water are common and usual, and so long continued in all ordinary years, as to leave a natural line impressed on the bank or shore and indicated by erosion, shelving, changes in soil characteristics, destruction of terrestrial vegetation, or other distinctive physical characteristics.

**Roads:** For purposes of these guidelines, roads include all sites of intentional surface disturbance for the purpose of vehicular or rail traffic and equipment use, including all surfaced and unsurfaced roads, temporary roads, closed and inoperable roads, legacy roads, skid trails, tractor roads, layouts, landings, turnouts, seasonal roads, fire lines, and staging areas.

**Section 10 and 404 Regulatory Programs:** The principal federal regulatory programs, carried out by the U.S. Army Corps of Engineers, affecting structures and other work below mean high water. The Corps, under Section 10 of the River and Harbor Act of 1899, regulates structures in, or affecting, navigable waters of the U.S. as well as excavation or deposition of materials (e.g., dredging or filling) in navigable waters. Under Section 404 of the Federal Water Pollution Control Act Amendments (Clean Water Act of 1977), the Corps is also responsible for evaluating application for Department of the Army permits for any activities that involve the placement of dredged or fill material into waters of the United States, including adjacent wetlands.

**Waters of the United States:** Currently defined by regulation to include all navigable and interstate waters, their tributaries and adjacent wetlands, as well as isolated wetlands and lakes and intermittent streams.

## 9.0 REFERENCES

- Baker, C.O. and F.E. Votapka. 1990. *Fish Passage Through Culverts*. Federal Highways Administration & USDA Forest Service. FHWA-FL-90-006. 67 pages. (Available from USDA Forest Service publications, San Dimas Laboratory, CA)
- Bates, K. 1992. *Fishway Design Guidelines for Pacific Salmon*. Working paper 1.6. (Available from Ken Bates, Lands and Restoration Program Chief Engineer, Washington Dept. of Fish and Wildlife. 600 Capitol Way North, Olympia, WA, 98501-1091.)
- Beechie, T., E. Beamer, and L. Wasserman. 1994. *Estimating Coho Salmon Rearing Habitat and Smolt Production Losses in a Large River Basin, and Implications for Habitat Restoration*. North Am. J. Fish. Mgt. 14:797 - 811.
- Behlke, C.E., D.L. Kane, R.F. McLean, and M.D. Travis. 1991. *Fundamentals of Culvert Design for Passage of Weak-Swimming Fish, Final Report*. Alaska DOT&PF and USDT, Federal Highway Administration, FHWA-AK-RD-90-10. 177 pages.
- California Department of Fish and Game. 1998. *California Salmonid Stream Habitat Restoration Manual, 3<sup>rd</sup> Edition, Part X Fish Passage Evaluation At Road Crossings* (Part X is in preparation, expected fall 2001).
- California Department of Fish and Game. 2001. *Culvert Criteria for Fish Passage*.
- Clay, C.H. 1995. *Design of Fishways and Other Fish Facilities, 2<sup>nd</sup> Edition*. Lewis Publishers, CRC Press (imprint), Boca Raton, FL. 248 pages.
- Evans, W.A. and B. Johnston. 1980. *Fish Migration and Fish Passage: a Practical Guide to Solving Fish Passage Problems*. U.S. Forest Service, EM - 7100 - 2, Washington, D.C.
- Furniss, M.J., T.D. Roelofs, and C.S. Yee. 1991. *Road Construction and Maintenance*. American Fisheries Society Special Publication 19:297-323.
- Gebhards, S., and J. Fisher. 1972. *Fish Passage and Culvert Installations*. Idaho Fish and Game Rep. 12 pages.
- Groot, C., and L. Margolis, editors. 1991. *Pacific Salmon Life Histories*. Univ. British Columbia Press, Vancouver. 564 pages.
- Hassler, T.J. 1987. *Species Profiles: Life Histories and Environmental Requirements of Coastal Fishes and Invertebrates (Pacific Southwest) Coho Salmon*. U.S. Fish Wildl. Serv. Biol. Rep. 82(11.70). U.S. Army Corps of Engineers, TR EL-82-4. 19 pages.

- Johnson, A. and J.F. Orsborn. Undated, circa 1990. *Welcome to Culvert College*. Washington Trout, Duvall, WA. 67 pages.
- Kay, AR., and R.B. Lewis. 1970. *Passage of Anadromous Fish Through Highway Drainage Structures*. California Division of Highways, Dist. 01 Res. Rep. 629110. 28 pages.
- Katopodis, C. 1992. *Introduction to Fishway Design*. Working Document from Fish Passageways and Diversion Structures Course presented by National Education and Training Center, USFWS.
- Lauman, J.E. 1976. *Salmonid Passage at Stream-Road Crossings*. Oregon Dept. of Fish and Wildlife.
- McClellan, T.J. 1970. *Fish Passage Through Highway Culverts*. U.S. Dept. Trans., Federal Highway Administration and Oregon State Game Comm., Portland OR. 16 pages.
- Meehan, W.R., editor. 1991. *Influences of Forest and Rangeland Management on Salmonid Fishes and Their Habitats*. American Fisheries Society Special Publication 19.
- ODFW, 1997. Oregon Department of Fish and Wildlife *Guidelines and Criteria for Stream-Road Crossings*. 7 pages.
- Pearsons, T.N., G.A. McMichael, S.W. Martin, E.L. Bartrand, A. Long, and S.A. Leider. 1996. *Yakima Species Interactions Studies Annual Report 1994*. U.S. Department of Energy, Bonneville Power Administration Annual Report 1994. No. DOE/BPB99852-3.
- Poulin, V.A., and H.W. Argent. 1997. *Stream Crossing Guidebook for Fish Streams, a Working Draft*. Prepared for British Columbia Ministry of Forests. 80 pages.
- Sandercock, F.K. 1991. *Life History of Coho Salmon*. Pages 397-445 in C. Groot and L. Margolis (ed.s.), *Pacific salmon life histories*. Univ. British Columbia Press, Vancouver. 564 pages.
- Shirvell, C.S. 1994. Effect of changes in streamflow on the microhabitat use and movement of sympatric juvenile coho salmon (*Oncorhynchus kisutch*) and chinook salmon (*O. tshawytscha*) in a natural stream. *Can. J. Fish. Aquat. Sci.* 51:1644-1652.
- Salmonid Restoration Federation Conference. 1996. *Culvert Fish Passage Design and Retrofitting Workshop*. Fortuna, CA. 30 pages.
- U.S.D.A., Forest Service, 1999. *Water Road Interaction Series*.

- U.S. Fish and Wildlife Service. 1983-19\_\_\_. *Species Profiles: Life Histories and Environmental Requirements of Coastal Fishes and Invertebrates*. U.S. Fish Wildlife Service, Biol. Rep. 82(11). U.S. Army Corps of Engineers, TR EL-82-4.
- Waples, R.S. 1991. *Definition of "Species" under the ESA: Application to Pacific Salmon*. U.S. Dep. Commer., NOAA Tech. Memo., NMFS, F/NWC-194, 29 pages.
- Washington State Department of Fish and Wildlife, 1999. *Design Guidelines for Fish Passage Design at Road Culverts*.
- Washington State Department of Transportation. 1998. *Juvenile and Resident Salmonid Movement and Passage Through Culverts. Final Report. Rept. No. WA-RD 457.1*. (Available through the National Technical Information Service, Springfield, VA 22616).
- Washington State Department of Transportation. 1997. *Fish Passage Program Department of Transportation Inventory Final Report*. G. Johnson (Project Leader) and nine others. 58 pages.
- Washington State Department of Transportation. 1996. *Investigation of Culvert Hydraulics Related to Juvenile Fish Passage. Final Report. Rept. No. WA-RD 388.1*. (Available through the National Technical Information Service, Springfield, VA 22616 )
- Weaver, W.E., and D.K. Hagans. 1994. *Handbook for Forest and Ranch Roads*. Mendocino County Resource Conservation District. 161 pages.
- Wietkamp, L.A., T.C. Wainwright, G.J. Bryant, G.B. Milner, D.J. Teel, R.G. Kope, and R.S. Waples. 1995. *Status Review of Coho Salmon from Washington, Oregon, and California*. U.S. Dep. Commer., NOAA Tech. Memo., NMFS-NWFSC-24, Northwest Fisheries Science Center, Seattle, Washington. 258 pages.
- Ziemer, G.L. 1961. *Fish Transport in Waterways*. Alaska Dept. of Fish and Game. 2 pages.

## **Internet Resources:**

California Department of Fish and Game

<http://www.dfg.ca.gov>

National Marine Fisheries Service Southwest Region

<http://swr.nmfs.noaa.gov>

Washington Department of Fish and Wildlife Fish Passage Technical Assistance

<http://www.wa.gov/wdfw/hab/engineer/habeng.htm>

Oregon Road/Stream Crossing Restoration Guide, Spring 1999 (with ODFW criteria)

<http://www.nwr.noaa.gov/1salmon/salmesa/4ddocs/orfishps.htm>

FishXing software and learning systems for the analysis of fish migration through culverts

<http://www.stream.fs.fed.us/fishxing/>

USDA Forest Service Water-Road Interaction Technology Series Documents

<http://www.stream.fs.fed.us/water-road/index.html>

British Columbia Forest Practices Code Stream Crossing Guidebook for Fish Streams

<http://www.for.gov.bc.ca/tasb/legsregs/fpc/fpcguide/stream/str-toc.htm>

### **Please direct questions regarding this material to:**

National Marine Fisheries Service

Hydraulic Engineering Staff

777 Sonoma Avenue, Suite 325

Santa Rosa, CA 95404

Phone: (707) 575-6050

Fax: (707) 578-3425

Email: [nmfs.swr.fishpassage@noaa.gov](mailto:nmfs.swr.fishpassage@noaa.gov)