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Influence of Forest and Rangeland Management on Anadromous Fish Habitat in Western North America

PLANNING FOREST ROADS TO PROTECT SALMONID HABITAT

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USDA FOREST SERVICE
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William R. Meehan, Technical Editor

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Preface

This is one of a series of publications summarizing knowledge about the influences of forest and rangeland management on anadromous fish habitat in Western North America. This paper addresses the effects on fish habitat of naturally occurring watershed disturbances and sets the scene for future discussions of the influences of human activities.

Our intent in presenting the information in these publications is to provide managers and users of the forest and rangelands of Western North America with the most complete information available for estimating the consequences of various management alternatives.

In this series, we will summarize published and unpublished reports and data as well as the observations of resource scientists and managers developed over years of experience in the West. These compilations will be valuable to resource managers in planning uses of forest and rangeland resources, and to scientists in planning future research. The extensive lists of references will serve as a bibliography on forest and rangeland resources and their uses for Western North America.

Previous publications in these series include:

1. "Habitat requirements of anadromous salmonids," by D. W. Reiser and T. C. Bjornn.

2. "Impacts of natural events," by Douglas N. Swanston.

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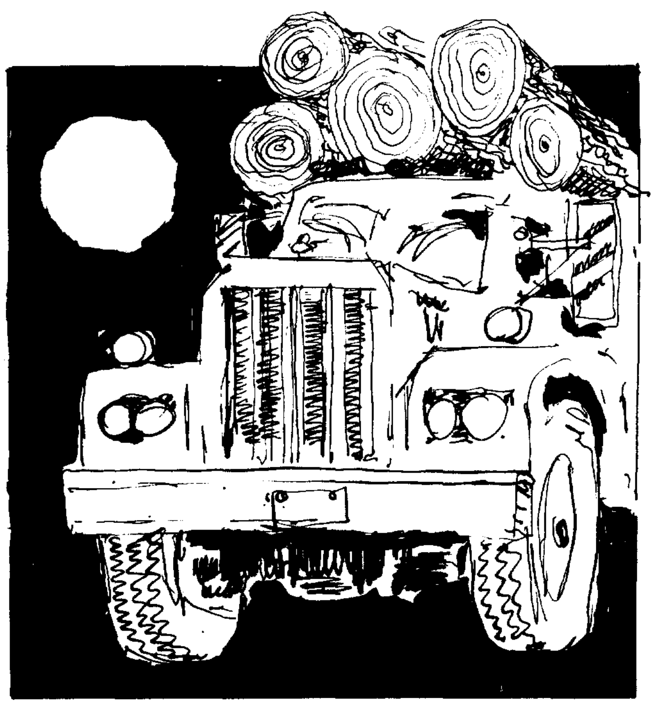
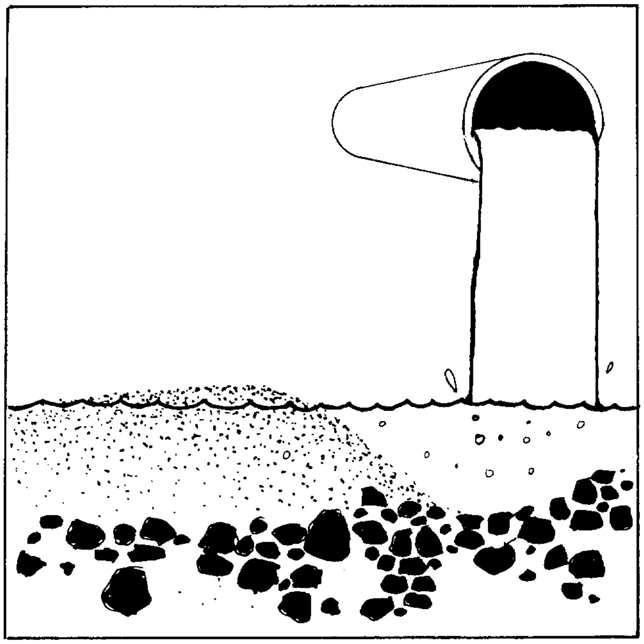
INTRODUCTION

A forest transportation system can have significant effects on anadromous fish and their habitats. Often, the effects have been adverse. Examples of adverse changes caused by forest roads, log sorting, and log-storage areas include increased sediment and organic debris in streams, changes in water quality and quantity, formation of physical barriers to the movement of adult and juvenile fish, and increased human access to previously remote or isolated areas.

This report describes how elements of a forest transportation system cause environmental changes that affect anadromous fish habitat and provides guidelines for the design, construction, and maintenance of these facilities to minimize adverse effects. In the first publication in this series, Reiser and Bjornn have discussed habitat requirements of anadromous salmonids; we will limit our discussion to effects on the fish and their habitats that directly stem from forest roads, log sorting, and log-storage areas.





SEDIMENTATION

The fact that forest roads cause increased erosion and sedimentation cannot be disputed. Increased sediment in streams after construction of roads can be dramatic and long-lasting. The incremental sediment contribution per unit area from roads is often many times that from all other land-management activities, including log skidding and yarding. Based on total area, however, both roads and logging appear to contribute eroded material nearly equally. Gibbons and Salo (1973) reviewed over 25 articles on the impact of timber harvesting on stream environments and concluded that forest roads are the primary initiator of erosion caused by human activities.

The primary mechanisms by which sediment from roads reaches streams are mass soil movement and surface erosion. Because forests and steep terrain seem, for the most part, to go together, mass-movement erosion is the predominant mode of sediment transport from forest roads. Swanston and Swanson (1976) described four main types of mass movements common to Western forest lands. Soil creep, slump-earthflows, debris avalanches, and debris torrents are differentiated mainly by speed of travel and shape of the failure surface. The construction of roads across some slopes can initiate or accelerate slope failure--from several to hundreds of times, depending on such variables as soil type, slope steepness, presence of subsurface water, and road location (Anderson 1971, Larse 1971, Swanston 1971, Swanson 1975, Swanston and Swanson 1976).

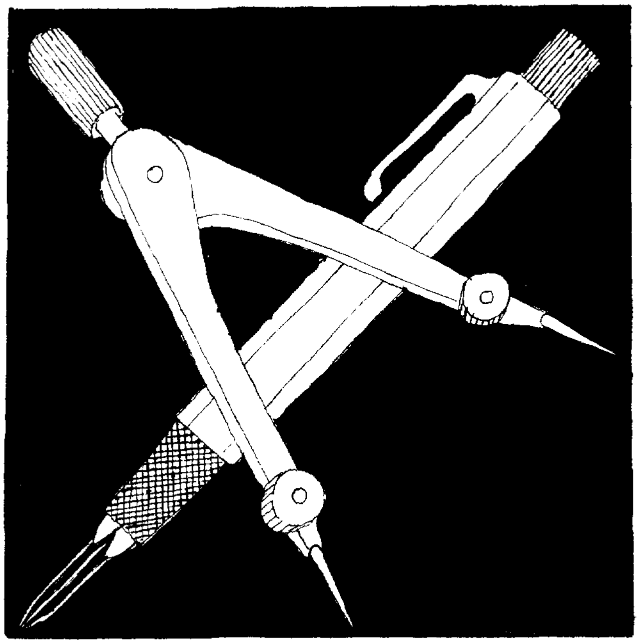
The construction of a road, landing, or log-sorting area on a hillslope is a severe and concentrated disturbance. Such construction can initiate mass movements of soil by overloading the slope from improper fill construction, undercutting an already marginally stable slope, and impeding or changing surface and subsurface runoff regimes (Larse 1971, Burroughs et al. 1976). Table 1 shows how severely roads can increase erosion rates as indicated by the rate of debris-avalanche erosion in four widely separate watersheds in Western Canada and the United States (Swanston and Swanson 1976). The values shown are only for debris avalanches and do not include amounts from other road-associated mass or surface events.

Table 1--Debris-avalanche erosion in forest, clearcut, and roaded areas (Swanston and Swanson 1976).

Site	Period of record	Area		Slides	Debris-avalanche erosion	Rate of debris-avalanche erosion relative to forested areas
	Year	Percent	Km^2	Number	$M^3/km^2 \cdot yr$	
Stequaleho Creek, Olympic Peninsula (Fiksdal 1974)						
Forest	84	79	19.3	25	71.8	X 1.0
Clearcut	6	18	4.4	0	0	0
Road right-of-way	6	3	0.7	83	11 825	X 165
			24.4	108	71.8	
Alder Creek, western Cascade Range, Oregon (Morrison 1975)						
Forest	25	70.5	12.3	7	45.3	X 1.0
Clearcut	15	26.0	4.5	18	117.1	X 2.6
Road right-of-way	15	3.5	0.6	75	15 565	X 344
			17.4	100		
Selected Drainages, Coast Mountains, S.W. British Columbia (O'Loughlin 1972, and personal communication)						
Forest	32	88.9	246.1	29	11.2	X 1.0
Clearcut	32	9.5	26.4	18	24.5	X 2.2
Road right-of-way	32	1.5	4.2	11	282.5[1/]	X 25.2
H. J. Andrews Experimental Forest, western Cascade Range, Oregon (Swanson and Dyrness 1975)						
Forest	25	77.5	49.8	31	35.9	X 1.0
Clearcut	25	19.3	12.4	30	132.2	X 3.7
Road right-of-way	25	3.2	2.0	69	1 772	X 49

1/ Calculated from O'Loughlin (1972, and personal communication), assuming that the area in road construction in and outside clearcuttings is 16 percent of the area clearcut.

In addition to sediment originating from mass erosion associated with roads, erosion from road surfaces also contributes sediment to streams. Surface erosion from fill and cut slopes, road surfaces, and drainage ditches can severely affect streams below the right-of-way (Burns 1970, Brown and Krygier 1971, Larse 1971, Gibbons and Salo 1973, Farrington and Savina 1977). Although this type of erosion is difficult to measure, investigations in specific soil types and climatic conditions have given some idea of the soil loss from forest roads (Fredriksen 1965, Megahan and Kidd 1972). For example, Haupt (1959) found that road-fill slopes were the primary source of sediment moving downslope. Packer and Haupt (1966) assessed losses by surface erosion from forest roads in the northern Rocky Mountains and presented guidelines to reduce surface erosion and sedimentation.



CONTROLLING SEDIMENTATION THROUGH PLANNING AND DESIGN

Larse (1971) pointed out that the most important steps to minimize the impact of road construction on streams usually occur during reconnaissance, planning, and route selection, rather than during or after construction. He and others have also repeatedly pointed out that problems can be reduced by including specialists such as geologists, soil scientists, fisheries biologists, and hydrologists on the planning team. Key environmental problems and constraints are too often overlooked when routes are located and roads designed by one person. Numerous guides for reducing and controlling erosion from roads have been devised (Trimble and Sartz 1957, Haupt 1959, Packer and Haupt 1966, Gonsier and Gardner 1971, Larse 1971, Burroughs et al. 1976, Megahan 1977). Larse (1971)[1/] summarized guidelines for route selection to minimize erosion as follows:

- Plan roads to take maximum advantage of natural log landing areas.
- Take advantage of benches, ridge tops, and the flatter transitional slopes near the ridges and valley bottoms. Avoid midslope locations on steep, unstable slopes. Grades of 14-16 percent are practical for low-use roads.
- Locate valley-bottom roads to provide a buffer strip of natural vegetation between road and stream. Position roads on the transition between the toe slope and terrace to protect the road slopes from flood erosion. Roads should not be built in valley bottoms if encroachment on the stream will result.
- Locate ridge-top roads to avoid headwalls at the source of tributary drainages.
- Vary road grades, when possible, to reduce road-surface erosion and flows from culverts and drainage ditches.
- Select stream crossings carefully to take advantage of the best drainage.

[1/] For more detailed recommendations refer to Larse (1971).

In addition, where stream protection for fisheries is important, the recommendation by Farrington and Savina (1977) that no roads be built in a stream's inner gorge should probably be added to the above six recommendations. Farrington and Savina's recommendation may be considered merely an extension of Larse's third guideline, however.

After the route is selected, positive measures to reduce erosion should be incorporated into the road design and construction. The following recommendations by Larse (1971, see footnote 1) summarize good erosion-control measures that should be built into forest roads:

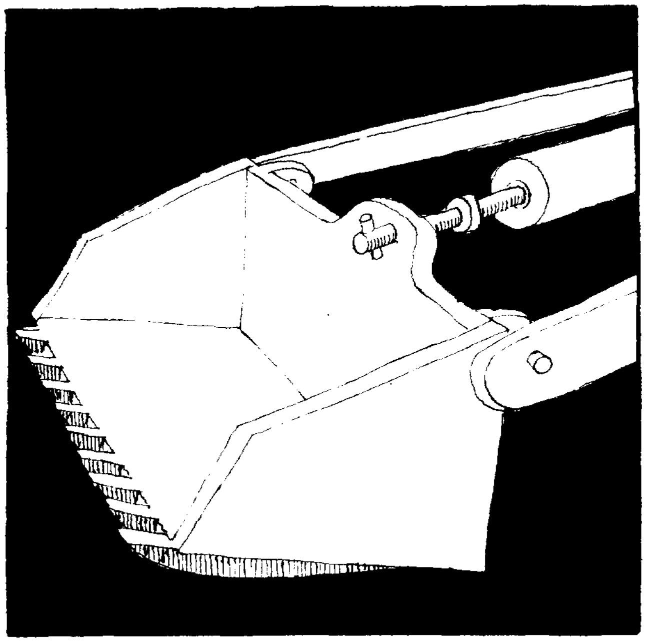
- Within limitations necessary for type and volume of traffic, fit roads to terrain with minimum of road width.
- Minimize excavation with a balanced earthwork design whenever possible. Bench or terrace and drain natural slopes to provide a sound foundation for embankments.
- Design rolling grades to reduce surface water velocity and culvert requirements, but avoid coinciding horizontal and vertical curves that concentrate surface runoff.
- Design cut and fill slopes as steep as possible consistent with the stability and strength of soil and rock formations. Round tops of cut slopes to reduce sloughing and surface ravel.
- Use retaining walls, with properly designed drainage, to reduce excavation, contain bank material, and prevent stream encroachment.
- Vary ditch and culvert requirements depending on topography, road gradient, soil erodability, and expected intensity of rainfall.
- Place culverts to avoid discharge onto erodible slopes or into streams. Install cross-drainage culverts immediately upgrade of headwalls and stream crossings to prevent ditch sediment from entering the stream.
- Design drainage structures to accommodate the flow of streams based on at least a 25-year flood frequency (50 years for large permanent bridges and major culverts), with due consideration given to the possibility of bedload and debris restricting flow capacity of the structure.
- Determine the extent and type of fish habitat before selecting criteria for structure design. Bridges and arch culverts are preferred in streams with migratory fish. Where culverts are used, gradient should be less than 1 percent, and a constant minimum flow of 5-6 inches should be provided at maximum velocities of 6-8 ft/s during low-water stages. Scouring at the outlet can be eliminated by energy dissipators, such as heavy rock riprap, weirs, or gabions.

- Avoid channel changes and protect embankment with riprap, masonry headwalls, or other retaining structures. Align large culverts with the natural course and gradient of the stream. Design the placement of large culvert inverts lower than the natural streambed. Floatable debris during high streamflow can plug small culverts and restrict flow at larger culverts and bridges, causing severe road embankment, streambank erosion, or channel changes. Trash racks, if properly designed, constructed, and maintained, can reduce culvert plugging. Trash racks can sometimes be barriers to fish movement; other measures to insure culvert or bridge survival should be considered.

- Most forest roads should be surfaced. The type of surface will usually be determined by traffic, maintenance objectives, desired service life, and the stability and strength of the road foundation material.

- Provide for vegetative or artificial stabilization of cut and fill slopes in the design process.

- Prior to completion of design drawings, field check the design to assure that it fits the terrain, drainage needs have been satisfied, and all critical slope conditions have been identified and adequate design solutions applied.



ROAD CONSTRUCTION AND MAINTENANCE

A challenge to the roadbuilder is to construct the designed facility with a minimum of disturbance, without damage to or contamination of the adjacent landscape, water quality, and other resource values. Some of the most severe soil erosion can be traced to poor construction practices, insufficient attention to drainage during construction, and operations during adverse weather conditions.

Construction operations can be conducted in most terrain and climatic conditions if the roadbuilder takes precautions to minimize soil erosion and stream sedimentation. Good technical engineering work will not itself control erosion during construction, but work must be deliberately planned, scheduled, and controlled so that different phases are performed under optimum conditions. When soil moisture is excessive, earthwork operations should be suspended and measures taken to weatherproof the partially completed work. Work within or adjacent to streams and water channels should not be attempted during periods of high streamflow, intense rainfall, or migratory-fish spawning.

The clearing of debris underlying, supporting, or mixed with embankment or waste material is a common cause of road failure and mass soil movement. The necessary slope bonding, shear resistance, and embankment density for maximum stability cannot be achieved unless organic debris is disposed of before embankment construction is started. Woody debris must also be removed from all drainage channels and headlands above or at the source of drainage courses.

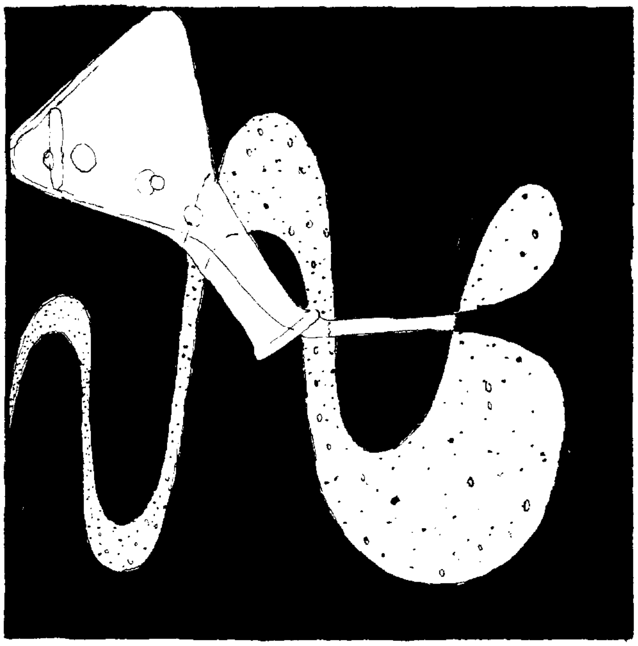
Although many techniques are commonly practiced to minimize erosion during construction, the most meaningful are related to how well the work is planned, scheduled, and controlled by the roadbuilder and those responsible for determining that work satisfies design requirements and land-management objectives.

Planned regular maintenance is necessary to keep roads in good condition, but maintenance is too often neglected or improperly performed, resulting in deterioration. The vast network of existing forest roads, many of which have only light or intermittent use, present real problems as fuel and other maintenance costs increase.

To build and use a road requiring no maintenance is neither practical nor economical. Maintenance requirements and expense related to traffic use can and should be considered in planning and design to insure that the completed road can be maintained most economically. Where soil erosion and sedimentation are of concern to the forest manager, the additional expense of constructing a road with proper attention to its stability and proper drainage can generally be amortized in a few years by lower cost of upkeep.

Suggested maintenance practices to prevent or control erosion and stream sedimentation are presented by Larse (1971, see footnote 1):

- Blading and shaping should be performed to conserve existing surface material.
- Road inlet and outlet ditches, catchbasins, and culverts should be kept free of obstructions.
- Slide material should be removed promptly when it obstructs drainage systems.
- Herbicides should not be used where they might contaminate water courses.



ROAD STABILIZATION ADDITIVES

The use of various chemicals to improve bearing capacity and quality of running surface of forest roads has had a varied history in the Western United States. Probably the most common additive applied on forest roads is some type of oil to minimize dust. Freestone (1972) estimated that 200 million gallons a year of waste crankcase oil were added to rural roads in the United States. The amount of other waste and nonwaste oils applied to rural roads in the United States, including forest roads in the West, is unknown.

In addition to oils, other chemical compounds used to improve forest road quality include sodium chloride, calcium cloride, hydrated lime, and waste pulpmill liquors. Commercial formulations especially designed for road stabilization also are being used more commonly on forest roads. Unfortunately, we know even less about the use of chemical stabilizers on forest roads than we do about road oil.

Most of the published information on road stabilization with chemicals is for the Eastern United States and Canada (Duncan 1965, Gayer 1965, Paterson et al. 1970), and we have never found the question of water-quality impacts addressed.

Because of the increasing cost and decreasing availability of high-quality surfacing rock, the use of various road-stabilizing additives on Western forest roads can only increase. With increased use, surface and subsurface runoff from oiled and chemically treated roadways could certainly cause localized water-quality problems that could affect fish and their habitat. Little research has been done that can allow us to guess at the consequences of increased road-additive use.

Burger (1973) studied the acute toxicity and long-term effects of Chevron PS-300[2/] road oil, a commonly used dust-control agent, on juvenile coho salmon (Oncorhynchus kisutch (Walbaum)). The 96-hour TL_{50} for fish weighing 274/lb and 22/lb were 1350 and 1500 parts per million, respectively. Long-term (30-53 days) effects of exposure to road oil included reduced growth rates, increased susceptibility to disease, and histological abnormalities of liver and spleen tissue.

2/ The use of trade, firm, or corporation names in this publication is for the information and convenience of the reader. Such use does not constitute an official endorsement or approval by the U.S. Department of Agriculture of any product or service to the exclusion of others that may be suitable.

A study of runoff from rural roads by Freestone (1972) indicated that 99 percent of road oils left the roadway. How much was lost by volatilization, adhesion to vehicles, dust transport, biodegradation, or by rain runoff, however, could not be determined. The effect of heavy metals in the road oils may be more important than the effect of the oil itself. Clearly the location of the road relative to waterways, method of application, occurrence of rain after application, and other factors are important in evaluating the possibility of significant contamination of fish habitat.

Our search of the literature produced nothing on the effects of road-stabilization chemicals on fish or their habitat. A fairly extensive literature is available on the effects of sodium chloride and calcium chloride on water quality, but only in their use as deicing agents (Struzeski 1971). Deicing salts are applied at 10 to 20 times the rate used for road stabilization. The method and season of application are also different for the two purposes; the deicing literature is therefore of little value for inferring water-quality impacts from increased use of this chemical for road stabilization in western forests.

Little is known about the consequences of increased use of road oil and stabilizing chemicals, and we are not even sure there are deleterious effects to anadromous fish or their habitat under current application practices. The likelihood of increased use of road-stabilizing additives in western forests, however, indicates that the effects on water quality deserve future research.

ROADS AND FISH MIGRATION

Salmon (*Oncorhynchus* spp.), steelhead (*Salmo gairdneri* Richardson), and other anadromous fish require unobstructed access to upstream spawning areas. Road culverts can be barriers to migration, usually because of outfall barriers, excessive water velocity in the culvert, insufficient water in the culvert, lack of resting pools below culverts, or a combination of these conditions (fig. 1).

The incorporation of fish passage facilities must be based on an assessment of habitat quality and access. Natural barriers downstream or immediately upstream from the site may preclude the need for fish passage facilities. In one National Forest, standard policy is to provide fish passage when 1/4 mile or more of good-to-excellent fish habitat exists above the pipe. Usually, a knowledgeable fisheries biologist must be consulted to assess the habitat.

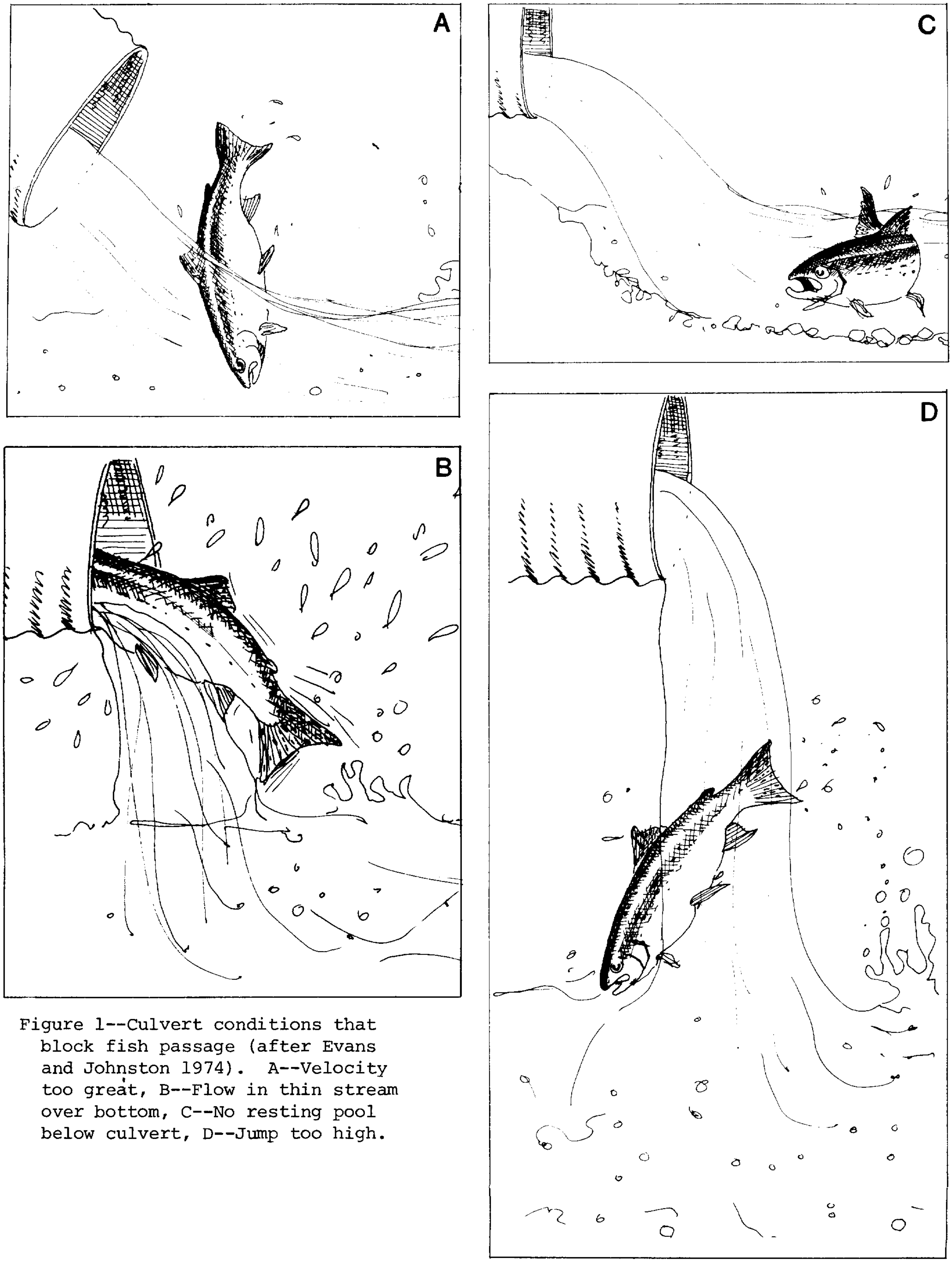


Figure 1--Culvert conditions that block fish passage (after Evans and Johnston 1974). A--Velocity too great, B--Flow in thin stream over bottom, C--No resting pool below culvert, D--Jump too high.

Because bridges usually cause less disturbance to streams than culverts, they are often preferred for assuring fish passage. Where concrete foundations and piers are constructed, however, bridges have created problems, such as scour and lowering of streambeds. Construction of anti-scour weirs, sills, and aprons may be required to prevent changes in the streambed.

Log bridges should not cause serious problems for fish passage if properly constructed and maintained. Where log bridges have caused problems, it is usually because there is insufficent stream channel clearance to accommodate high flows. Bridge and earth abutments then either wash out, causing damage to the stream below, or remain in place, catching debris and forming a debris barrier to migration.

Unfortunately, building bridges on low-volume forest roads often proves to be uneconomical or impractical, and culverts become necessary. Forethought can greatly reduce or eliminate the barrier effects a particular culvert can have; sometimes culverts must be substantially redesigned. Most obstructions, however, can be easily prevented if the potential is recognized during planning.

If culverts are deemed necessary for crossing a stream, the road designer should be aware of several factors that affect the fish and also of the choices of drainage structure and location. The first question is whether or not the stream above the proposed culvert is used by anadromous fish. If not, the culvert design problem is reduced to the typical one of adequate discharge capacity. If the answer is yes, however, then the designer must know which species are in the stream, their life history, and the season or seasons of migration. For fish to overcome obstacles in their migration, the following conditions are necessary:

- A resting pool should be present immediately below the obstacle. This allows the fish to conserve energy and obtain a good start at overcoming the obstacle.
- Individual jumps should not be too high. The lower the jump, under water conditions that occur when migration takes place, the less difficulty the fish will have in passing over the obstacle. In general, a single vertical jump of 1 foot can be negotiated by resident adult trout. If a series of jumps is required, however, a half foot at each is preferable. Salmon and steelhead can normally negotiate single jumps of 2-3 feet without difficulty. In a series, however, individual jumps should not be over a foot high.

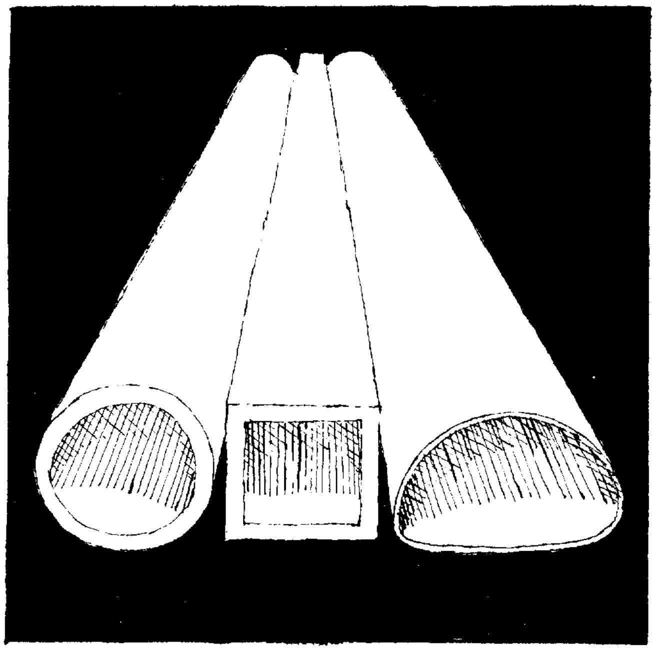
- In general, 6 inches is minimum water depth for resident trout; 1 foot is required for salmon and steelhead. Maximum allowable velocities should be around 4 feet per second (ft/s) for trout and 6 ft/s for salmon and steelhead. These maximum velocities vary with distance and fish species.[3/]

- If swimming distance is over 50-100 feet in a difficult passage, resting pools may be required enroute. This applies to culverts and bridge aprons in particular. The need is determined by examining the average swimming ability of the least capable species using the stream relative to water velocities and distance for passage through the structure.

- Fish are often near exhaustion after passing over or through a difficult obstacle and require a resting area upstream. If one is not available, the fish are often swept downstream over the obstacle and must again exert the energy to surmount it.

- Three hydraulic criteria are important. The most desirable culvert installation is one that causes no sudden increase in water velocity above, below, or through the culvert. Culverts are best located where the stream reach is of similar alignment above and below the culvert for several hundred feet. And, the culvert gradient should be as near zero as possible. When these three conditions are not met, problems in fish passage may occur.

[3/] Unpublished report, "Fisheries handbook of engineering requirements and biological criteria. Useful factors in life history of most common species," by M. C. Bell. Submitted to Fish.-Eng. Res. Program, Corps of Eng., North Pac. Div., Portland, Oreg. 1973.

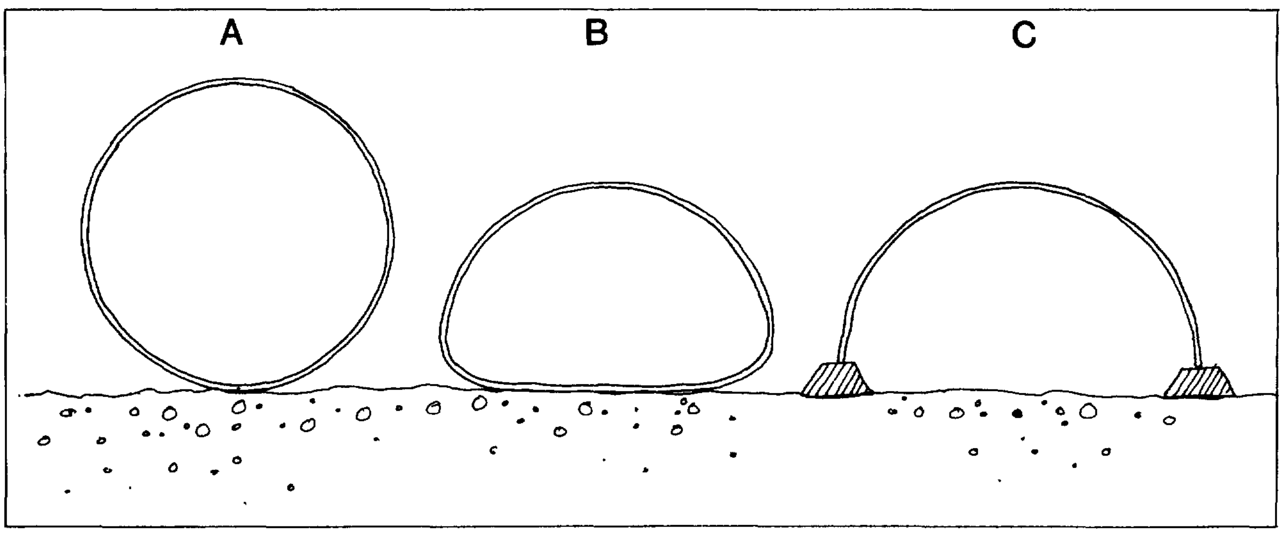


Metal culverts, classified by shape, are standard corrugated round, standard corrugated pipe-arch, and structural plate-arch (fig. 2). The first two may be prefabricated, as is usual for the smaller sizes (up to 60 inches diameter and 72-x-44-inch span by rise), or may be of multiplate design. Type three culverts are always of multiplate design because they are so large and usually fabricated on site.

TYPES OF CULVERTS

Three types of metal culverts are commonly used on western forest roads. (Cylindrical concrete culverts generate extremely high water velocities because they are smooth inside. Internal velocities may be many times those in corrugated metal culverts of the same diameter and gradient. Concrete culverts are thus not suitable for fish passage.)

Figure 2--Typical cross sections of the most commonly used metal culverts on forest roads. A--Corrugated round metal culvert, B--Corrugated pipe-arch metal culvert, C--Structural plate-arch with concrete footings (also available in semicircular cross section).



The structural steel arch set in concrete footings (fig. 2c) is the most desirable culvert type for fish because the natural stream is left undisturbed. Little contracting in width occurs at either end of the culvert, and no signficant changes in velocity. Where concrete footings are not practical, split wide-flanged buried steel footings have been used recently in place of concrete footings. Disadvantages of this installation are mainly increased cost of installation and the high fill needed. Many fisheries biologists believe that the arch type is the only acceptable culvert where fish passage is required (Evans and Johnston 1974).

Pipe-arch culverts (fig. 2b) are less desirable than the structural steel arch, but they can usually be installed to allow fish passage. Fabricated in smaller sizes, they can be used in smaller, lower fills where structural steel arches would not fit. Where pipe arches are used, the gradient must be kept below 1 percent to minimize water velocities. During periods of low flow, the water in culverts with this shape may be spread so thin across the bottom that fish passage is impossible. Baffles may then be needed to increase the flow depth through the pipe-arch (baffle systems are discussed in more detail later).

Although the standard corrugated round culvert (fig. 2a) is the type most commonly used on western forest roads, it is the least desirable for fish passage. Because the width constriction from stream channel to culvert is usually severe, the gradient of the tube must be at or near zero percent to minimize water velocities through the pipe. This type of culvert is also most likely to be installed with its outfall above the tailwater elevation, producing an outfall barrier (fig. 1). Elevated outfalls of this type are to be avoided or mitigated by some means.

Thousands of streams have had culvert crossing with little or no thought to the effects on fish populations. One poorly installed culvert can affect the fish population of an entire small stream drainage. Poor culvert design and location can still be ranked among the most devastating problems for fish habitat in western forests.

Some general considerations for culvert installation are:

- Avoid installation of round culverts where fish passage might be difficult. Install either open-arch culverts or bridges, especially if culverts longer than 100 feet are required or where the stream gradient is steep (>2 percent).

- A single large culvert is better than several small ones, because it is less likely to become plugged and carries water at much lower velocity.

- Diameter of culverts must be adequate to pass maximum flows. Washing out of culverts and their earth fills, besides damaging the road, is also a source of sedimentation.

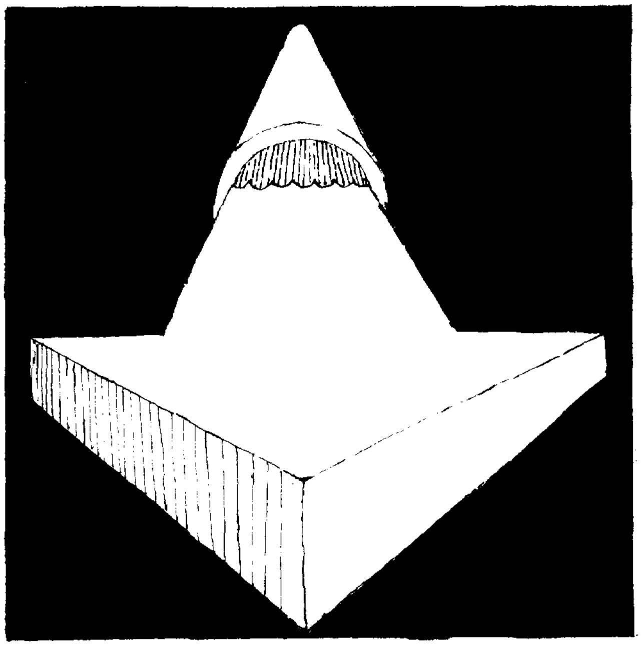
- Place the entire culvert length slightly below normal stream grade to reduce fish passage problems and prevent a lowered streambed. Strive for an installation gradient at or near zero percent; otherwise, avoid round culverts.

- The two most important considerations for fish in culverts are the maximum acceptable water velocity and the minimum acceptable water depth for the species.

- Because streams used by salmonids often fluctuate widely with occasional high peak flows, an acceptable practice on construction projects has been not to require flow conditions suitable for fish passage during the 5 percent of the year when flow peaks are highest (Evans and Johnston 1974). These flood peaks are unusually high and normally short. Fish normally do not migrate during peak flows, so little disruption of fish migration occurs. The practice often results in substantial savings in construction costs for fish passage. The aim, therefore, should be to insure fish passage during 95 percent of a year, or 90 percent of the time on a 6-month basis. Any structure for fish passage must function through a sufficiently wide range of flows to accommodate the period of migration.

- Avoid baffling of culverts if possible or use a larger culvert, a reduced gradient, or both. Baffles normally require additional maintenance and occasionally cause debris accumulations. Baffles are sometimes necessary with high water velocities or in correcting fish passage problems at existing culverts.

- Where culverts are installed in stream sections with steep gradients, improve resting pools, cover, and bank projection along the stream for several hundred feet above and below the culvert. Maintaining a stable stream bottom through the culvert-influenced area is essential.



WATER VELOCITY IN CULVERTS

Swimming ability of salmonids increases with size of the fish. Hence what species uses the culvert has a bearing on the allowable maximum velocity. Specific velocity limits for any anadromous species cannot now be cited with authority, but some general guidelines are available for adult fish. Metzker (1970) reported that for trout up to 15 inches, eight ft/s should be considered maximum for short distances. Adult salmon can travel through and sustain velocities of 12 ft/s for short distances. Metzker also pointed out that the culvert velocity a fish can overcome varies not only with the fish's size, but also with the distance between resting pools below and above the culvert. The Oregon State Game Commission (1971) recommended maximum water velocities of 8 ft/s for adult salmon and steelhead and 4 ft/s for trout. The recommended velocities in Oregon, however, are for round culverts up to 100 feet (30.5 m) in length. Water velocities in longer culverts should not exceed 6 ft/s for adult salmon and steelhead and 3 ft/s for trout.

To aid road designers in estimating the water velocities through culverts, both the Oregon State Game Commission (1971) and the USDA Forest Service (Evans and Johnston 1974) have produced series of culvert velocity curves based on Manning's equation (Chow 1959). The Oregon State Game Commission curves are for round metal culverts only, ranging in diameter from 24 to 84 inches. Gradients range from 0.25 to 5.0 percent. Figure 3 is an example of the Oregon velocity curves for a 72-inch culvert. Because fish passage through culverts normally occurs between a minimum depth of 3 inches and a maximum depth of two-thirds the pipe diameter, the Oregon curves cover only these depths.

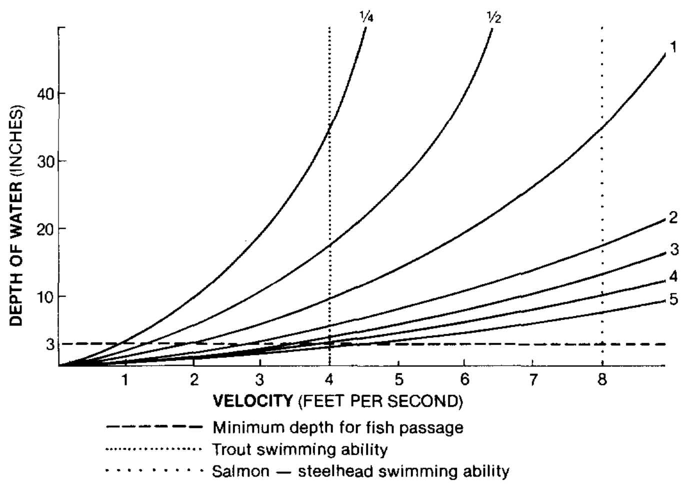


Figure 3--Velocity curves for a 72-inch diameter round culvert (after Oregon State Game Commission 1971).

The USDA Forest Service velocity curves are more detailed than the ones for Oregon; curves have been provided not only for round culverts (36- to 120-inch), but also for concrete box culverts (26- to 120-inch) and for 3-x-1, corrugated metal pipe-arches (7 ft x 5 ft 1 inch to 16 ft 7 inch x 10 ft 1 inch, span by rise). Also the USDA Forest Service curves yield both velocity and depth of flow for any given discharge, culvert gradient, and diameter. Figure 4 illustrates the format of the USDA Forest Service curves for a metal pipe-arch.

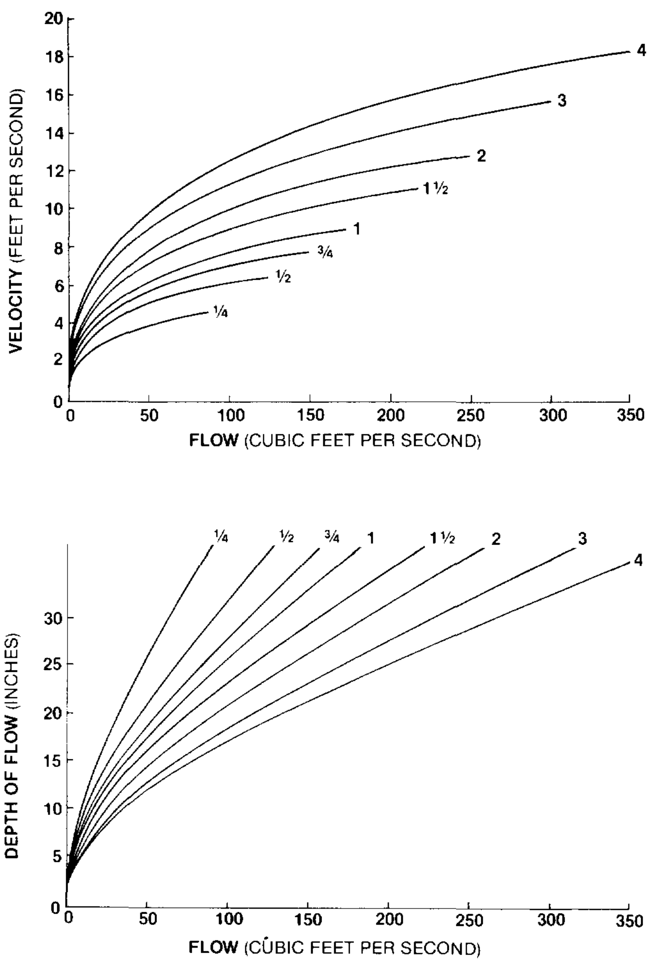


Figure 4--Velocity and depth-of-flow curves for a 7-foot by 5-foot 1-inch pipe-arch (after Evans and Johnston 1974).

Salmonid spawning streams in the West are often mountain streams with steep gradients. Even culverts placed on the same grade as the original streambed may exhibit water velocities greater than migrating fish can overcome; to control water velocities in culverts then, installing baffles may be necessary.

Constructing a fish passage facility through a culvert essentially opposes the reason for the culvert, which is to discharge water downstream at the highest possible rate with the smallest culvert possible. On the other hand, the structure for fish passage attempts to produce pockets of low velocity in the culvert where fish can rest momentarily. To provide these low velocities, energy dissipators of some form are required--normally, baffles or small water barriers.

Baffle designs are probably as numerous as the people installing them. Little information is currently available on the hydraulic principles of various types of baffles. Additional applied research in this field should be encouraged. The best information on baffle design is in a Washington Department of Fisheries report (McKinley and Webb 1956); the principles are sufficiently sound to be used as present guidelines, pending results of further research.

Certain general principles have been developed through long experience with baffles in culverts:

- Avoid using baffles whenever possible. Solve your fish-passage problems preferably through considerations of bridges, arch culverts or round culverts of sufficient size, and installations of low water velocity at or below streambed level.

- If higher velocities, extensive distance, or both are unavoidable in a round or box culvert installation, baffles will be necessary. Baffles and resultant quieter waters allow a fish to swim in short spurts straight through high velocities and enter a rest area parallel to the higher velocity flow.

- A large single culvert provides better fish passage than several smaller ones. Where multiple units are required, only one must be baffled to pass fish. Select the culvert for baffling based on the route most likely to attract fish. At such installations, provisions should be made for diverting low flows through the baffled culvert only.

- The baffle design illustrated in figure 5 is recommended for general use by the California Region of the U.S. Forest Service (Evans and Johnston 1974). For the design in figure 5 to be readily adaptable to installations of various sizes, the dimensions have been given as percentages of total width of the baffled section. These

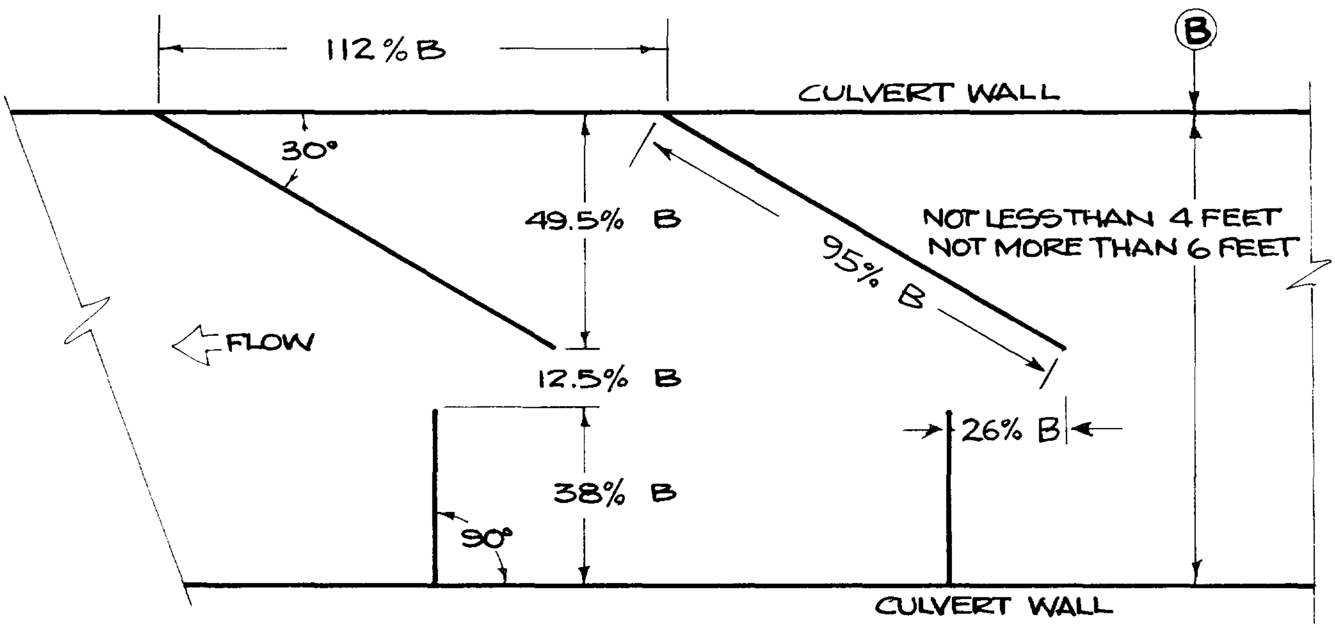


Figure 5--Baffle-pattern arrangement for metal culverts (after Evans and Johnston 1974). B equals clear width of box culvert, intercept width is 1 foot above invert (round or arch culverts), and all baffles are 1 foot high.

dimensions and angles of baffles have been determined through research and should be adhered to. Baffles should be a minimum of 1 foot high and 5-6 inches wide.

- Calculate the relative efficiency of the culvert with and without baffles, because the passage of water through the culvert will be impaired by the baffle structures. Because a large safety factor is required, most culverts are overdesigned for the discharge conditions, and the actual impairment of the culvert's ability to discharge is relatively small. The ultimate culvert size required is, of course, a decision for the engineer.

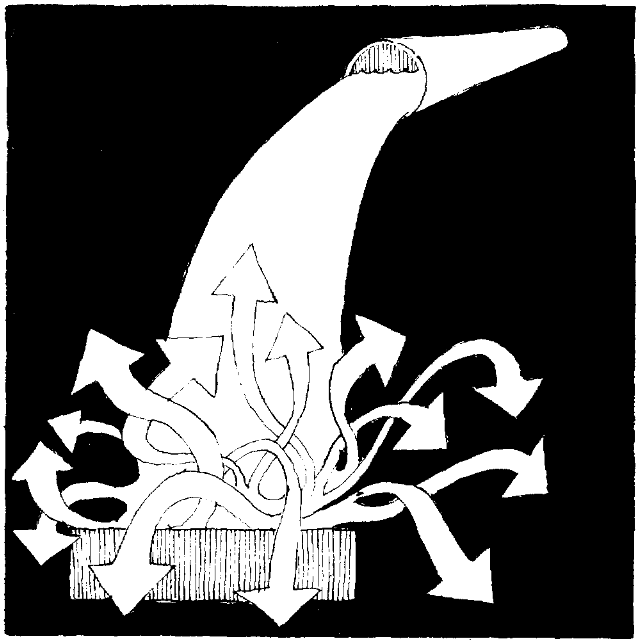
- Construction materials for baffles may be wood, metal, or concrete, depending upon the local situation. Wood is sometimes preferable because it offers greater resilience when hit by moving objects and also can be replaced more easily. Concrete baffles may be pre-cast and drilled or grouted into place. Metal baffles are normally bolted onto the culvert floor, using metal plates for added strength.

- "Most baffles are designed to operate best when water flow is just overtopping them and their effectiveness is inversely proportional to the depth of water over them." (Gebhards and Fisher 1972).

- Placing baffles properly in a new culvert before its installation is far less expensive than trying to alter an installed culvert.

- For round metal culverts, a minimum culvert diameter of 5 feet is required to provide a 4-foot-wide space for baffle installation (fig. 5).

- Baffles may have value other than controlling velocity; for example, they increase water depth in the pipe to provide fish passage during low flow periods. Another example would be to convert a culvert with a steep gradient into a series of pools--in effect, creating a modified fish-ladder.



CULVERT OUTFALL BARRIERS

Culverts can be insurmountable barriers to migrating fish when the outlet of the culvert is so far above the tailwater that fish cannot enter the pipe; this condition is termed an outfall barrier (fig. 1).

Where new culverts are to be installed on streams with migrating fish, every attempt should be made to avoid constructing an outfall barrier. Putting a new culvert outlet below the tailwater elevation is sometimes not possible, or--more commonly--an existing culvert forms an outfall barrier.

One way to correct a culvert outfall barrier is to provide for one or a series of low-head dams below the culvert outfall (fig. 6). These dams may be nothing more than hand-placed rock "reefs" or wire-basket gabions filled with local rock, or concrete sills. These downstream dams raise the tailwater elevation and flood the culvert. Access by fish is not only enhanced, but water velocity in the culvert is decreased. The downstream dams should not create outfall barriers themselves and should therefore be limited to about 1 foot in height or, for dams of greater heights, have a pass-through notch in the center. Because the backflooding decreases velocity and hence discharge, a culvert of larger diameter may be necessary to handle peak flows. Also, armouring the downstream side of the low-head dams may be necessary to prevent scouring from the cataracts formed.

In some streams, the range of flows is so wide that it is impossible not to have the culvert outlet above tailwater at some time. Also, where severe fluctations in flow require large culverts, problems are sometimes encountered in providing fish passage during low flows because of the shallow flow over the broad culvert bottom. Then, stacked- or multiple-culvert installations can be used to provide fish passage (fig. 7). Placing the stacked culverts at different elevations assures adequate discharge capacity as well as fish passage over a wider range of flows. The lower, smaller culvert would concentrate low flows and assure fish passage then. Note our previous statements on the inhibitory effects full culverts have on fish passage.

Figure 6--Gabion or concrete sills can raise tailwater elevation to facilitate fish entry into the culvert; this weir construction was used to improve fish passage at the mouth of Gold Creek (after Evans and Johnston 1974).

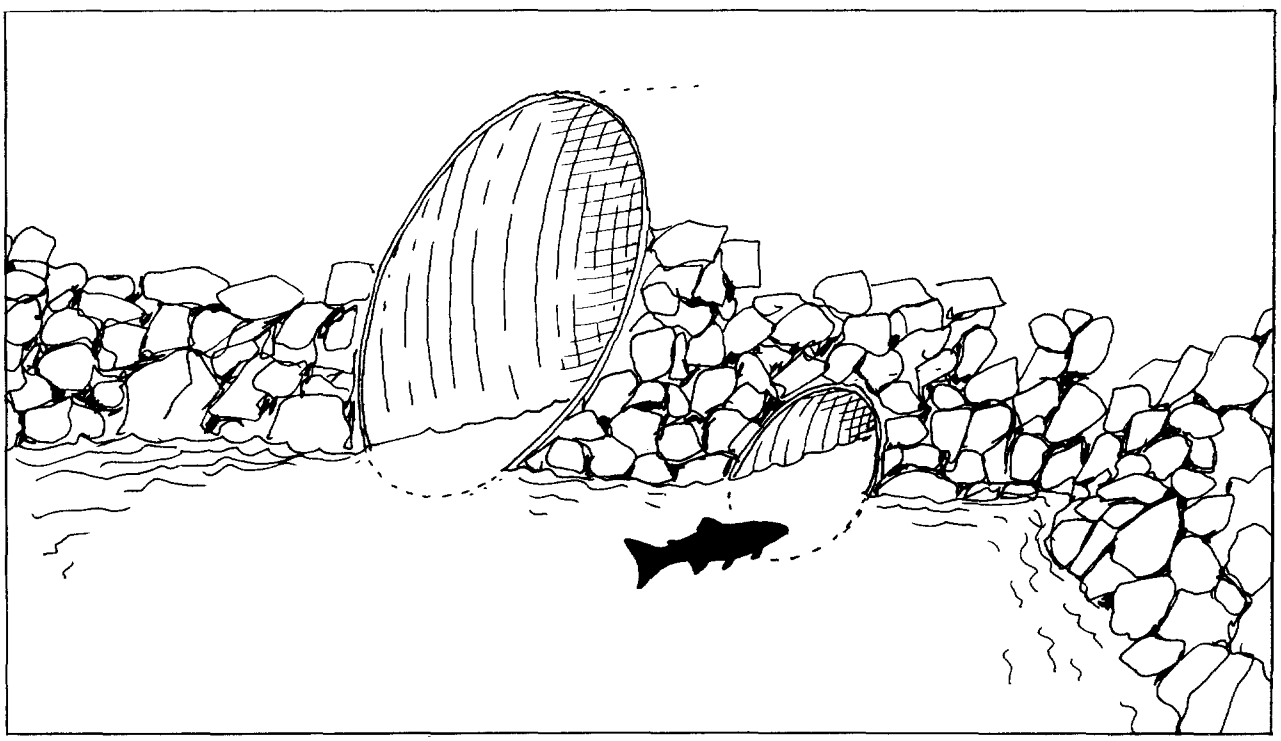
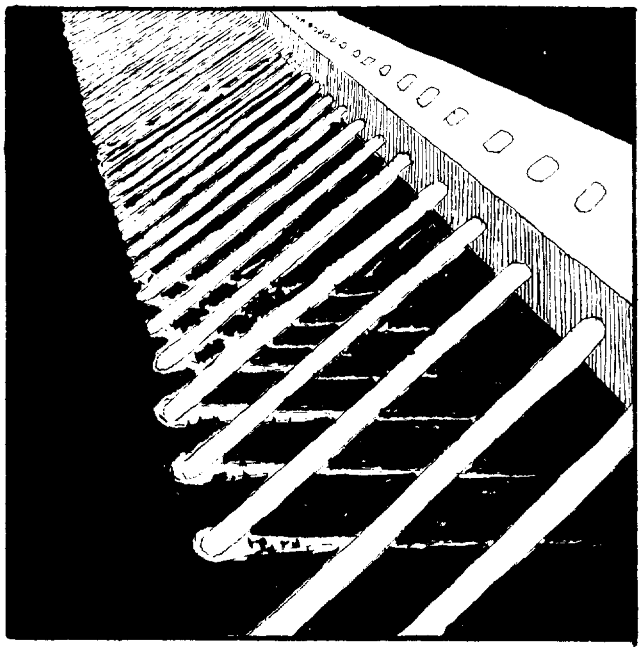


Figure 7--Fish passage may be provided in streams that have wide ranges of flows by providing multiple culverts.



STRUCTURES FOR DEBRIS CONTROL

The use of debris-control structures--such as trash or debris racks--is growing in western forests. A partial reason is the increased cost of replacing culverts and washed-out roadways; trash racks are often mandated by forest practice regulations.

Unfortunately, trash racks are detrimental to fish passage. The same freshets that often bring debris downstream are those in which many fish can move up to spawning areas. Although the protected culvert may not be a velocity or outfall barrier, a debris-laden trash rack is almost always impassable to fish. Debris-catching structures on streams used by migrating fish should be avoided.

To compensate for the loss of culvert protection from a debris-catching structure, the culvert should be large enough to let the debris pass through it. Passing debris through the culvert is as valid an alternative as intercepting it above the inlet, and this alternative should not be overlooked. Of course, increasing the culvert diameter adds to its cost, and sometimes increasing the diameter may not be practical. On the other hand, when debris can be passed through the structure without clogging, maintenance costs will be lower than when debris is intercepted and must then be removed.

SUMMARY

Forest road systems, along with other forest-management activities, can adversely affect a stream's ability to provide spawning and rearing habitat for anadromous fish. Guidelines are available for road construction and maintenance with minimal impact on anadromous fish habitat. Properly designed and placed culverts and debris-control structures can also help to minimize the impacts on fish habitat of forest road systems.

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