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of Transportation

Federal Highway
Administration

Fish Passage Through Culverts

prepared by

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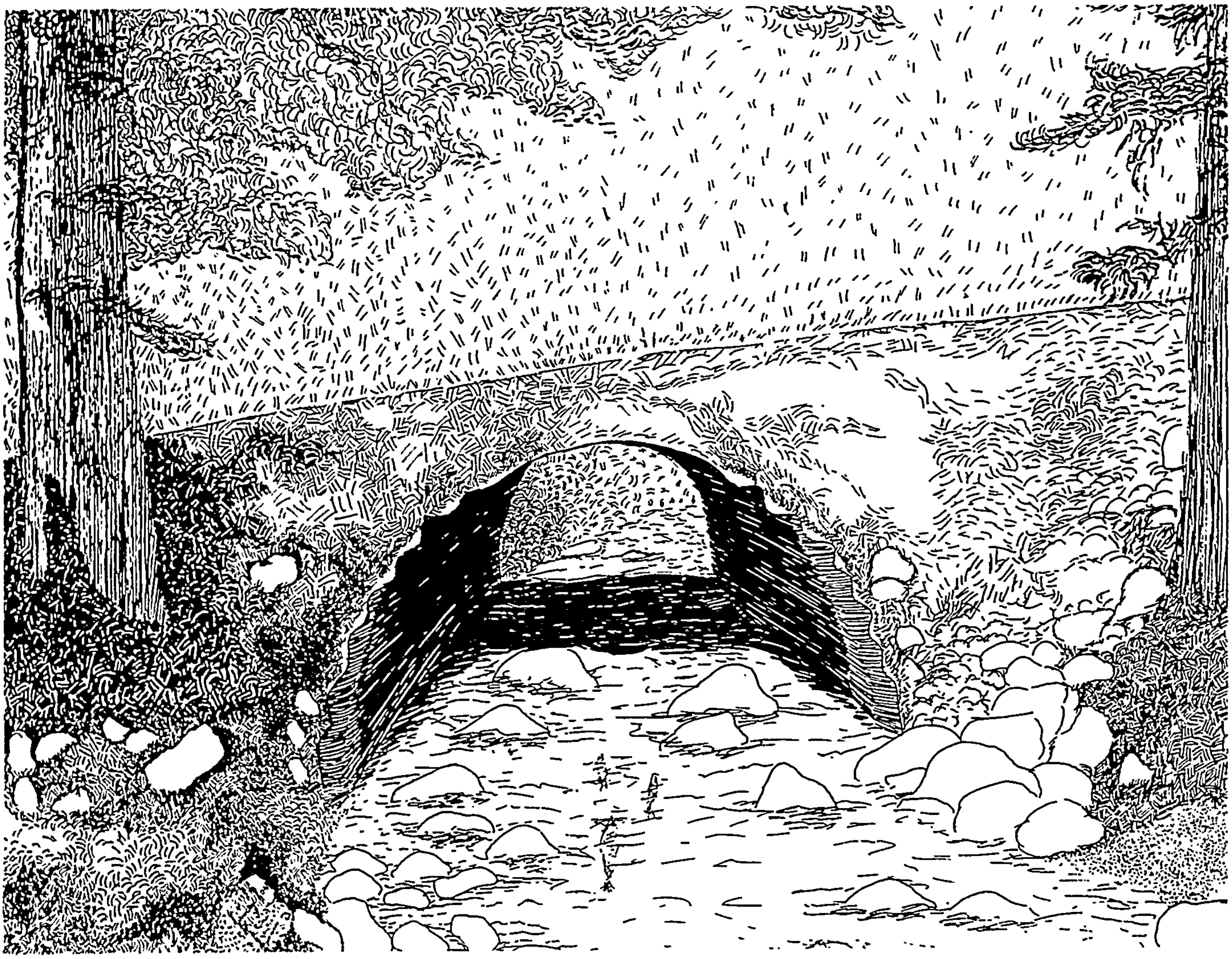
Agriculture

Forest Service



Report No. ~~FHWA~~-FL-90-006

November 1990

FOREWORD

This study was funded as a part of the Coordinated Federal Lands Highways Technology Implementation Program. It is intended to serve the immediate needs of those who design and construct Federal Lands Highways, but is also made available to all other interested parties.

This report reviews, summarizes, and updates current information on fish passage through culverts. The scope of the report is limited to highway drainage structures, not including bridges. This distinction is made in an effort to concentrate on those road drainage structures that are most commonly used in fish passage situations. This publication should be of value to the fish biologists, engineers, and hydrologists who design the projects and make current decisions on fish passage at drainage structures.

Thomas O. Edick
Federal Lands Highway Program Administrator
Federal Highway Administration

NOTICE

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16. Abstract

As the number and range of many fish species have declined and the recreation demand for fish has increased, the importance of protecting the remaining populations has also multiplied. At new culvert installations, fish passage considerations and needs have increased in complexity. A high percentage of existing drainage structures are approaching or have passed their life expectancy. The task of replacing, modifying, and/or retrofitting the surviving structures will dwarf past programs for providing fish passage through culverts.

This report is intended to review, summarize, and update current information on fish passage through culverts. The scope of the report is limited to highway drainage structures, not including bridges. This distinction was made in an effort to concentrate on those road drainage structures that are most commonly used in fish passage situations. The publication is primarily issued for the fish biologists, engineers, and hydrologists who will be designing the projects and making current decisions on fish passage at drainage structures.

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Anadromous; cruising speed; sustained speed; burst speed; adfluvial; culverts; hydraulic jump; riprap; perching; aufeis.	No restrictions. This document is available through the National Technical Information Service, Springfield, VA 22161

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Unclassified	Unclassified	67	

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METRIC (SI*) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
	LENGTH			
in	inches	2.54	millimetres	mm
ft	feet	0.3048	metres	m
yd	yards	0.914	metres	m
mi	miles	1.61	kilometres	km
	AREA			
in^2	square inches	645.2	millimetres squared	mm^2
ft^2	square feet	0.0929	metres squared	m^2
yd^2	square yards	0.836	metres squared	m^2
mi^2	square miles	2.59	kilometres squared	km^2
ac	acres	0.395	hectares	ha
	MASS (weight)			
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg
	VOLUME			
fl oz	fluid ounces	29.57	millilitres	mL
gal	gallons	3.785	litres	L
ft^3	cubic feet	0.0328	metres cubed	m^3
yd^3	cubic yards	0.0765	metres cubed	m^3

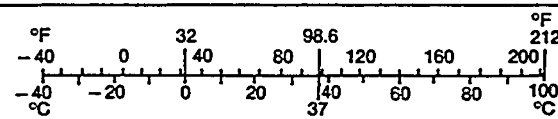
NOTE: Volumes greater than 1000 L shall be shown in m^3.

	TEMPERATURE (exact)			
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
	LENGTH			
mm	millimetres	0.039	inches	in
m	metres	3.28	feet	ft
m	metres	1.09	yards	yd
km	kilometres	0.621	miles	mi
	AREA			
mm^2	millimetres squared	0.0016	square inches	in^2
m^2	metres squared	10.764	square feet	ft^2
km^2	kilometres squared	0.39	square miles	mi^2
ha	hectores (10 000 m^2)	2.53	acres	ac
	MASS (weight)			
g	grams	0.0353	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams (1 000 kg)	1.103	short tons	T
	VOLUME			
mL	millilitres	0.034	fluid ounces	fl oz
L	litres	0.264	gallons	gal
m^3	metres cubed	35.315	cubic feet	ft^3
m^3	metres cubed	1.308	cubic yards	yd^3

	TEMPERATURE (exact)			
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



These factors conform to the requirement of FHWA Order 5190.1A.

* SI is the symbol for the International System of Measurements

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INTRODUCTION

Unhindered fish passage at stream crossings is an important consideration in the engineering of the extensive road network of the United States of America. The identification and planning for installation and replacement of road drainage structures to facilitate fish passage is an area of high national need. This responsibility will require unprecedented cooperation among biologists, engineers, and hydrologists.

The purpose of this publication is to provide a set of broad guidelines for the engineer and fish biologist to design, construct, and maintain an acceptable structure with fish passage capabilities. Although this report is written for fish passage through culverts, many of the principles can be adapted to the design of any drainage structure.

This report includes a synthesis of many references on fish passage through road drainage structures. This synthesis does not spell out the detailed technical methods used for analysis and design. It will not replace the need for project level consultation between the fish biologist and the engineer, nor will it replace the need for professional evaluation and design on a site specific basis. However, it should aid such professionals in their effort to obtain an acceptable structure.

Many stream crossings are culvert installations. These installations consist of a variety of road drainage structures, including corrugated metal pipes, box culverts, and natural bottom arches. There has been an increasing recognition that these crossings should not only be engineered for road alignment and grade but also to allow unhindered fish passage.

For many fish, migration is essential to the survival of the species. For example, fish that travel from the sea up river to spawn (anadromous) begin a maturation process geared to culminate when they reach their spawning habitat. Improperly selected and placed culverts can be barriers to such migration, thereby adversely affecting fish production and populations. These culverts are commonly located near the ends of the migration runs creating the ultimate irony of denying fish access to their spawning areas after swimming hundreds, if not thousands of miles. However, anadromous fish are not the only fish that migrate.

Many resident fish species such as trout, pike, and grayling migrate upstream and downstream during their life cycle seeking a variety of aquatic habitats which might include spawning, rearing, or hiding habitat. Although these migrations may only be a few miles, they can be as important for the long term survival of the species and maintenance of fish production.

Avoiding or minimizing obstruction to fish passage is an important step that the engineer must make. Often it requires consultation with a fish biologist to insure that all fish passage considerations are recognized. Today's engineer and fish biologist must not only consider culvert design for efficient water passage, but also heed such factors as fish species, water velocity, water depth, culvert length and slope, and specific streambed conditions. Poorly planned, designed, or constructed culverts may become serious problems to the production of fish runs and in some cases the survival of fish species.

There are often differing philosophies on what a proper structure should be and what are acceptable impacts. This publication should provide sufficient information for agency managers and technical experts in the preparation of policies that have been confusing in the past.

Fish Passage Through Road Drainage Structures

Road drainage structures represent a variety of potential obstacles to fish passage. These include natural and man-caused obstacles created or aggravated by drainage structures. The most common problems are typically associated with excessive water velocities or vertical barriers to fish passage. Figure 1. Other problems can include:

1. The velocity of water over a given length of structure in relation to fish capabilities.
2. Depth of water in the structure at high, moderate, or low flows. Figure 2.
3. Icing and debris problems.
4. Design flows in relation to annual hydrographic and seasonal time of fish passage.
5. The size and species of fish passing through the structure.

The resolution of these diverse factors can easily tax the combined effort of biologists, engineers, and hydrologists working on proposed projects. If only one discipline is working on a proposed road drainage structure, fish passage could be compromised, structures may fail, and increased structure costs result. All three disciplines must be considered and balanced. In keeping with this premise the body of this publication is divided into biological, engineering, and hydraulic sections. A glossary containing a list of specific words relating to these disciplines involved in this report is included as Appendix B. In addition, an annotated bibliography and a number of case examples are also provided in Appendix C for further in depth study of a particular area of interest.

Figure 1. High water velocities and vertical barriers obstruct fish passage

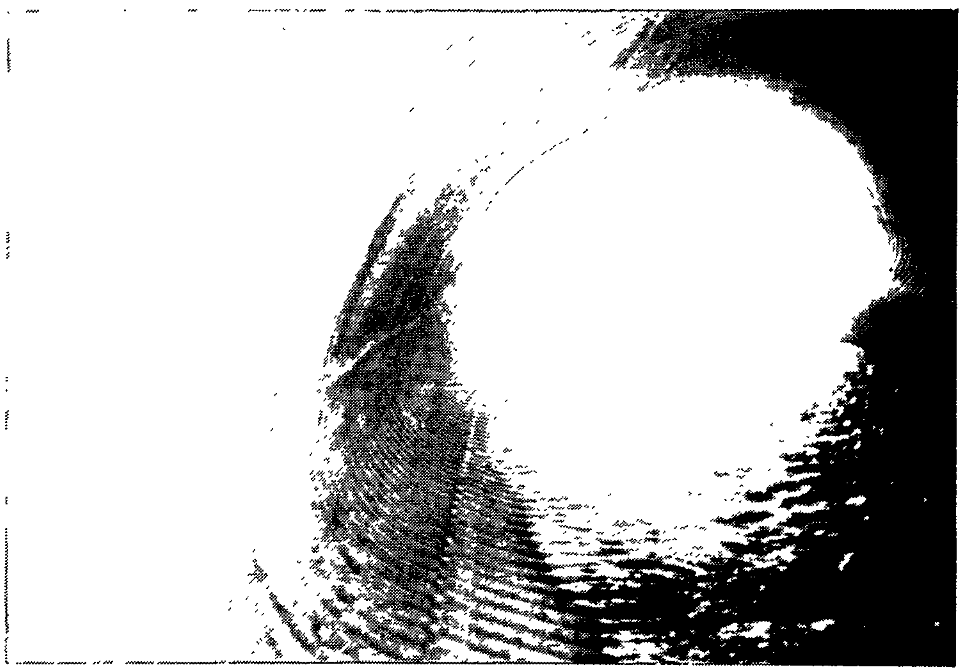


Figure 2. Example of inadequate water depth

BIOLOGICAL CONSIDERATIONS

ADULT FISH

The vast majority of past research and reports regarding fish passage at road drainage structures has been oriented to adult anadromous fish. The traditional approach to assessing fish capabilities has been to divide swimming speeds of adult fish into various activity categories such as cruising, sustained, and burst speed, Bell, 1973, Dane, 1978. The cruising speed is usually defined as the speed at which a fish can swim for an extended period of time without tiring. Sustained speed is the speed a fish can maintain for a prolonged period, (typically several minutes or hours), but results in fatigue. Burst speed is defined as the speed at which a fish can swim for just a very short time frame (one to several seconds).

The sustained speed has been often identified as the appropriate criterion for determining whether water velocity would block migrating fish. Not surprisingly, there is substantial overlap among these categories of swimming speed depending on the environmental conditions and testing methods utilized in measuring the performance of various species of fish.

Figure 3 identifies some swimming capabilities of common fish. Each species has different swimming capabilities. Figure 4 shows the variation in swimming speeds for various adult fish. In addition, different sizes of the same fish species commonly have different capabilities. Figures 5 & 6 display some of the swimming capabilities of common species of fish of different sizes.

Other Limiting Factors

Other factors can also affect the capability of adult fish attempting to traverse culverts and highway structures. Culverts that require fish to leap or jump over falls or other obstructions present a unique barrier to fish. A wide variety of hydrologic, physical, and behavioral considerations dictate whether a given fish will overcome a barrier. Stuart, 1962, provides a comprehensive discussion of these factors for salmon and trout.

The sex and physical condition of the fish attempting passage, including past injuries, diseases and sexual maturity, can affect the capability of adult fish passage. Specific site conditions such as water temperature, levels of water pollution, and the darkness of a culvert are limiting factors. Generally, these factors are not major considerations in determining fish passage conditions. Dane, 1978, gives an excellent overview of a number of these considerations.

The length of the structure is commonly used as a significant criterion in determining the fish passage capability of an installation. However, length is not a single criterion by itself. Velocity over a given length in relation to fish capabilities is a more appropriate consideration.

Culvert installation guidelines commonly assume that all fish of a particular species are uniform performers. Actually, fish capabilities vary within the same species. Equally important is the location of the structure in relation to the migratory corridor. Capabilities are generally thought to decline as spawning fish migrate upstream.

JUVENILE FISH

Although the majority of research on fish passage has historically been geared to adult anadromous fish passage (especially salmon and steelhead trout), juvenile anadromous species also exhibit a variety of upstream migrations. Skeesick, 1970, was one of the first authors to document a consistent upstream migration of juvenile coho salmon in the fall of each year. The 10-year study on Spring Creek - Wilson River, Oregon, did not investigate the reasons for the upstream migration of juveniles, although it speculated that "the juvenile coho moved into the small streams to escape the high flow, turbid-water environment in the main rivers in the spring."

Other authors; Bustard and Narver, 1975, Cederholm and Scarlett, 1982, Scarlett and Cederholm, 1984, have documented fall and winter migrations of juvenile anadromous fish especially into tributary streams and riverine ponds. Particularly susceptible to blockages are juvenile anadromous fish, such as steelhead trout, sockeye, chinook, and coho salmon, that remain in fresh water for substantial periods of time before migrating downstream. Of these species, juvenile sockeye salmon are particularly vulnerable in some of the stream systems that require an upstream migration to reach suitable rearing habitat, Dane, 1978.

Some studies, however, have shown a lack of upstream fish movements, making blanket statements regarding juvenile patterns of movement difficult. It is clear that upstream migrations of juvenile anadromous fish and movement into tributaries do occur. These migrations are very much at risk by drainage structures, especially those only designed for adult fish migration. In a stream system managed for wild fish production, blocking juve-

Specie	Cruising Speed	Sustained Speed	Burst Speed
Brown Trout	0 - 2.3	2.3 - 6.1	6.1 - 12.8
Carp	0 - 1.3	1.3 - 3.9	3.9 - 8.4
Chinook	0 - 8.9	8.9 - 10.8	10.8 - 21.9
Coho	0 - 8.9	8.9 - 10.5	10.5 - 21.7
Grayling	0 - 2.6	2.6 - 6.9	6.9 - 14.1
Lamprey	0 - 1.0	1.0 - 3.0	3.0 - 6.2
Shad	0 - 2.3	2.3 - 7.2	7.2 - 15.1
Sockeye	0 - 3.3	3.3 - 10.2	10.2 - 20.7
Steelhead	0 - 4.6	4.6 - 13.8	13.8 - 26.6
Suckers	0 - 1.3	1.3 - 5.2	5.2 - 10.2
Trout	0 - 2.0	2.0 - 6.6	6.6 - 13.5
Whitefish	0 - 1.3	1.3 - 4.27	4.3 - 8.9

Figure 3. Relative swimming speeds ft/sec of average size adult fish as reported by Bell (1973).

Species	Max FT/Sec.	Experiments
Atlantic Salmon	8.53	Kreitmann (1928)
Atlantic Salmon	6.56	Schmassmann (1928)
Atlantic Salmon	26.58	*HRI of Leningrad
Atlantic Salmon	12.47	As above but not in large numbers
Atlantic Salmon	7.87 - 9.18	HRI of Leningrad
Brown Trout	12.79	Kreitmann (1933)
Brown Trout	5.58	Schmassmann (1928)
Brown Trout	7.22	HRI of Leningrad
Carp	1.21	Kreitmann (1933)
Chinook Salmon	14.43	Paulik and DeLacy (1957)
Chinook Salmon	21.98	Collins and Elling (1960)
Chinook Salmon	21.98	Weaver (1963)
Coho Salmon	12.14	HRI of Leningrad
Coho Salmon	17.38	Same
Grayling	7.22	Kreitmann (1933)
Lamprey	6.23	Same
Pike	1.41	Kreitmann (1933)
Sockeye Salmon	10.17	Paulik and DeLacy (1957)
Steelhead Trout	26.57	Same
Steelhead Trout	26.57	Collins and Elling (1960)
Steelhead Trout	12.14	Paulik and DeLacy (1957)
Tench	0.46	Kreitmann (1933)
Trout	11.48	Denil (1938)
Whitefish	4.59	HRI of Leningrad

* Hydrotechnical Research Ins. of Leningrad

Figure 4. Maximum swimming speed of fish. Watts, 1974.

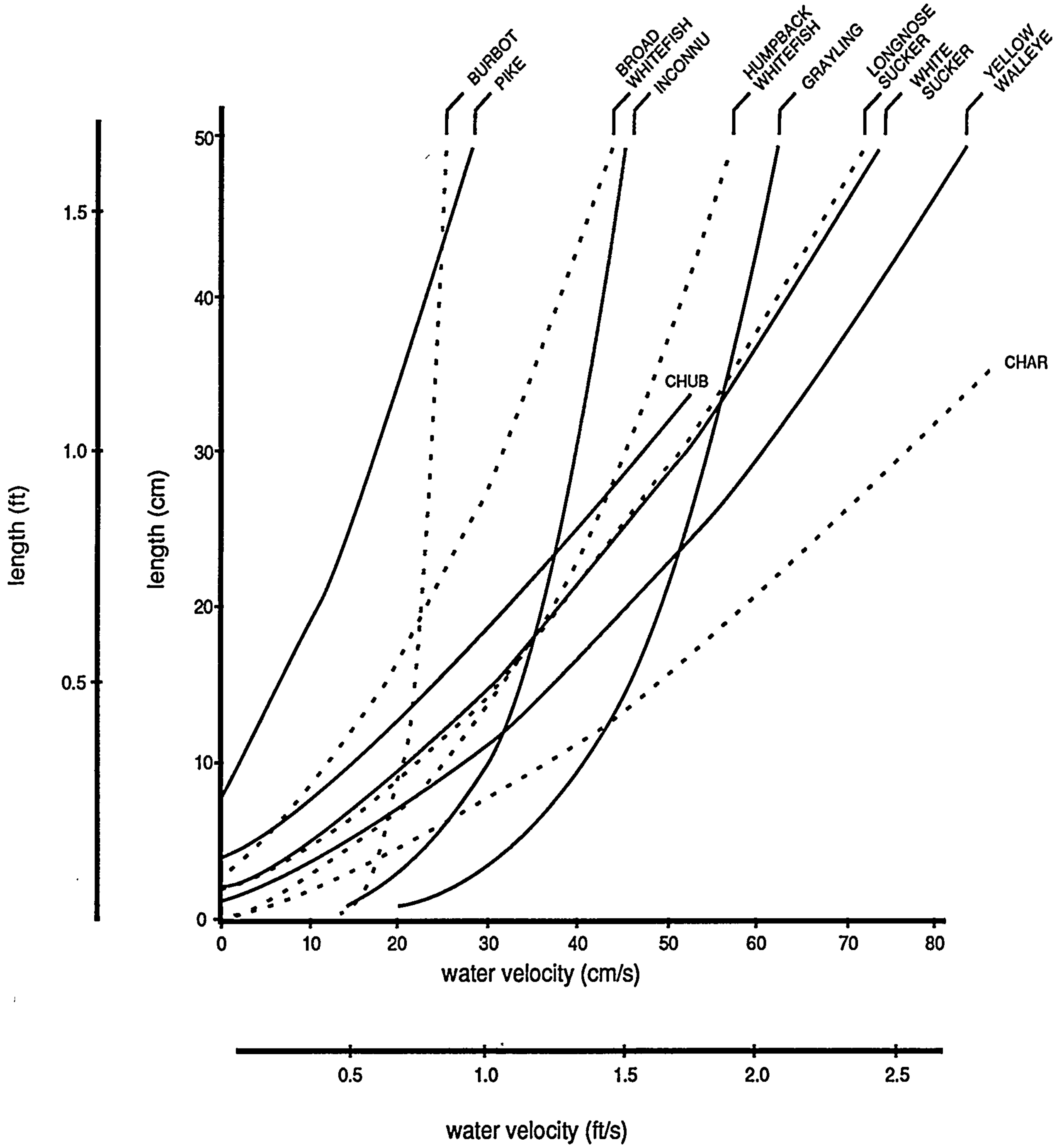


Figure 5. Relationship between fork length and ability to move 100m in 10 min in water velocities up to 80 cm/s for fish from the MacKenzie River. Jones, Kiceniuk, and Bamford,1974.

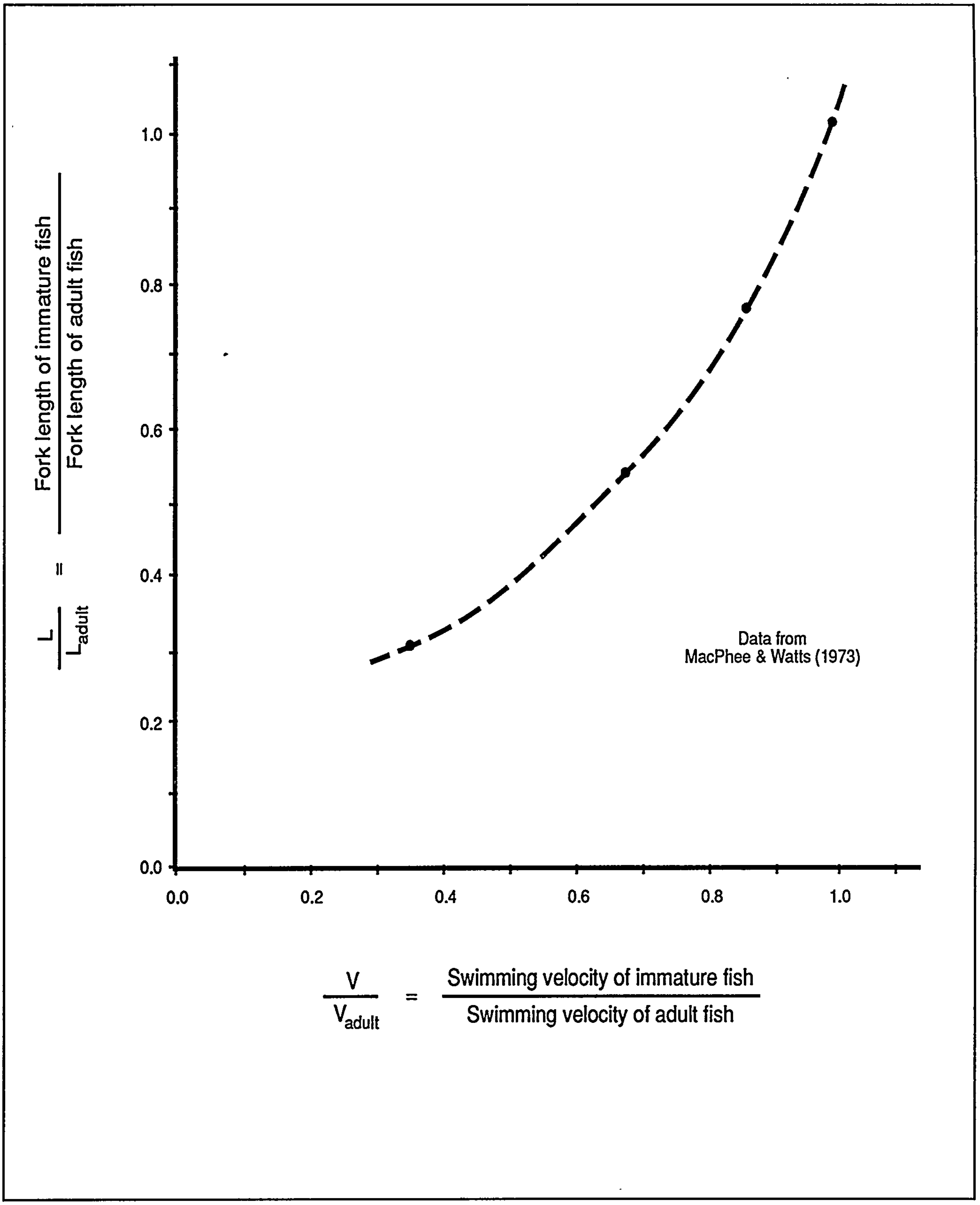


Figure 6. Relative swimming velocity versus relative length of fish based on grayling data. McPhee and Watts, 1976.

nile fish movements into tributary streams can lower production by arbitrarily limiting the capability to rear fish and increasing juvenile mortality, Leider, Chilcote, and Loch, 1986.

Upstream migrations of juvenile resident fish have also been documented in several studies. Typically, these have been fall migrations of juveniles from mainstem streams into tributaries. In these cases, the presence of culverts or other drainage structures on smaller tributary streams can make upstream juvenile movements difficult, Bernard and Israelsen, 1982.

The degree to which juvenile fish passage is needed at drainage structures is not well established. Some authors believe that it is not a high priority in culvert design, while others can cite specific passage situations where juvenile fish passage is essential.

With this uncertainty, it is perhaps not surprising that regulations requiring culverts to be capable of juvenile fish passage have been slow in developing. One exception to this has been in Washington State, which has site specific requirements (as determined by the Regional habitat manager) to provide upstream salmonid fingerling passage to overwintering habitat such as tributaries draining ponded off channel areas, Washington Dept. of Fish and Game, 1989. These types of habitat have been found to be extremely important in the survival and production of coho salmon, Peterson and Reid, 1984.

RESIDENT FISH SPECIES

Resident fish species also exhibit a variety of instream movements. These include adfluvial spawning migrations of cutthroat trout, and other salmonid fish species, as well as instream movements of resident fish from unknown causes. Like anadromous fish, upstream movements of resident fish are commonly blocked by culverts and drainage structures. Water velocities that can accommodate adult salmon and steelhead passage commonly obstruct resident fish species. Culvert outfalls easily jumped by older resident fish can block younger fish.

In streams containing only resident populations of fish, the decision is regularly made (consciously or inadvertently) to obstruct upstream fish passage. Since resident fish species can reproduce above natural (and presumably man-caused) barriers, fish production is commonly assumed to be relatively unchanged in year-round stream systems. Genetic segregation, however, could characterize the upstream fish populations. If a barrier were placed below an occasionally dry channel, a complete loss of resident fish production above the barrier would ultimately follow.

In some streams, fish passage has been purposely caused by installing culverts and highway structures to obstruct certain fish movement. This practice has occurred in a number of locations, particularly in the eastern United States to prevent the movement of undesirable fish species (personal communication with Roger Radtke, USDA - Forest Service). This type of design can unintentionally obstruct the passage of fish less capable of those considered during structure design.

IMPACTS OF DELAYED FISH MIGRATION

A predominant philosophy that has historically governed fish passage considerations has been that fish migrations should not be delayed at road drainage structures. This belief, while being theoretically attractive, has conflicted with the reality that most drainage structures impede fish passage to some degree. In addition, many fish species exhibit limitations on their own upstream migrations during periods of heavy runoff or during adverse fish passage conditions. In some instances, the attempt to avoid any interference with fish passage has led to the placement of large drainage structures that are extremely expensive and probably impede the passage of fish at lower streamflows.

Although many culvert installations have caused delays in fish migrations, there has been remarkably little research on the effects of various delays. The majority of research has been directed at assessing the impacts of delayed migration on Arctic grayling and a few other species, Dryden and Stein, 1975, Tillsworth and Travis, 1987, and Behlke, Kane et al., 1989. One definitive study on the effects of spawning delays on Arctic grayling is Carlson, 1987. That study demonstrated that some delay did not appear to adversely affect spawning effort or success. As delays lengthened, an increasingly adverse impact to spawning occurred.

Some researchers have proposed that no more than a 3 to 6 day delay should occur at culvert crossings. The lack of site specific streamflow information at many streams, however, makes precise determination of flow regimes difficult. Hence it is impossible to specifically incorporate a precise window of acceptable delay. Because of varying streamflows and streamflow calculations, a culvert designed to potentially delay fish for 3 days could commonly delay fish for substantially shorter or longer periods of time.

TIMING OF FISH MIGRATIONS

Figure 7 displays the periods of spawning of some fish species in Montana, Idaho, and Eastern Washington. This figure is meant only as a guide for the engineers to show that various species of fish spawn at different times. It is imperative that the engineer consult with the fish biologist to determine the species of fish and the migration period to properly design a culvert to allow fish passage. These periods will vary in different parts of the country for various species of fish.

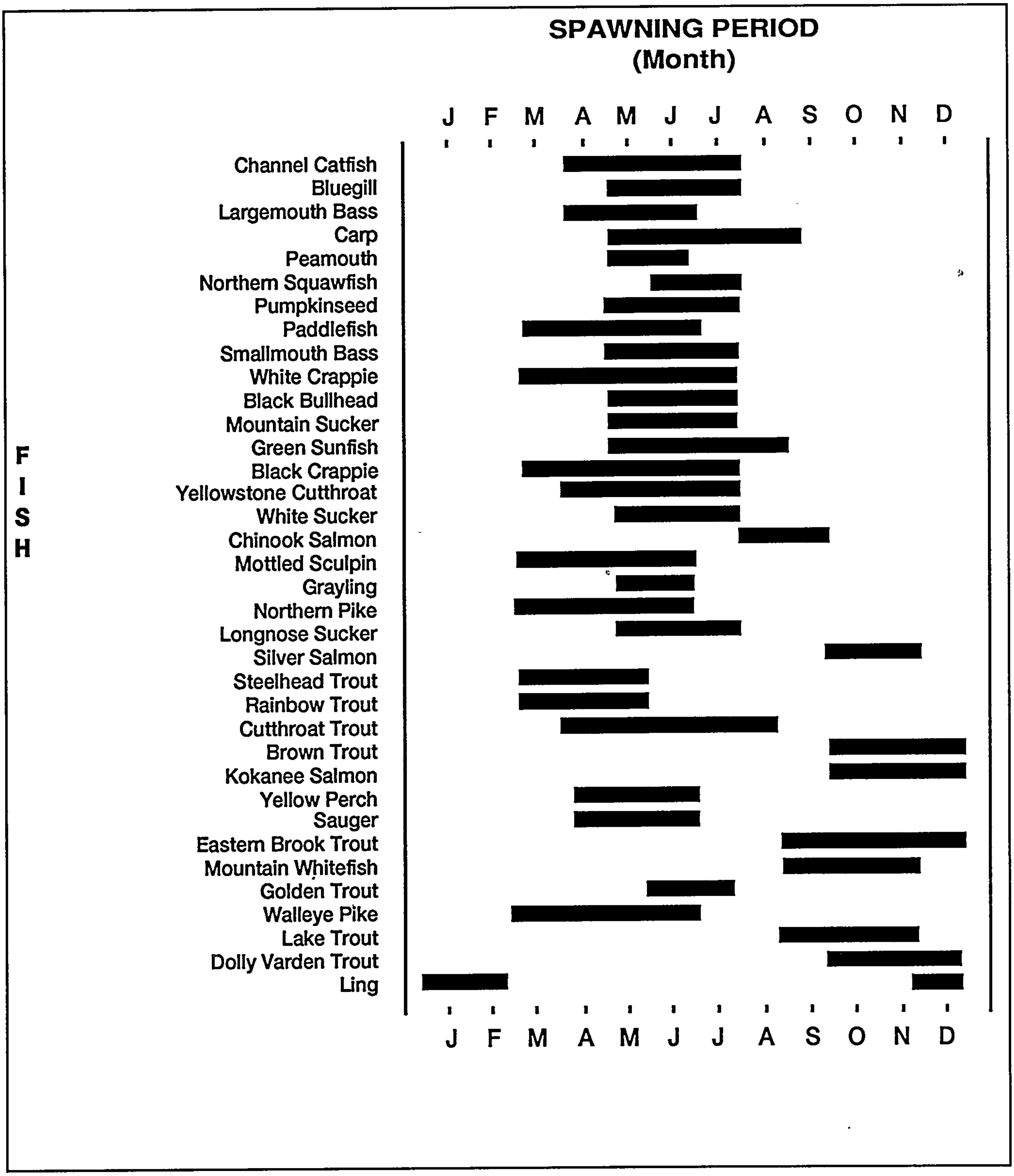


Figure 7. Period during which some fishes spawn in the Northern Region.

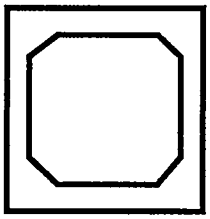
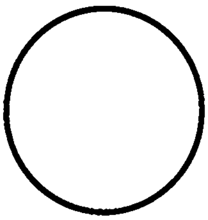
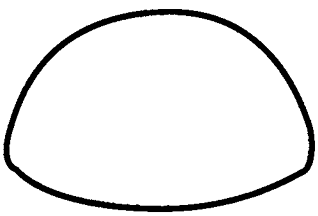
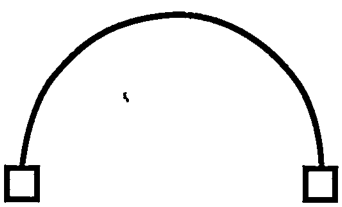
SHAPE	CHARACTERISTICS
 ***BOX (Square)***	– WIDE BOTTOM AREA; BACKWATER INFLUENCE IS GREATER THAN FOR CIRCULAR OR ELLIPTICAL SHAPES. – CAN BE PLACED SIDE BY SIDE TO MAXIMIZE END AREA. – BAFFLE DESIGN AND CONSTRUCTION SIMPLIFIED.
 ***CIRCULAR***	– DEPTH OF WATER AT LOWER DISCHARGES IS GREATER THAN THAT OF OTHER COMMON SHAPES, IMPROVING FISH ACCESS DURING LOW FLOWS. – INFLUENCE OF BAFFLES ON CULVERT HYDRAULICS IS REDUCED.
 ***PIPE ARCH***	– WIDE BOTTOM AREA; BACKWATER INFLUENCE IS GREATER THAN FOR CIRCULAR OR ELLIPTICAL SHAPES. – LOW PROFILE; ADVANTAGEOUS FOR SITUATIONS IN WHICH HEADROOM IS LIMITED OR UPSTREAM WATER STAGE MUST BE MINIMIZED.
 ***ARCH***	– PERMITS STREAM SUBSTRATE TO BE RETAINED WITHIN THE CULVERT AND APPROXIMATES THE NATURAL CONDITIONS WITHIN THE NATURAL CHANNEL.

Figure 8. Common culvert shapes. Dane, 1978 (modified).

ENGINEERING CONSIDERATIONS

Installation of any road drainage structure will create a change in natural morphology and hydraulic parameters. Many of the changes are potentially detrimental to fish passage. However, these changes may be short-lived or minimized by proper consideration of their effects during design and construction of drainage structures. There is no one structure that always is the optimum choice for all stream crossings. Each structure has its own short-term and long-term effects on stream habitat. It is up to the fish biologist, engineer, and hydrologist to weigh all the factors, such as fish habitat requirements, road alignment, and economics when selecting a preferred structure.

TEMPORARY DRAINAGE STRUCTURES

Temporary structures are those that are needed to serve short term needs, such as traffic by-passes while a permanent structure is constructed. Water quality issues aside, it is important that these structures be removed before the fish migration season so as not to impact fish passage during that critical period. If the project cannot be constructed during non-migration period, these temporary structures should also be designed and installed to allow for fish passage.

If a temporary bridge is properly constructed and removed as soon as it is no longer required, it will probably not cause serious barrier problems. Most problems with temporary bridges occur because of inadequate waterway areas causing increased velocities and stream damage below the structure.

Because temporary culverts generally allow for only water passage at low flow, they have a high potential of causing damage, particularly if they are left in place for peak flows. They are very susceptible to being plugged with debris and washing out or forming a fish barrier. Agencies should consider a policy to minimize the installation of temporary culverts that accomodate only low seasonal flow and if the project requires a temporary structure to maintain traffic flow.

Temporary dams or diversions allow water to be dammed or diverted generally during low flows to allow construction of permanent drainage structures. Despite their temporary nature, these dams or diversions can create fish passage problems if they are not properly constructed, maintained, and removed.

In general, temporary dams and diversions should not be constructed during the upstream fish migrations. Although the timing of fish migrations vary with species, elevation, and seasonal conditions, dams should generally not be constructed during fish migration periods and should be removed well before weather conditions force construction shutdown.

If diversions are required during fish migration, temporary fish ladders or jump pools can be installed to continue to provide passage. Such structures, however, should be expected to obstruct some fish passage.

Impoundment or diversion of water can also impede the downstream migration of fish, such as juvenile fish migrating in the spring months. Impoundments and diversions of only a few hundred feet can entrap or discourage large numbers of young fish from continuing their migration. This will seldom occur if the impoundment is small enough to permit a definite flow of current through the impounded area.

The water flowing from the impoundment or diversion should spill directly into a pool and should not drop in such a manner as to damage fish. The pool depth should be at least one-half the dam height, Evans and Johnston, 1980. Also, spilling and other diversion structures should be smooth surfaced to avoid abrasive damage to the fish passing down them. In no case should the water be allowed to spill directly over the dam onto a concrete slab or bedrock. This can kill fish passing over such a structure.

PERMANENT DRAINAGE STRUCTURES

Permanent structures are those associated with long term use of a road. These include bridges, box culverts, bottomless arches, and culverts. If these structures are improperly installed they can cause major fish passage problems. Box culverts and bottomless arches have many of the same characteristics as circular culverts. Many of the recommendations presented in this publication are valid for these types of structures as well. Figure 8, Dane, 1978.

CULVERTS

The most common type of drainage structure used in road construction is the corrugated metal culvert, however, concrete and wood are also used. Common culvert shapes include box (square), circular, pipe arch (squash), and bottomless arch culverts. Culverts are usually the cheapest structure to install, but unfortunately also cause the most fish passage problems.

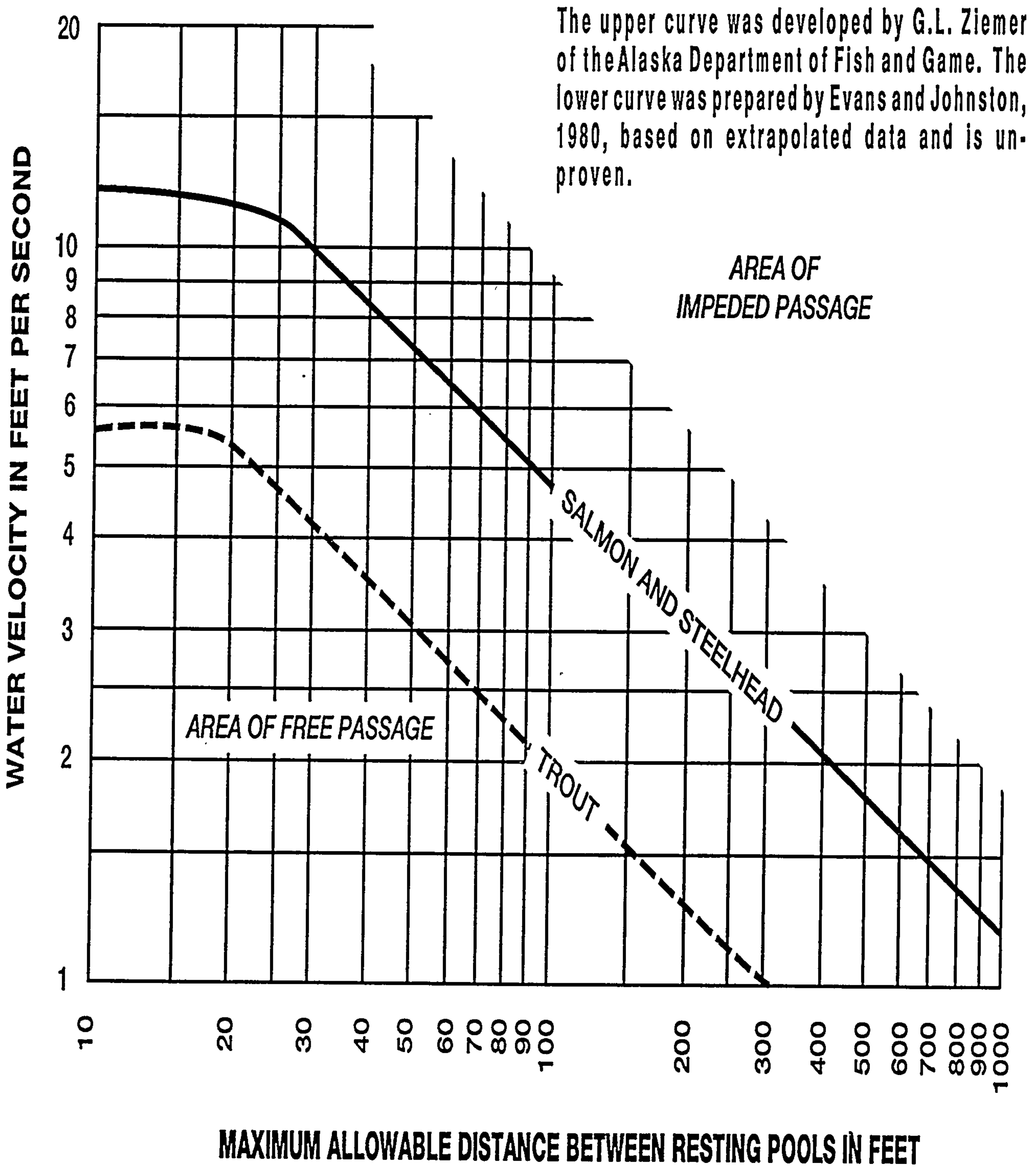


Figure 9. Swimming capability of migrating salmon (Alaska curve).

Box Culverts

Box culverts are used extensively in some parts of the country. Because they are usually constructed with a smooth bottom, which increases velocity and lowers flow, they restrict fish passage. Many times passage can be improved by using the techniques detailed in the section on General Culvert Installation Guidelines. Fish passage problems can usually be avoided if culverts are constructed without a bottom or are installed a couple of feet below stream grade. Fish normally have fewer problems passing through a box culvert if the bottom has native materials at natural grade. However, attention needs to be given to flushing material out of culverts. This action may cause pipe abrasion resulting in early replacement of the pipe. It may also cause downstream damage due to deposition or scour.

Any culvert installation that is not installed at the stream gradient may result in a change in water velocities which may create a drop below the culvert or may create a hydraulic jump at the head end of the culvert. If a drop occurs below the culvert outlet, it can sometimes be mitigated by installing a streambed weir with rocks, gabions, or other natural material such as logs. Normally, hydraulic jumps at the culvert head are impossible to mitigate. Installation of a larger culvert or multiple installations are the only alternatives. An experienced designer or hydraulic engineer will immediately observe that all the measures noted above are not to mitigate hydraulic jumps, but rather efforts to keep flows subcritical. Maintaining flows within acceptable tolerances will eliminate hydraulic jumps. A good designer will ideally strive for this positive result.

If concrete bottoms are used, they should be at least 6 in below the streamgrade with cross walls less than 3 in to collect natural streambed material. Another alternative could be to design a central sloping fishway to provide a low flow channel and low flow baffles for resting places, Evans and Johnston, 1980. There are important consid-

Figure 10. Bottomless arch culvert.

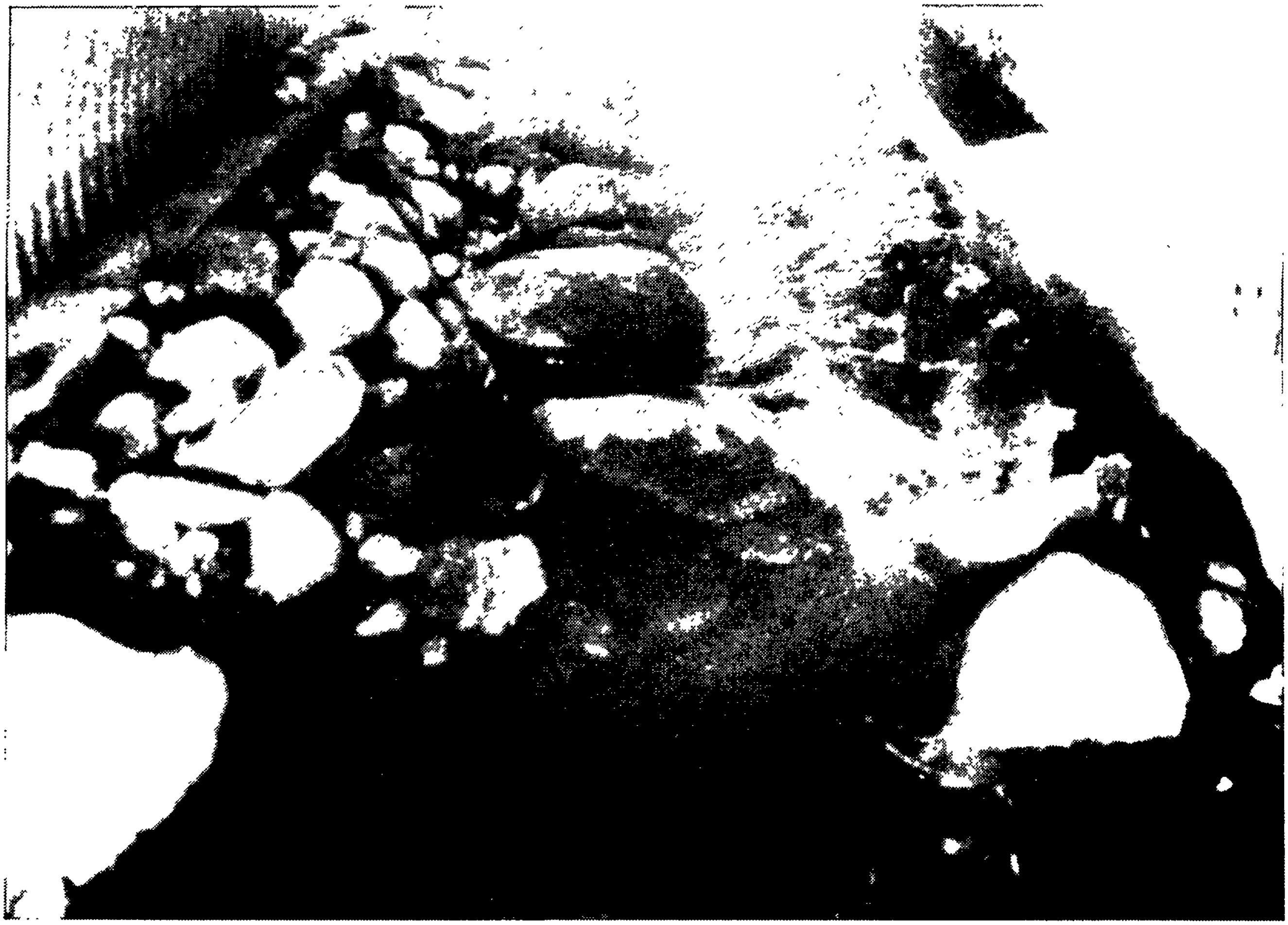


Figure 11. Streambed in bottomless arch culvert

erations if the culvert length or the water velocity exceed the parameters displayed for the fish species native to the water where the installation is located, Figure 9. There are times where the natural stream velocity exceeds these guidelines. It would be foolish to design a culvert to reduce these velocities as the fish in this particular stream would be able to negotiate the higher velocities. In addition, drastic changes in water velocity may have detrimental effects on the streambed conditions upstream or downstream of the culvert installation.

Bottomless Arch Culverts, Figure 10.
The most desirable type of culvert bottom for fish is one with native materials, Figure 11. As a result, bottomless arches are commonly singled out for installations requiring fish passage. It is important to note, however, that bottomless arches do require substantial disturbance to natural streambeds and streambanks due to excavation for the culvert footings.

The ideal bottomless arch is at least the same width as the stream channel. However, at this time technology limits the practical span of a bottomless arch to 40 ft, Evans and Johnston, 1980. The practical economic span is considerably less than that—about 25 ft.

There are some situations where bottomless arches need to be studied carefully. These include installations on streams with steep gradients (in excess of 8 to 10 percent), on highly unstable streambeds, on streams where the stream gradient changes within the reach of the drainage structure, and in areas where the peak flow channel is constricted by the structure. In all of these cases, stream channel erosion can undermine or wash out footings used to support the culvert. Often, in very steep gradients with stable streambeds, a natural bottom structure will reduce the scour potential by maintaining constant velocities.

The installation costs of bottomless arch culverts are substantially higher than other culvert installations. In addition, the installation procedure commonly takes several days due to the time needed to excavate, place concrete footings and allow them to set up prior to attaching the culvert. Bottomless arches may have a higher top elevation than other culvert installations, and at some crossings, this may not be acceptable.

Culvert Site Criteria

Problems with culvert installations can be minimized by careful selection of the crossing site. The ideal culvert site meets the following criteria:

1. There should be no sudden increase or decrease in the natural stream gradient or water velocity for at least 100 ft above or below the crossing location.

2. Ideally, a stream channel should have 100 ft of straight alignment above and below the culvert. The natural stream channel should have a straight alignment for at least 50 ft above the culvert. In such installations where alignment is limited at the outlet, it will be necessary to riprap the outlet.

If a culvert site is poorly located or improperly installed, it can be a detriment to the entire fish population on a small stream or affect the population of a stretch of a larger stream. Many times the most adverse impacts on fish populations in a stream can be traced to poor culvert location, design, or installation. However, sometimes a good culvert site is not an option. There are times when a road alignment or other circumstance dictates a crossing in a certain spot.

The key at that time is to fit the culvert to the site, regardless of conditions. In this case, only teamwork between the specialists will help bring a satisfactory solution.

Reduced Gradient and Depressed Invert Culverts

Many experts feel it is not a good policy to deviate from the natural stream gradient with the culvert grade. The best solution is to size the culvert big enough to allow the natural streambed to be placed in the culvert at the time of installation. The designer must realize that changing the gradient will most likely result in upstream or downstream erosion until a new equilbrium is reached. With that in mind, culverts have been installed at gradients less than natural stream gradients.

The rationale for laying culverts at less than natural grades is that fish can negotiate substantially steeper natural streambeds than culverts. For example, a culvert installation which followed a natural 5 percent grade line would likely block many upstream fish. If that culvert was installed at 3 percent, however, and headcutting produced an 8 percent reach upstream from the culvert, less hindered fish passage could result. If a culvert inlet was depressed and natural streambed materials were allowed to fill the culvert bottom, substantial improvement in fish passage is possible. In either case, the designer should note that headcutting is inevitable. This means that additional upstream and downstream scour and deposition will occur. If this is an absolute unacceptable consequence, another alternative should be looked at and the cost-benefit of the two alternatives compared.

Installing culverts at gradients less than natural stream grades should only be done when a careful hydrologic, engineering, and biological analysis is performed prior to installation. Such reduced grade installations will usually trigger headcutting upstream from the culvert, (unless other stream structures prevent it), or a jump at the outlet at the culvert if improperly installed. Most successful installations set the outlet elevation and then rotate the culvert barrel to achieve the desired grade. In no case should the outlet of the culvert be set higher than the natural streambed elevation. This will require careful monitoring the first several years following installation until the creek above the culvert stabilizes. Because of the instability of the upstream channel and the possibility of streambed materials accumulating within the culvert, additional oversizing of the culvert is commonly needed.

It should also be noted that nomographs that are commonly used to choose the culvert size based on slope gradient and predicted flow cannot be used. The commonly used nomographs are inappropriate for outlet controlled culverts and are misleading for inlet controlled, very low gradient installations. For these reasons, nomographs should not be used at sites where stream gradients vary or where pipes are buried, Figure 12. In these cases, the designer needs to perform his hydraulic analysis using reduced inlet area methods.

A concept variation on reduced gradient culverts is the depressed invert culvert. These culverts are designed to maintain a predetermined material in the culvert following installation. The material may consist of natural streambed or specified boulders and rocks. A detailed account of many of the hydrological considerations and calculations potentially associated with depressed invert installations is contained in Jordan and Carlson, 1987.

Culvert Coatings

In order to extend the useful life of corrugated metal pipes, various coatings can be applied to the inside or outside of the culvert. These coatings include bituminous compounds as well as other substances. In some cases, coatings can increase culvert life markedly, especially in erosive and/or corrosive stream channels.

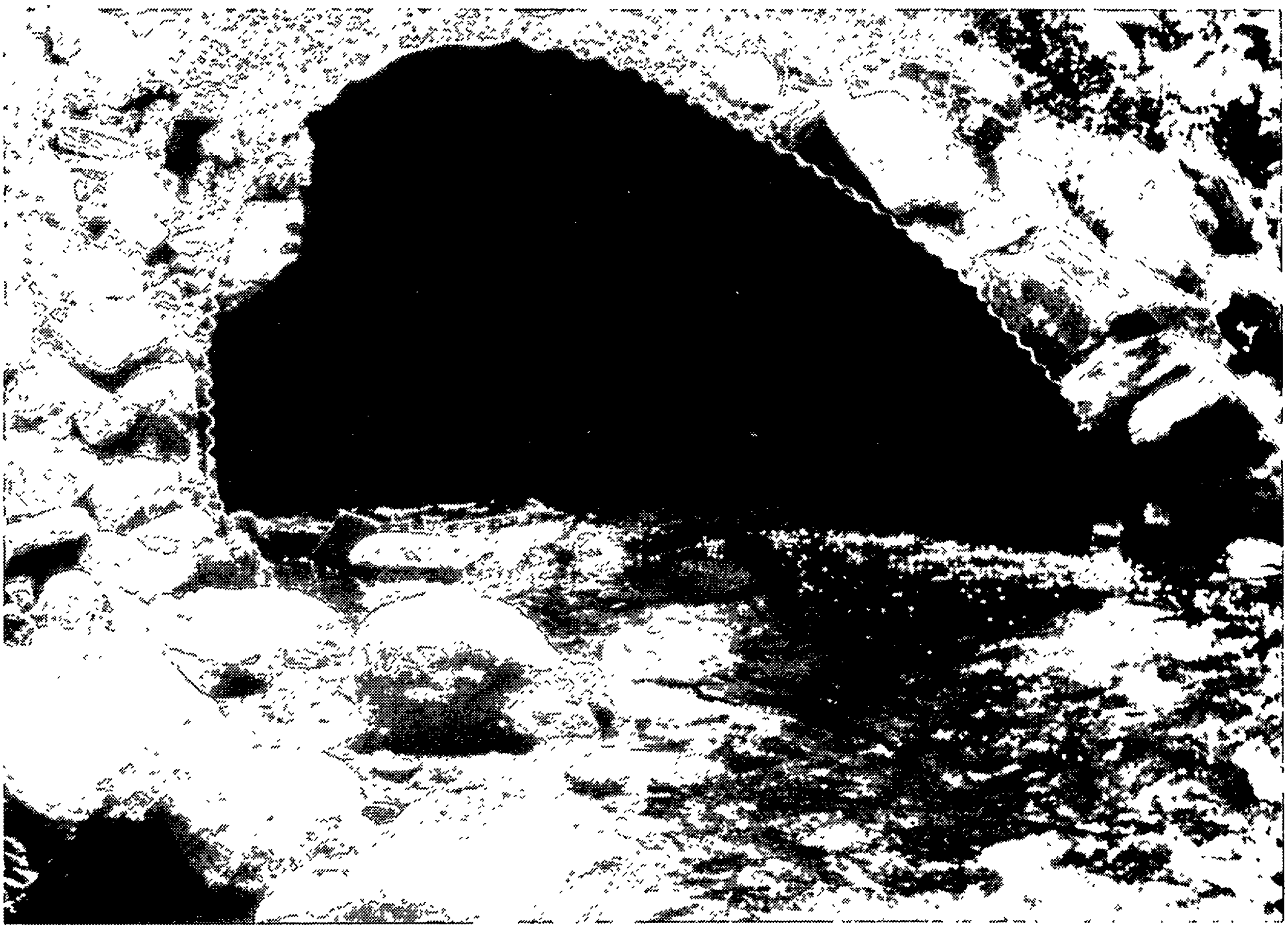


Figure 12. Buried culvert.

The substances can also have the effect of smoothing out the corrugations in a metal pipe and potentially increasing water velocities. In some instances, culvert corrugations are completely smoothed over due to additional asphalt treatment methods. However, if the basic culvert installation will provide good fish passage, coating of the culvert will not result in a significant decrease in fish passage capabilities. One exception to this may be the upstream passage of small and/or juvenile fish, which may use the corrugations to provide resting bays in the culvert.

Control of Sediment

Release of sediment into a stream can have serious impacts on fish and fish habitat. There are several obvious ways that sediment can affect fish populations.

1. Sediment can settle on spawning beds. It will eventually settle into the voids of the gravel and either smother the eggs or newly hatched fish (alviens) by hindering subsurface water circulation. Sediment can also create cobble imbededness, which effectively seals the spawning gravels to potential spawning fish.

2. Sediment can clog or abrade a fish's gills causing suffocation or infection.

3. Sediment will reduce the visibility in the stream, hindering the fish's ability to seek food.

4. Sediment also smothers and displaces the invertebrate organisms that serve as a food source for fish.

The most effective way to control sediment at a culvert installation site is to dewater the site, install the culvert in a dry condition, and insure that the site is as stable as possible before diverting the stream back through the pipe. In many cases, it is possible to take advantage of low flow conditions and realign the stream slightly to allow the structure to be installed in a dry condition. However, temporary structures are not without risk.

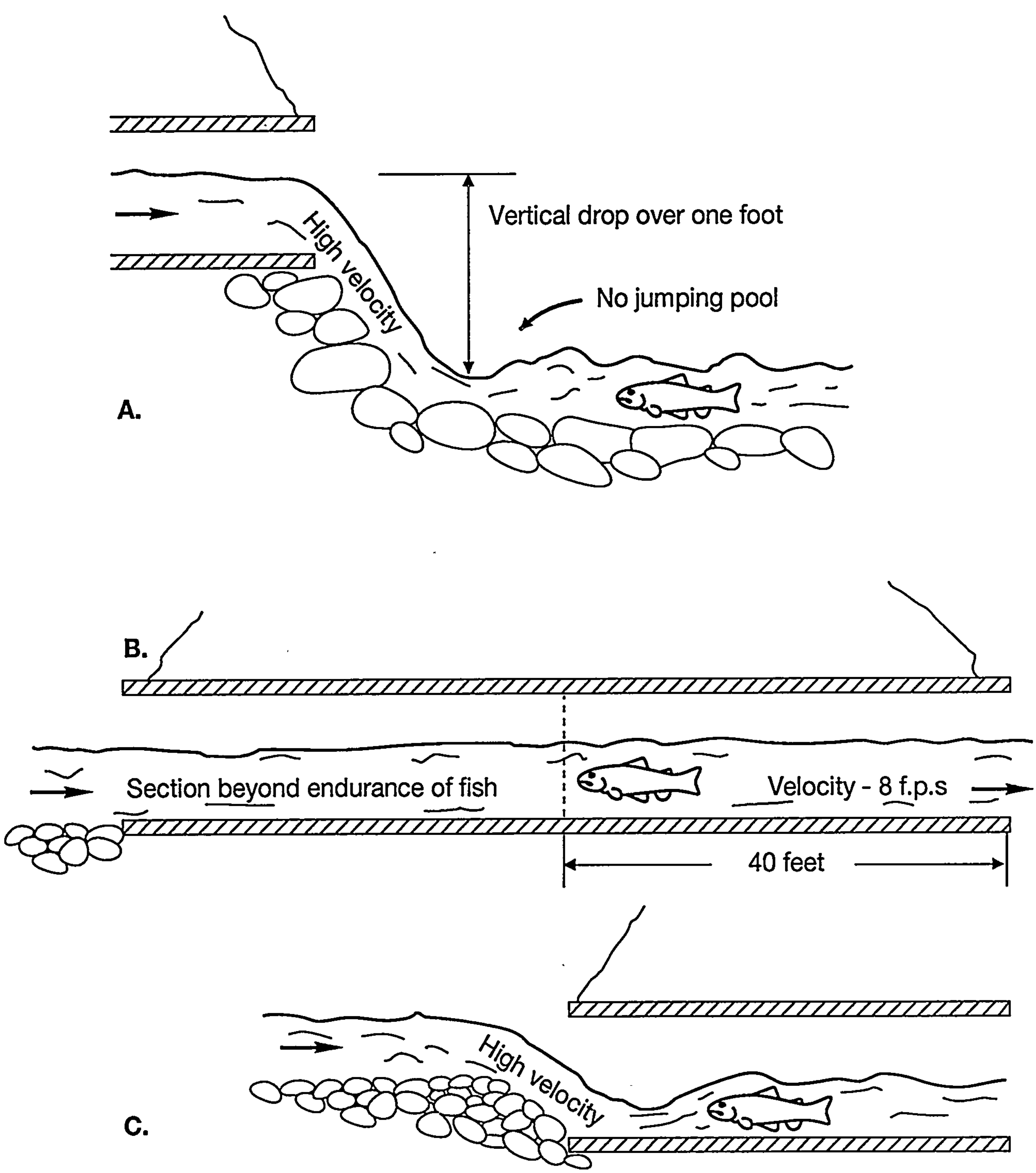


Figure 13. Undesirable conditions for passage of fish through culverts. Gebhards & Fischer, 1972.

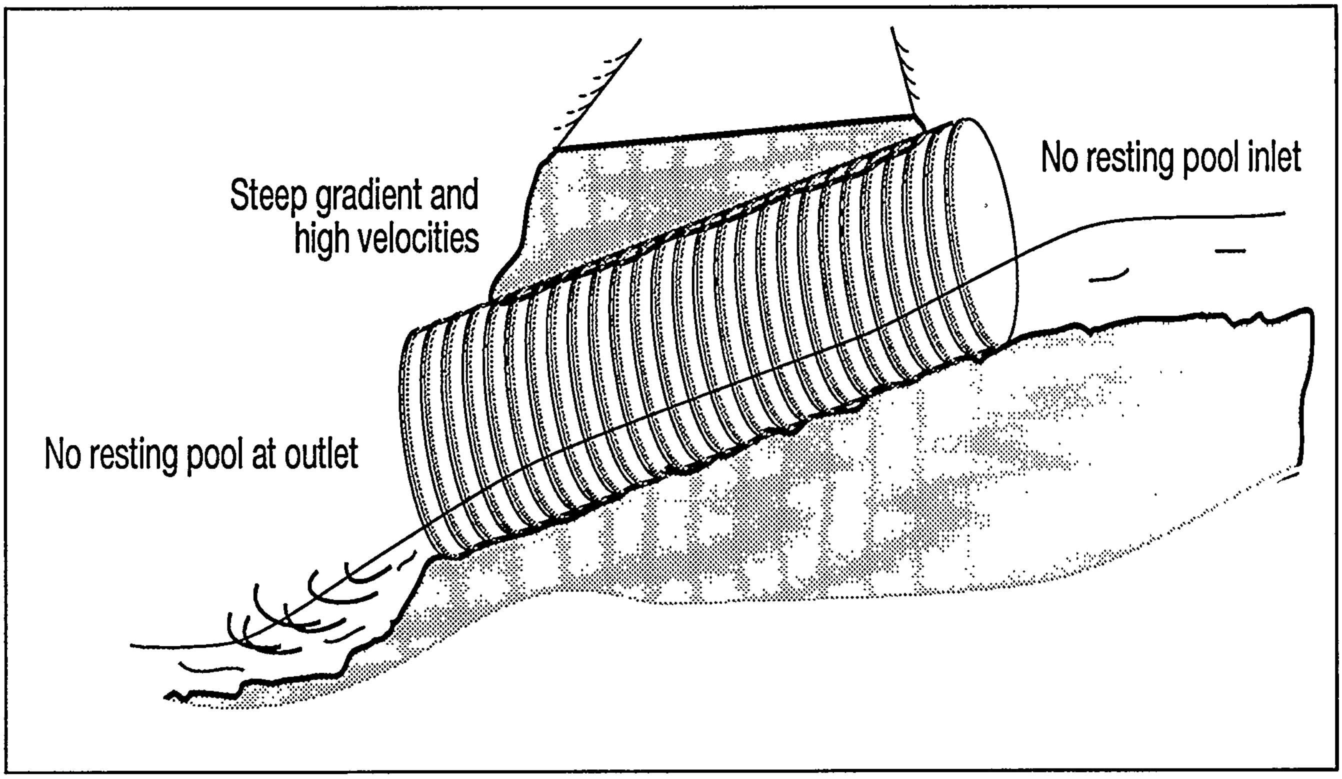


Figure 14. Installation unsuitable for fish passage. Evans and Johnston, 1980.

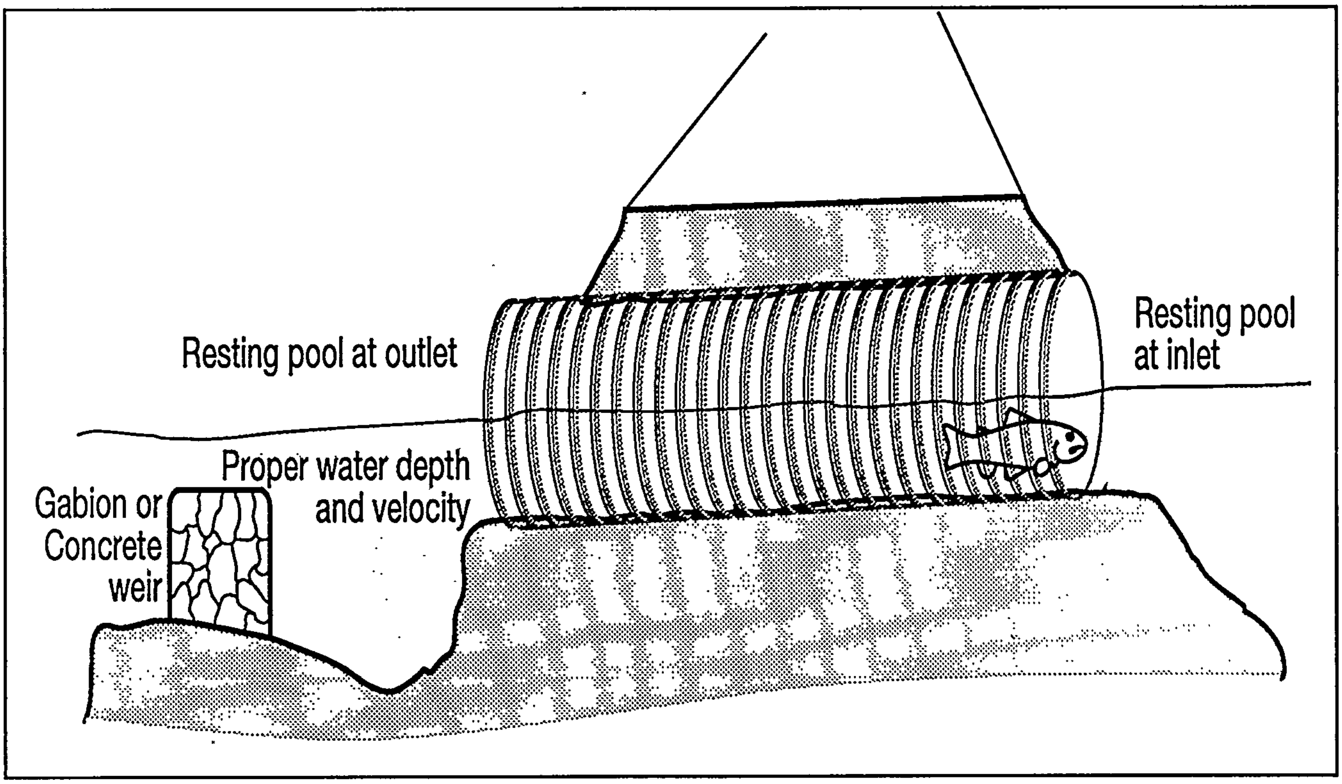


Figure 15. Installation suitable for fish passage. Evans and Johnston, 1980

Some of the points to consider can be found in the Temporary Drainage Structures section of this publication. Additionally, fish are not usually migrating at low flow. Generally, the lowest cost method of construction for the contractor is working under dry conditions. It also eliminates many of the water quality problems with downstream water users.

There are many methods available to the contractor for sediment control during construction. Some basic methods are documented in B.G. Dane's publication, 1978.

In those installations where select material is to be installed inside the culvert, exercise caution that the select material be as silt free as possible to reduce silt and sediment downstream. If natural streambed material is used, the gravel should be washed, hosed down with the silt, trapped and removed or placed with downstream sediment traps to catch the silt before the entire stream is diverted back through the culvert.

Additionally, more sophisticated methods of sediment control such as use of geotextiles have evolved as the issue ot sediment control has become more complex.

GENERAL CULVERT INSTALLATION GUIDELINES

There are some general guidelines to consider when installing culverts in fish streams. Figure 13, Gebhards and Fisher, 1972, depicts some of the undesirable conditions for fish passage through culverts. The end result is an installation that can be unsuitable for fish passage, Figure 14. With proper design and construction considerations a crossing can usually be suitable for fish passage, Figure 15.

1. In those places where fish passage is desired, bridges, bottomless arches, or partially buried pipe arch culverts are preferred over round pipes. This is especially true if pipes are over 100 ft long, if threatened or endangered species are involved, or if the stream gradient is steep enough that velocities through a round corrugated culvert become high enough to cause downstream errosion or pluge pools at the outlet. A gradient of around 4 percent should alert the designer to look at outlet velocities.

2. There are two schools of thought on multiple culvert installations, Figure 16. The first is that one large culvert is preferred over several small ones since the larger one is less likely to plug with debris and will carry water at a lower velocity, Evans and Johnston, 1980. The second is that multiple installations are acceptable in certain conditions. If there are multiple installations, one pipe can be sized to pass peak flows and the second could be designed to pass fish. However, it should be noted that occasionally adult fish have been observed to

Figure 16. Fish passage may be provided in streams that have wide ranges of flows by providing multiple culverts.

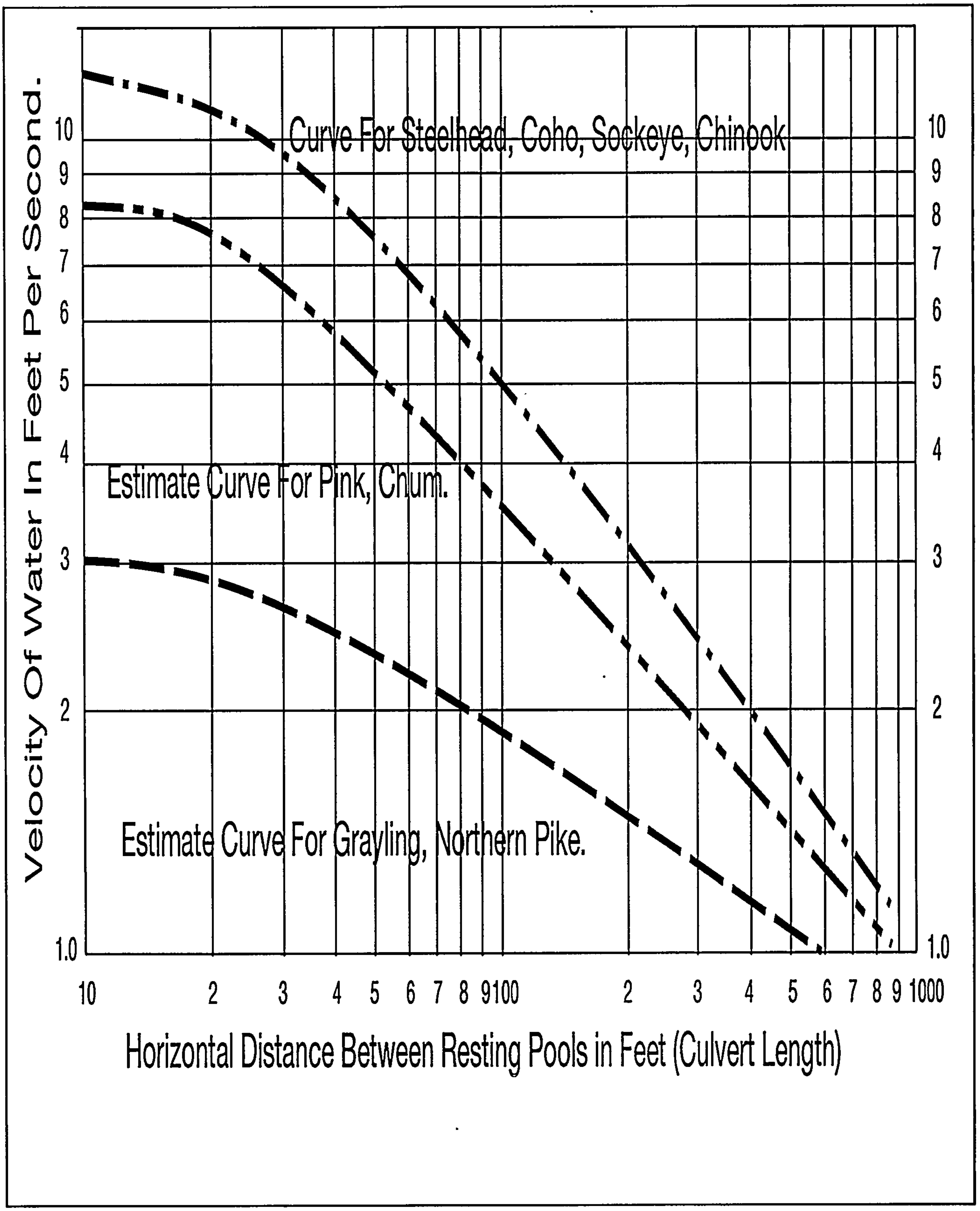


Figure 17. Swimming capability of migrating fish in fresh water. Ziemer, 1965 (modified).

jump into culverts with the higher velocity in multiple installations. Even though fish passage may be provided at one culvert, the fish may not choose that culvert.

3. Water velocities in smooth bottom culverts are usually two to three times those in corrugated metal pipes when the slope, pipe size, and other flow parameters are equal. In some studies, it has been found that migrating fish, especially juvenile fish, utilize the corrugations along the pipe as resting areas as they migrate through the pipe. Larger corrugations (6 by 2 in for steel structural plate, 9 by 2 1/2 in for aluminum structural plate, and 5 by 1 in for corrugated metal pipe) are preferred over smaller ones, Behlke et al., 1989.

4. Culvert diameters must be adequate to pass the maximum expected design flows and debris or other materials being transported by the design flows. Excess sedimentation from washed out culverts and the associated road fills can damage spawning and resting habitat. Most agencies have their own design flow parameters. Recommended minimum designs for those agencies who have not established such parameters should be to design a culvert to pass a 50-year flood at a static head and a 100-year flood with a headwater depth.

5. Consideration should be made for increases in peak flows due to urbanization, vegetative manipulation such as timber harvest or fire and other activities that increase the coefficient of run off. The designer should also be aware that increases in peak flows add increased bed load which may alter the preferred design structure.

6. Culverts should be designed and installed to keep the velocity of the water passing through the pipe equal to the predicted stream velocity at design flows. Many authors advocate maximum grades for culverts, but these can result in producing supercritical flows at the culvert inlet which can themselves become barriers to fish passage. See Inlet Drops section.

7. Two major considerations in designing culverts should be the maximum acceptable water velocity for the design period, Figure 17, and the maximum acceptable water depth (usually not less than 6 in for resident trout and at least 12 in for adult anadromous fish). Velocities for design flows through a structure should not exceed the natural stream velocity for the periods that fish passage is desired. Knowledge of specific stream flow parameters is highly desirable to obtain the optimum design. Site specific knowledge of fish performance may dictate an up or down deviation from the by-the-book solution.

8. Studies indicate that migrating fish can usually tolerate some delay in migration. An acceptable practice is to design culverts so that flow conditions are not suitable for fish passage during the 5 percent period of the year when flow peaks are their highest, Evans and Johnston, 1980. Fish do not generally migrate at highest peak flows, so this practice should cause little disruption of normal fish migration. This practice also often results in substantial savings in construction cost for fish passage.

9. As a general practice, culvert baffles are not recommended in lieu of installing a larger pipe or using a reduced pipe gradient where the inlet elevation of the pipe is dropped. However, at times baffles cannot be avoided. Some general guidelines are provided in the Baffles section. If baffles are installed, they must be designed in such a manner that the culvert can still handle peak flows and the baffles themselves do not become blockages to fish passage or debris accumulators. Baffles seem to work better with box culverts or unburied pipe arches to maintain the minimum flow depths.

10. Often, culverts are installed in streams with high gradients. In these cases the designer should provide for resting pools and bank protection for several hundred feet above and below the culvert installation, Figure 18. In order to prevent scour and stream degradation, it is important to maintain stream stability. Figure 19 provides a starting point for determining riprap sizing if no other design methods are available.

11. Although not usually recommended, culverts can be installed at gradients less than natural grade. For a more detailed discussion of this option, refer to the discussion in the Inlet Drops section.

12. More consideration should be given to the location of the stream crossings. Too often the roadway alignment dictates the culvert location. At least equal consideration should be given to hydraulic parameters and stream stability. Structures should be placed where the streambed is the straightest to insure that natural meanders are not cut off resulting in higher stream velocities or accelerated head cutting and streambed erosion up or downstream.

13. Riprap, when used on the upstream end of culverts, should be placed carefully. Dislodged riprap can result in reduced hydraulic capacity for culverts. It may also result in high velocity flows that hinder fish passage. Poorly placed riprap can also result in severely reduced inlet efficiency.

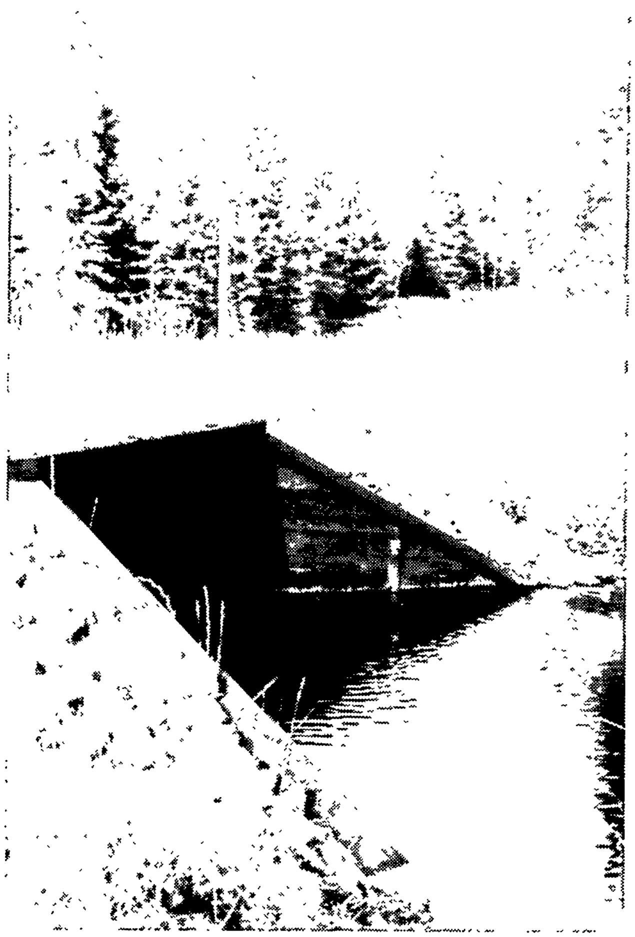


Figure 18. Bank protection

14. The use of concrete aprons at culvert openings is not recommended. The aprons make fish passage difficult or impossible because of increased velocities resulting from lower roughness coefficients or because many aprons are installed at steeper gradients than the culvert. Depth of water flow can also be a problem with concrete aprons.

15. An outlet pool with tailwater control should be designed and constructed at the downstream end of a culvert with critical migratory fish needs. The length and width of the outlet pool should be twice the diameter of the culvert (2D) and the bottom elevation of the pool should be at least two feet below the invert elevation of the culvert outlet.

16. All rehabilitative work within the stream channel should be completed before the stream is diverted back through the completed culvert. Disturbance of the natural vegetation and soil should be minimized. Undisturbed soil and natural vegetation is often superior to armouring of the stream. For example, where the road embankment needs to be protected, the embankment itself should be armoured instead of the streambanks above and below the culvert.

LIFE EXPECTANCY OF CULVERTS

Probably one of the most ignored factors in installations of corrugated metal culverts has been the life expectancy of the pipe. Although sizing of proposed culverts takes into account relatively long term hydrological events, little consideration is given to the design life of the pipe itself. In areas of high streambed abrasion or corrosive soils, the design life of pipes is less than 20 years. As a result, there are now literally millions of culverts approaching the end of their useful life. Many of these are located under substantial road fills and/or other structures making replacement of the pipe extremely expensive if not impossible.

One immediate crucial need facing biologists and engineers across the nation today is replacing these aging structures and continuing to provide fish passage. Although retrofitting new culverts into old pipes is an available option, McCrea, 1984, hydrological capacity and fish passage capabilities are usually reduced. If the road drainage structure is only marginal for fish passage to start with, retrofitting can block the remaining fish runs.

The identification and planning for replacement of existing road drainage structures is an area of high national need. This need will require unprecedented cooperation among biologists, engineers, and hydrologists. The dollars associated with drainage structure replacement will be staggering, as is the potential impact to remaining fish runs. Only through planning, can the trade-off be evaluated in a deliberate rational fashion, without the urgency of imminent or actual structure failure.

Recommended Riprap Size

(Based on Corps of Engineers publication EM-1110-2-1101, pages 11-31)

Water Velocity (fps)	Percent of Riprap Smaller Than: 100 wt. (lbs) [1]	100 size (feet)	50 wt. (lbs)	50 size (feet)	10 wt. (lbs)	10 size (feet)	Manning's "N" Value	AASHTO Riprap Gradation Class (a)	Forest Service Riprap Gradation Class (b)
6.5	25	.67	5	.40	1	.23	0.034	-	I
7.5	50	.88	10	.50	2	.27	0.036	-	II
8.0	100	1.04	25	.67	2	.27	0.0375	-	III
9.5	150	1.17	75	.95	10	.50	0.039	Facing	IV
9.75	250	1.42	100	1.04	15	.58	0.040	-	V
10.0	400	1.67	175	1.23	20	.62	0.041	Light	VI
10.5	700	2.02	300	1.52	25	.67	0.042	-	VII
11.5	1600	2.67	600	1.92	50	.88	0.044	1/4 Ton	VIII

1.) Assuming A Specific Gravity of 2.65

Riprap Size Classes based on:

a.) Standard Specifications for Highway Bridges, AASHTO, 14th Edition, 1989

b.) Forest Service Standard Specifications for Construction of Roads and Bridges, April 1985

Figure 19. Recommended riprap size.

Fish Species	Maximum Capablility Ft./Sec.	Acceptable Range Ft./Sec.	Reference Source
Juvenile Salmon		0 - 4	Saltzman and Koski
Trout & Steelhead		0 - 3	Metsker
Adult Cutthroat		0 - 4	Saltzman and Koski
Trout & age 1+		0 - 3	Metsker
Steelhead			
Adult Sea-run	6.4 - 13.5**	0 - 8	Saltzman and Koski
Cutthroat Trout	11.4*		
Adult Coho	12.2 - 17.5**	3.4 - 10.6	Bell
Salmon	10.6 - 21.5*	0 - 8	Saltzman and Koski
		0 - 8	Lauman
Adult Chinook	14.5 - 22.1**	3.4 - 10.8	Bell
Salmon	10.8 - 22.4*	0 - 8	Saltzman and Koski
		0 - 8	Lauman
Adult Steelhead	12.0 - 26.8**	4.6 - 13.7	Bell
Trout	13.7 - 26.8**	0 - 8	Saltzman and Koski
		0 - 8	Lauman

* From Bell (1975) using Trout
**From Calhoun (1966)

Figure 20. Swimming capabilities of fish species.

HYDRAULIC CONSIDERATIONS

In order to properly design any culvert, the engineer will need to consider several design parameters so that a culvert can be sized and designed properly. These parameters include fish species and age, maximum water velocity tolerance and the distance a fish can swim without a resting area. Baffles, natural rock boulders, or other resting areas may need to be designed to properly assist fish passage.

WATER VELOCITIES IN CULVERTS

The swimming abilities of fish are dependent on the fish size and species. Small fish, including juveniles and adult trout, are much more susceptible to velocity barriers. A relationship exists between the size (length) of the fish and their swimming capability; the smaller the fish, the lower the velocity tolerance. Therefore, if fish passage at a culvert crossing is geared only for adult fish, anadromous and residential fish production would be impacted upstream from the culvert.

Figure 20 summarizes some of the available information on swimming capabilities of fish and recommended ranges in water velocity through a culvert. To aid road designers in estimating water velocities through culverts, the USDA Forest Service, Evans and Johnston, 1980, has produced a series of culvert velocity curves based on Manning's equation. In addition, there are several computer software programs available that can calculate velocity, depth of flow, and other guidelines.

Outlet Velocity

The outlet velocity of a culvert is the velocity measured at the downstream end of the culvert. Many times outlet velocity is higher than the maximum velocity of the natural stream. As a result, this higher velocity can cause streambed scour and bank erosion for a limited distance downstream of the culvert. Permissible velocities at the outlet will depend on streambed type. It may be necessary to use some type of outlet protection or energy dissipator to reduce scour. Refer to Figure 19 as it gives comparable riprap sizes for various velocities for the designer to use in designing outlet protection.

Calculating the 10-Year Flood

The designer should use stream gauge data if it is available to calculate peak flows. Many times this data is not available and the designer must resort to the use of flood prediction equations or Manning's Equation. Velocities for design flow through a structure should not exceed the natural stream velocity of a 10-year flood (Q10). In some cases, a Q10-flood (one that occurs on average every 10 years) can be calculated using Manning's formula with representative stream cross section obtained from observing high water marks. However, the usual method of calculating design flows, without available streamflow records, is accomplished by the use of flood prediction equations. The designer should use the equations or analyses that are recommended for the local area. Many states, universities, and federal agencies such as the Soil Conservation Service and the U.S. Geological Survey have performed studies and published documents outlining local flood prediction equations.

Inlet and Outlet Control

There are two types of flow characteristics that are recognized in culvert design:

1. Culverts with inlet control.
2. Culverts with outlet control.

For each type of control a different combination of factors is used to determine the hydraulic capacity of a culvert. The designer must check both types of control and design for the most adverse.

Inlet control occurs when the culvert barrel is capable of conveying more flow than the inlet of the culvert will accept. When a culvert is flowing under inlet control, the capacity of the culvert is controlled by four factors:

1. Depth of headwater.
2. Cross-sectional area.
3. Inlet edge configuration.
4. Barrel shape.

Roughness, slope, and length of the culvert barrel and outlet conditions, including tailwater, are not factors in determining the amount of water that can flow through the culvert. Inlet control always results in supercritical flow immediately downstream from the inlet. Furthermore, the flow will remain supercritical throughout the length of the culvert unless a hydraulic jump forms at some point in the barrel. Sketches to illustrate inlet control flow for unsubmerged and submerged entrances are shown in Figure 21.

Under outlet control flow, factors at the culvert outlet or immediately downstream are determining the flow capacity of the culvert. The capacity is determined by the following eight factors:

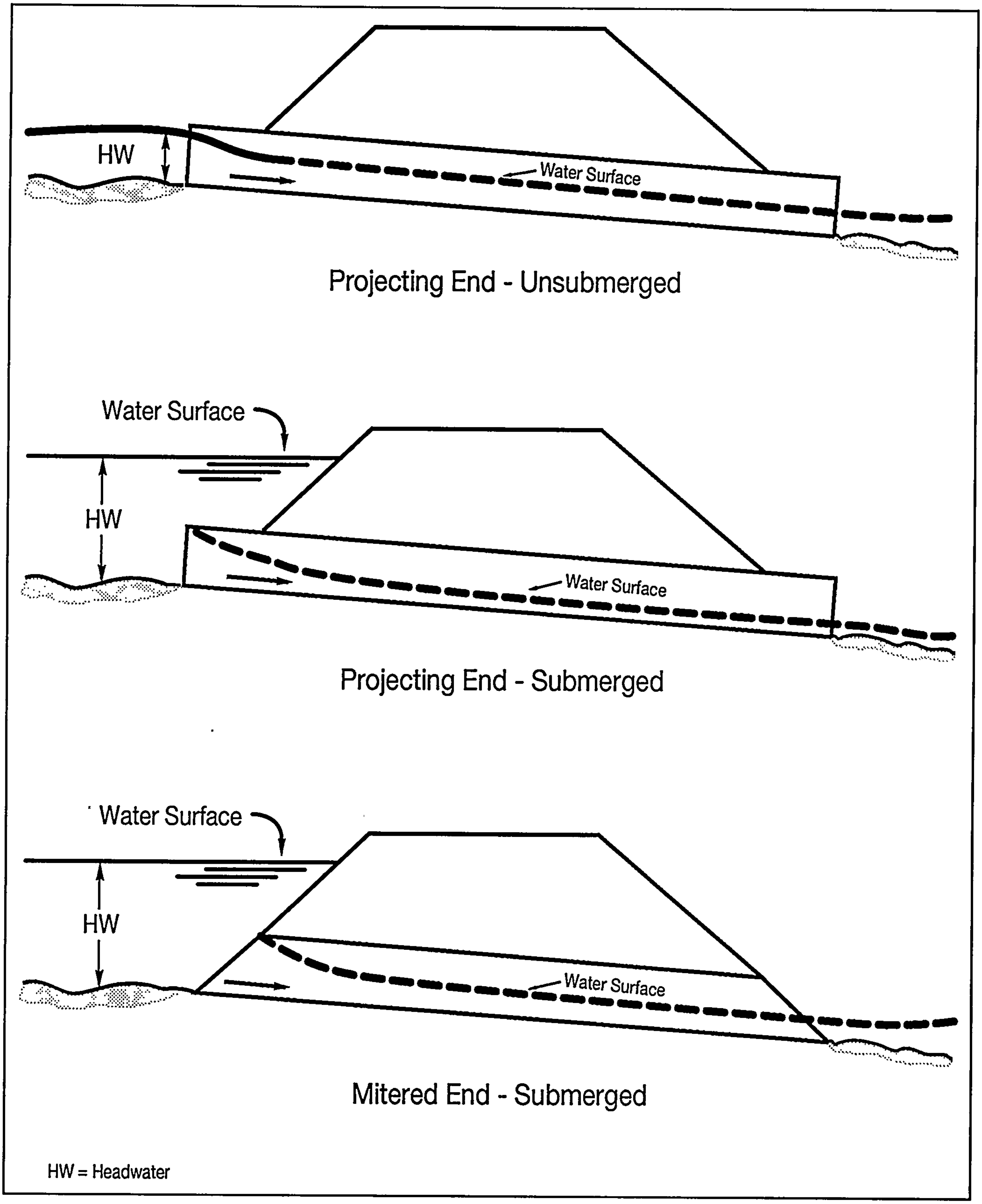


Figure 21. Typical culvert section under inlet control.

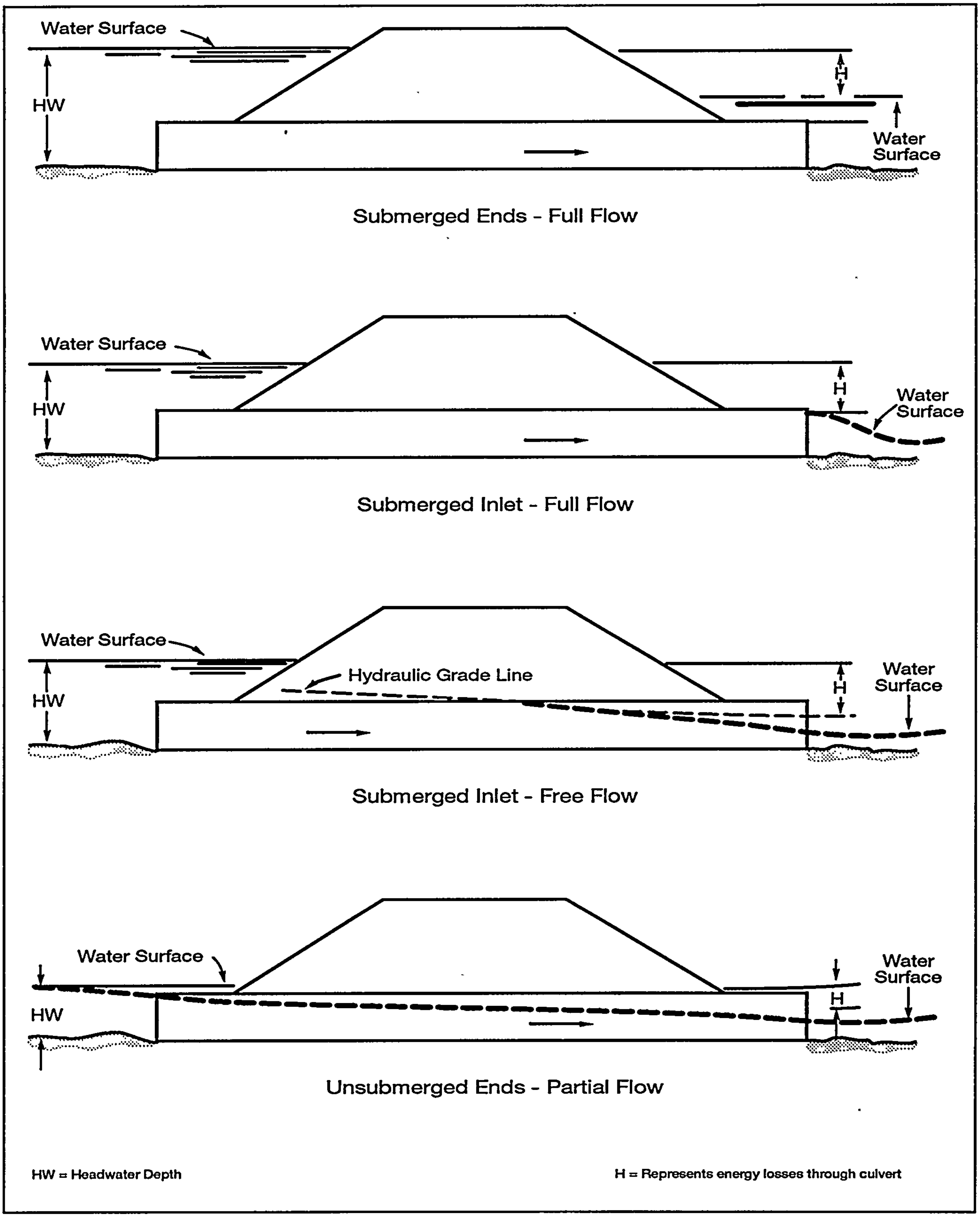


Figure 22. Typical culvert section under outlet control,

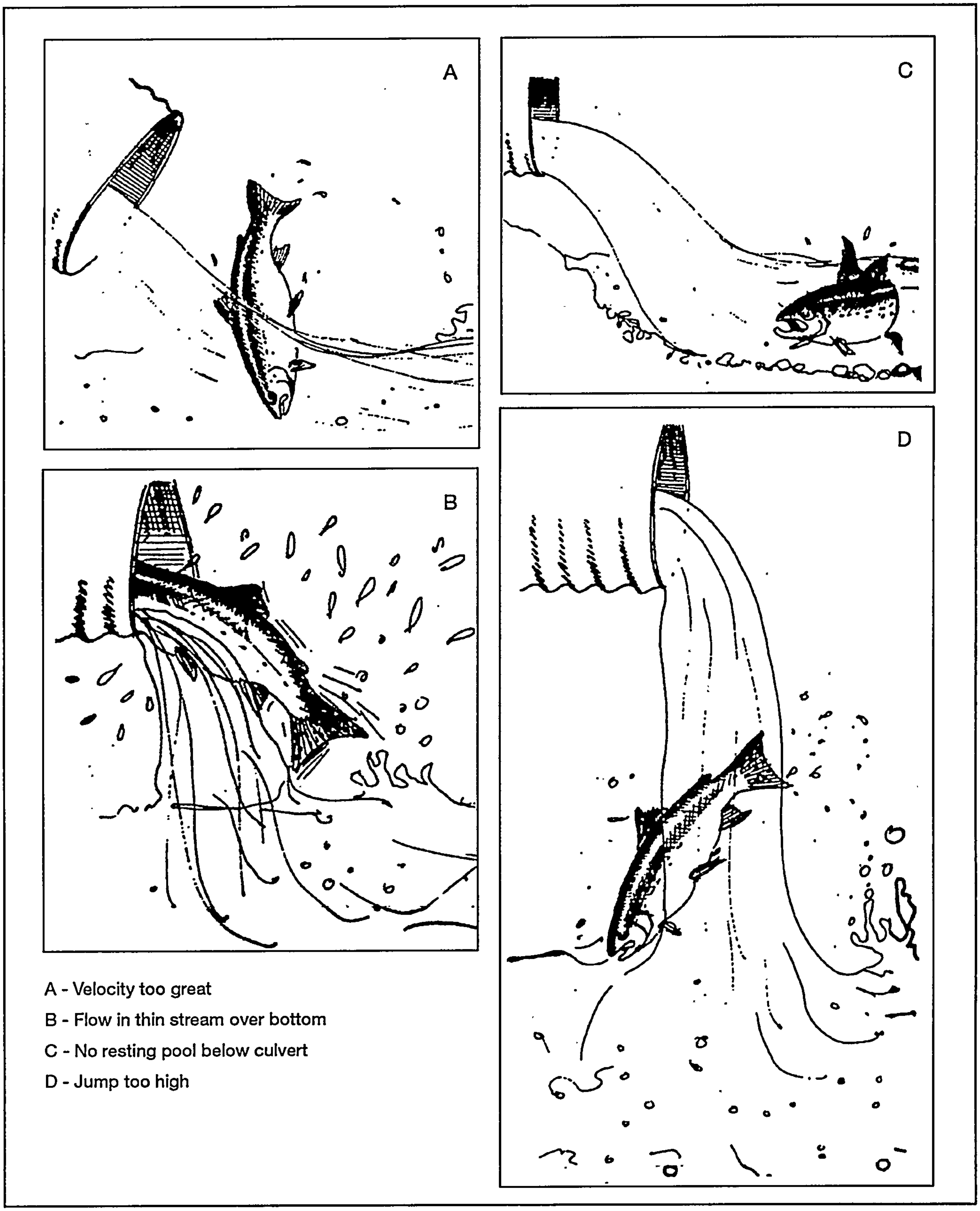


Figure 23. Common conditions that block fish passage. Evans and Johnston, 1980

1. Depth of headwater.
2. Cross-sectional area.
3. Inlet edge configuration.
4. Barrel shape.
5. Culvert slope.
6. Culvert length.
7. Culvert roughness.
8. Depth of tailwater.

Culverts flowing with outlet control may flow with the barrel full or partially full for their entire length or with the barrel full for only part of the length. In outlet control culvert length, roughness, and tailwater depth can have an appreciable effect on culvert performance. Sketches of types of outlet control flow are shown in Figure 22.

Where fish passage is a concern, the best culvert installation is one that allows open channel flow with no increases in flow pressure either at the inlet or the outlet. New installations, where fish passage is a concern, should strive to achieve open channel flow.

CORRECTING HYDRAULIC PROBLEMS

Culvert installations can commonly block fish migrations. Some of the more common conditions that block fish passage are depicted in Figure 23. Many times some of these conditions can be corrected by installing baffles, by correcting culvert outfalls, and by correcting culvert alignments.

Baffles

Baffles seem to be the answer to many of the design problems encountered in fish passage through culverts. They are not the panacea that they seem. In new installations, they should be considered as a last resort because of the difficulty in fabrication and the high maintenance costs. An objective look may indicate that a bottomless arch or even a bridge has a lower total cost, when both installation and maintenance expenses are considered.

Often culverts have been placed in streams with steep gradients. In these installations, even when the culverts are installed on the same gradient as the original streambed, velocities passing through the culvert exceed the maximum velocity allowable for fish passage. In these cases, adding baffles may be necessary to reduce velocities.

Although McClellan, 1970, found that a baffle system will enhance fish passage, construction of culvert baffles is usually not a recommended practice. Baffles significantly reduce the hydraulic efficiency of a culvert. McKinley and Webb, 1956, found that the efficiency of a 10 ft box culvert on a 3.5 percent slope was reduced by 31 percent for baffles 12 in high and by 43 percent for baffles that were 16 in high.

The effect of the offset baffles on culvert efficiency was documented by Engle, 1974, in Figure 24. Hydraulic efficiency has also been estimated by subtracting the cross-sectioned area displaced by the baffle system from the total culvert area and increasing the roughness coefficients in Manning's formula during capacity calculations. Installation of baffle systems within a culvert will change the operation of a culvert from inlet control to outlet control. Culverts originally operating under outlet control will continue to do so, Dane, 1978.

The design life of most baffles installed in a culvert is typically substantially less than the culvert itself and usually requires periodic maintenance. In addition, the installation of some baffle systems can significantly reduce the life expectancy of the culvert.

When installing baffles in a box culvert, it may be advisable to construct a system in only a portion of the culvert bottom to minimize the reduction in capacity of the culvert. The two channels can be separated by a low divider wall. A divided box culvert will present some problems for fish passage as fish will have to decide on one of two possible routes. The choice is usually influenced by the hydraulics at the outlet where the fish are attracted by certain turbulent conditions. If the fish are not sufficiently attracted to the baffled section, construction of a barrier or division structure at the outlet of the unbaffled section may be necessary to discourage fish migration in the unbaffled culvert.

The purpose of a baffle system is to produce a pocket of low velocity water in the culvert where fish can momentarily rest during high flows. The system must also maintain adequate water depth during low flows. Very little information is available on the hydraulic principles involved in using various types of baffles. The best early information on baffle design is in a Washington Department of Fisheries report, McKinley and Webb, 1956. The principles advocated in this publication have been used by most baffle designs, pending results of further research.

The baffle design illustrated in Figures 25 & 26 is recommended for general use and is taken from the Idaho Fish and Game Department, Gebhards & Fisher, 1972. They derived their design from McKinley and Webb, 1956. For the design in Figures 25 & 26 to be readily adaptable to installations of various sizes, the

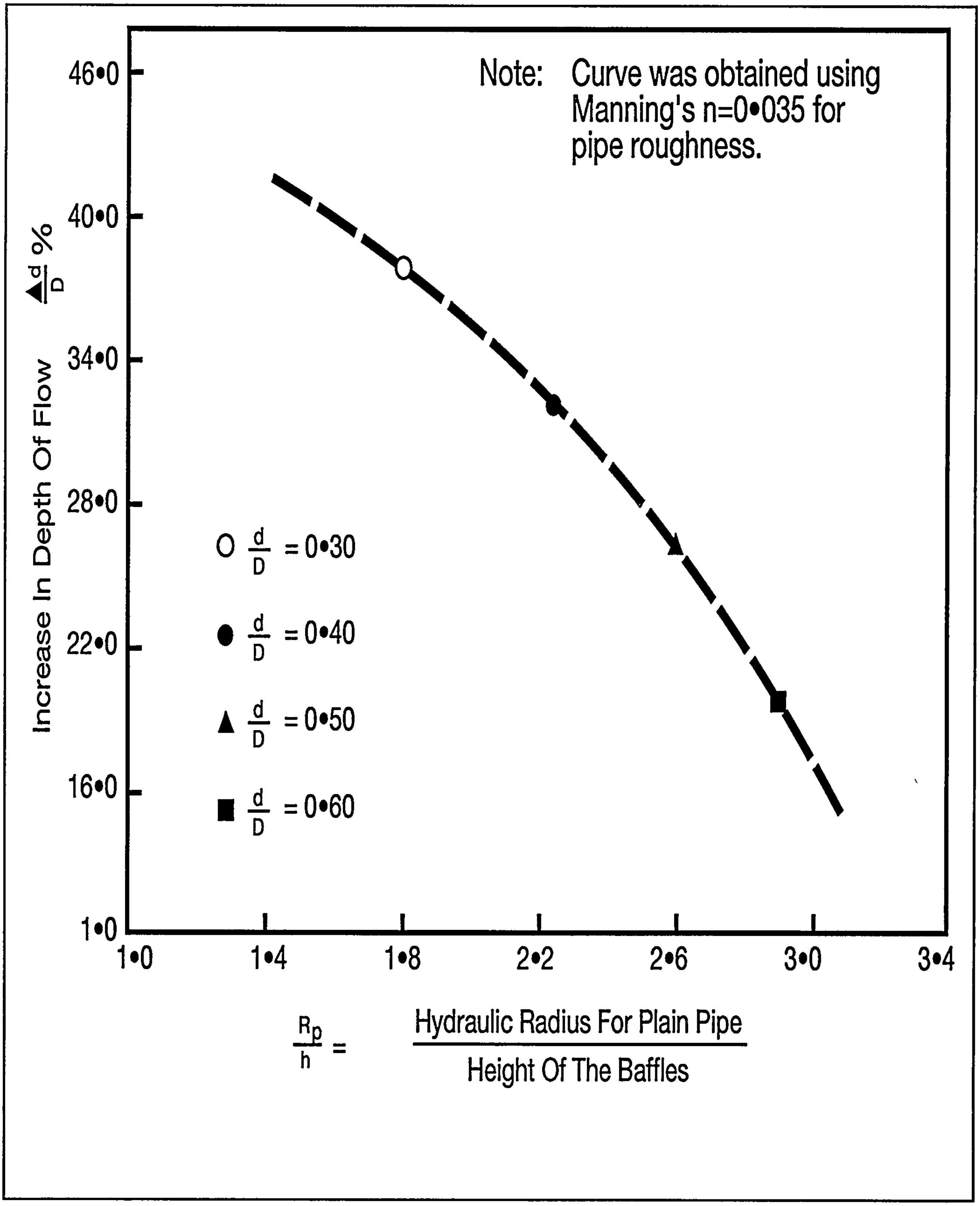


Figure 24. Increase in depth of flow due to offset baffles (Engel, 1974).

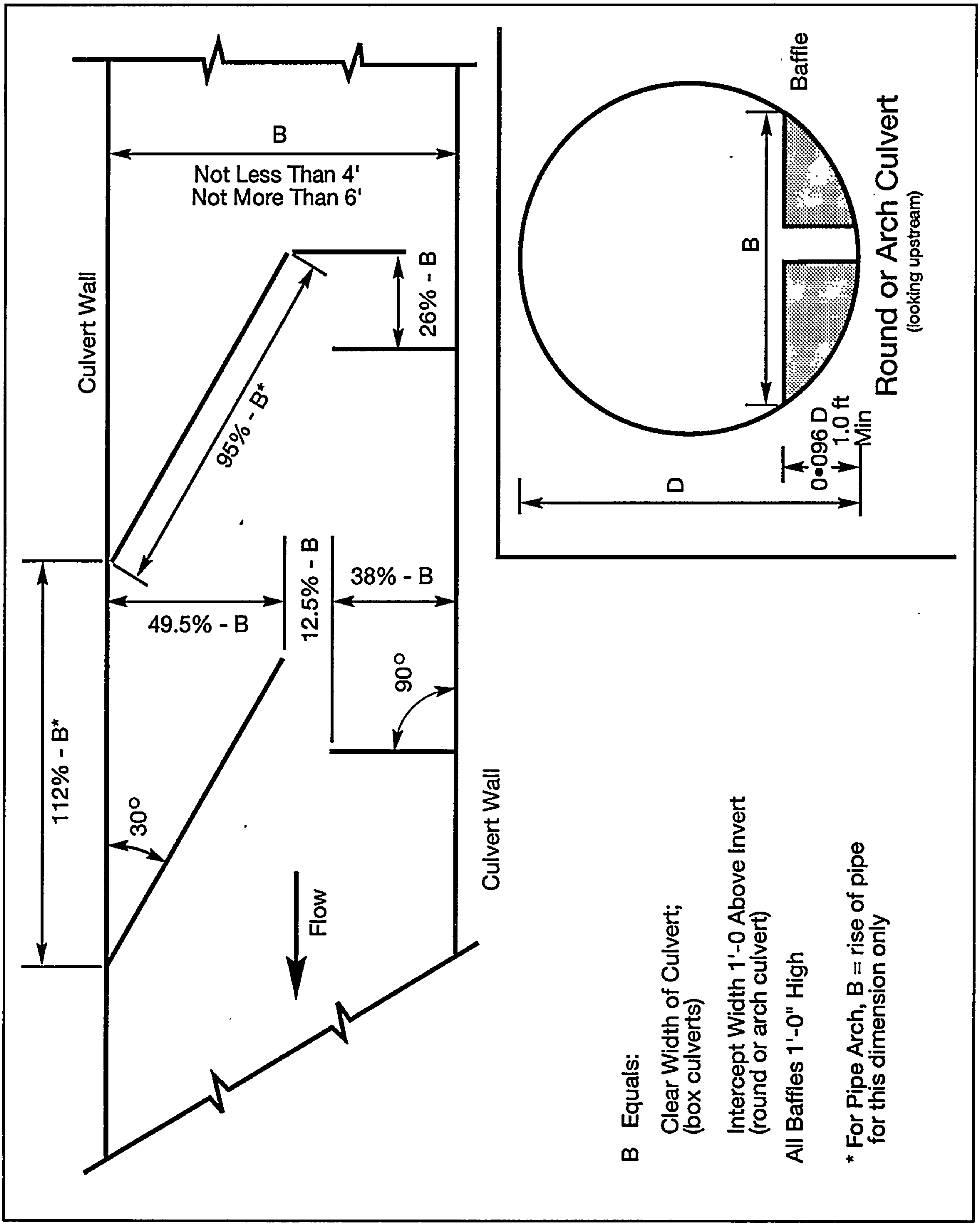


Figure 25. Culvert baffles. McKinley and Webb, 1956.

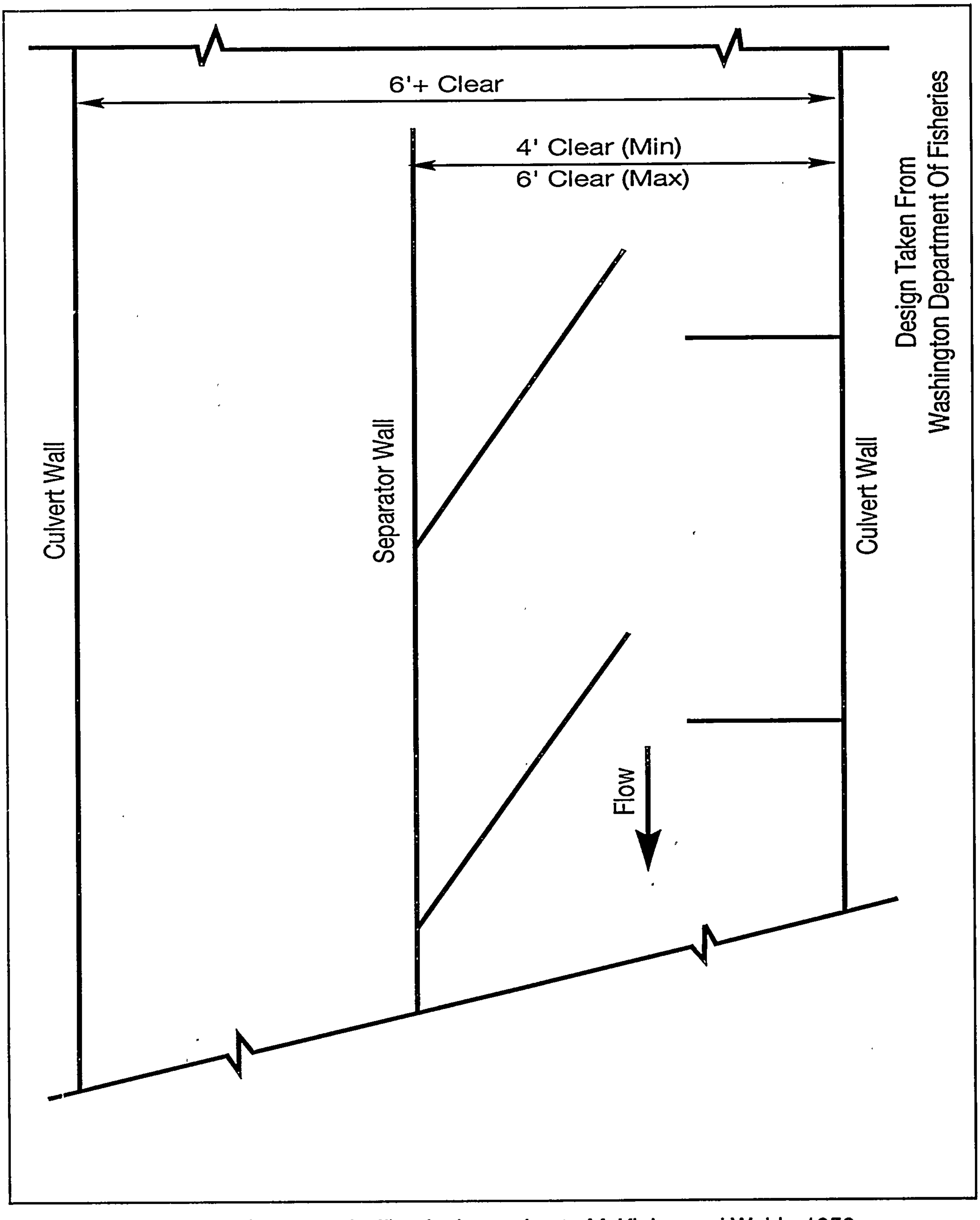


Figure 26. Separator baffles for box culvert. McKinley and Webb, 1956.

dimensions have been given as percentages of total width of the baffled section. These dimensions and the angles of baffles have been determined through research and should be adhered to. Baffles should be a minimum of 1 ft high and 5 to 6 in wide.

The designer should always keep in mind that fish passing through a culvert will seek the lower velocity areas. Figure 27 displays the cross-sectional velocity of water flowing through a typical culvert. Behlke, et al, 1988, report that fish passage does not take place on the bottom of a culvert as is popularly believed. Fish will often migrate along the sides of a culvert near the water surface where velocities are lowest. Smaller fish will swim close to the wall of a pipe near the corrugations. In the absence of baffles the authors advocate that the largest corrugations possible should be used where fish passage is critical --- 6 by 2 in for steel structural plate, 9 by 2 1/2 in for aluminum structural plate and 5 by 1 in for corrugated metal pipe. The above researchers propose further studies be conducted on baffles on culvert walls versus baffles on culvert bottoms.

Several general principles have been developed through long experience with the baffles system.

1. Avoid using baffles wherever possible. Resolve fish passage problems through use of bridges, arch culverts, or culverts of sufficient size to reduce velocities.

2. Corrugated metal pipes and pipe arches are designed as flexible structures. Unless the baffle system is equally flexible, the system will have a higher potential for structural failure than the pipe itself.

3. If higher velocities or extensive distance are unavoidable in a round or box culvert installation, baffles may be necessary. Baffles and the 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.

4. A large single culvert usually provides better fish passage than several smaller ones. Where multiple units are required, only one must be baffled 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. Consider installing a separate fish passage culvert so that a baffle system is not required for fish passage.

5. Multiple culverts can be installed to provide for fish passage at the same time allowing for high flows. This alternative may be less expensive than installing a baffle system in a culvert.

6. Calculate the relative efficiency of the culvert with and without baffles, as the passage of water through the culvert will be impaired by the baffle structures. Most culverts are over designed for the discharge conditions, (to provide the necessary large safety factor), and the actual impairment of the culvert's ability to discharge may be relatively small. Refer to Figure 24, Engle, 1974.

7. 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. Simply bolting the baffle to the culvert floor is inadequate. It usually pulls loose during flood flows.

8. Most baffles are designed for peak performance when water flow is just overtopping them and their effectiveness is inversely proportional to the depth of water over them, Gebhards and Fisher, 1972.

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

10. For round metal culverts, a minimum culvert diameter of 5 ft is required to provide a 4 ft wide space for baffle installation, Figures 25 & 26. Culverts that are less than 5 ft in diameter should generally not be equipped with baffles. Other alternatives need to be considered, such as natural bottom culverts.

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. Also a culvert with a steep gradient can be converted into a series of pools—in effect, creating a modified fish ladder.

Culvert Outfall Barriers (Perching)

Culverts can often have 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 generally occurs when the outlet is installed above the stream elevation or velocities through the pipe are high enough to wash out the stream below the culvert. This condition is referred to as an outfall barrier or culvert perching. Figure 28.

A perching problem can be corrected by installing one or a series of low head dams below the culvert outfall. Often these dams may be little more than hand placed rock,

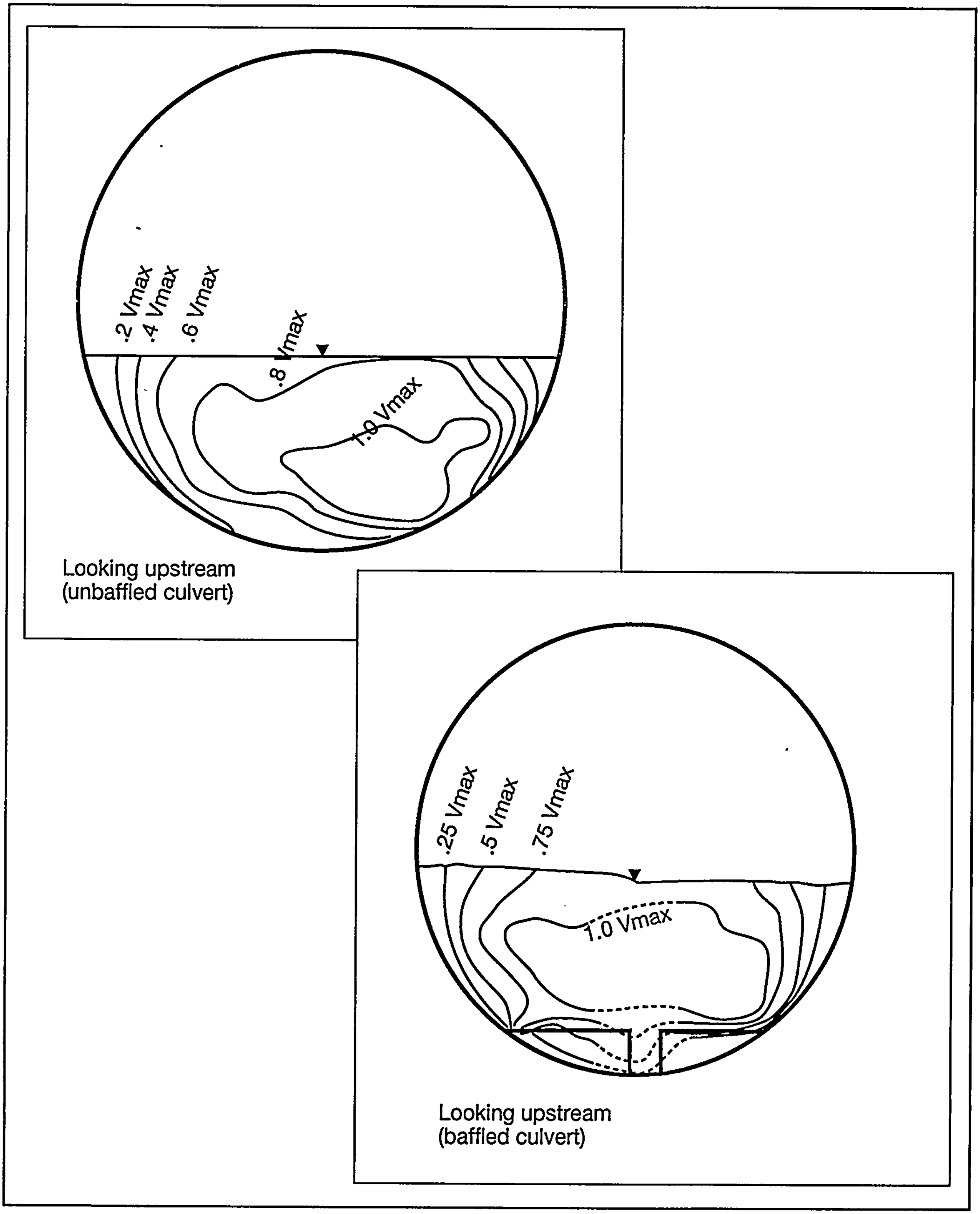


Figure 27. Typical velocity section for unbaffled and baffled culverts. Katopodis, 1978 (modified).

gabion baskets filled with local rock, concrete sills, or logs. Figures 29 & 30. The purpose of these dams is to raise the tailwater elevation and flood the culvert outlet. The end result is enhanced fish access and reduced culvert velocity at the outlet. The low head dams down stream should therefore be limited to a 1-ft drop or have a weir to allow for fish passage. It may be necessary to install several downstream dams to get the desired elevation if the culvert outfall barrier is excessive.

The general purpose of these tailwater control structures is fourfold.

1. The structure provides a resting pool for migrating fish before they swim into the higher velocity culvert.

2. Creating a backwater into the pipe allows for adequate water depths in the culvert. However, backwatering reduces the pipe capacity. Retrofitting small diameter pipes in this manner may not let the culvert pass peak flows. For large diameter pipes, this loss of capacity is usually negligible.

3. A backwater reduces the velocity at the culvert outlet thereby enhancing fish migration.

4. Much of the energy from the culvert is dissipated in the pool created by the tailwater control section. The pool provides a transition zone between the culvert and the natural channel downstream.

Determining if a perching problem will occur is essential in proper culvert design. One method for calculating the probability is to use Manning's Equation to determine the flow in the pipe. If velocities are expected to increase substantially through the pipe, then perching at the culvert outfall is likely to occur. This can be mitigated by providing tailwater structures as outlined above or by

Figure 28. Perching.

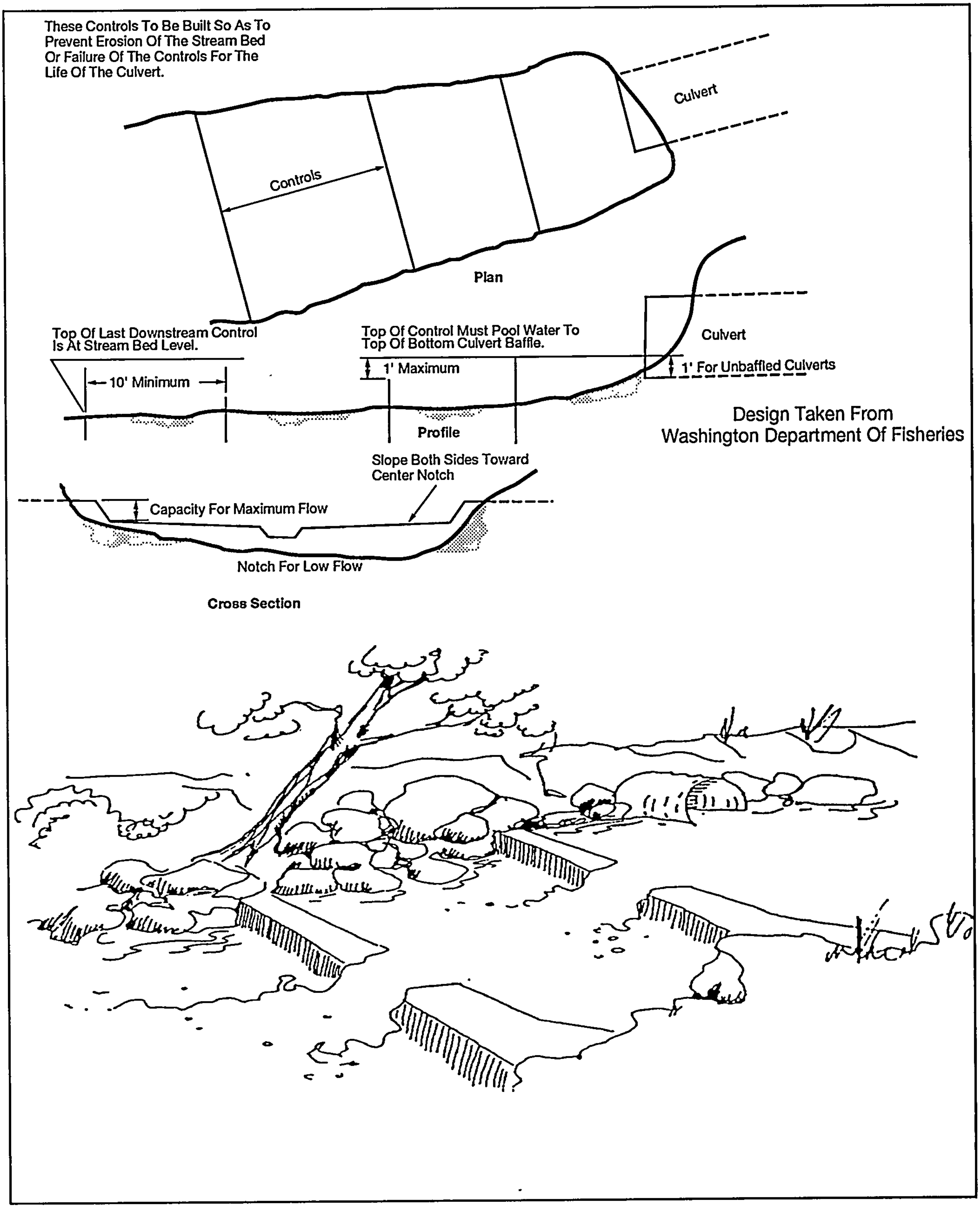


Figure 29. Gabion or concrete sills can raise tailwater elevations to facilitate fish entry into culverts. Evans and Johnston, 1980.

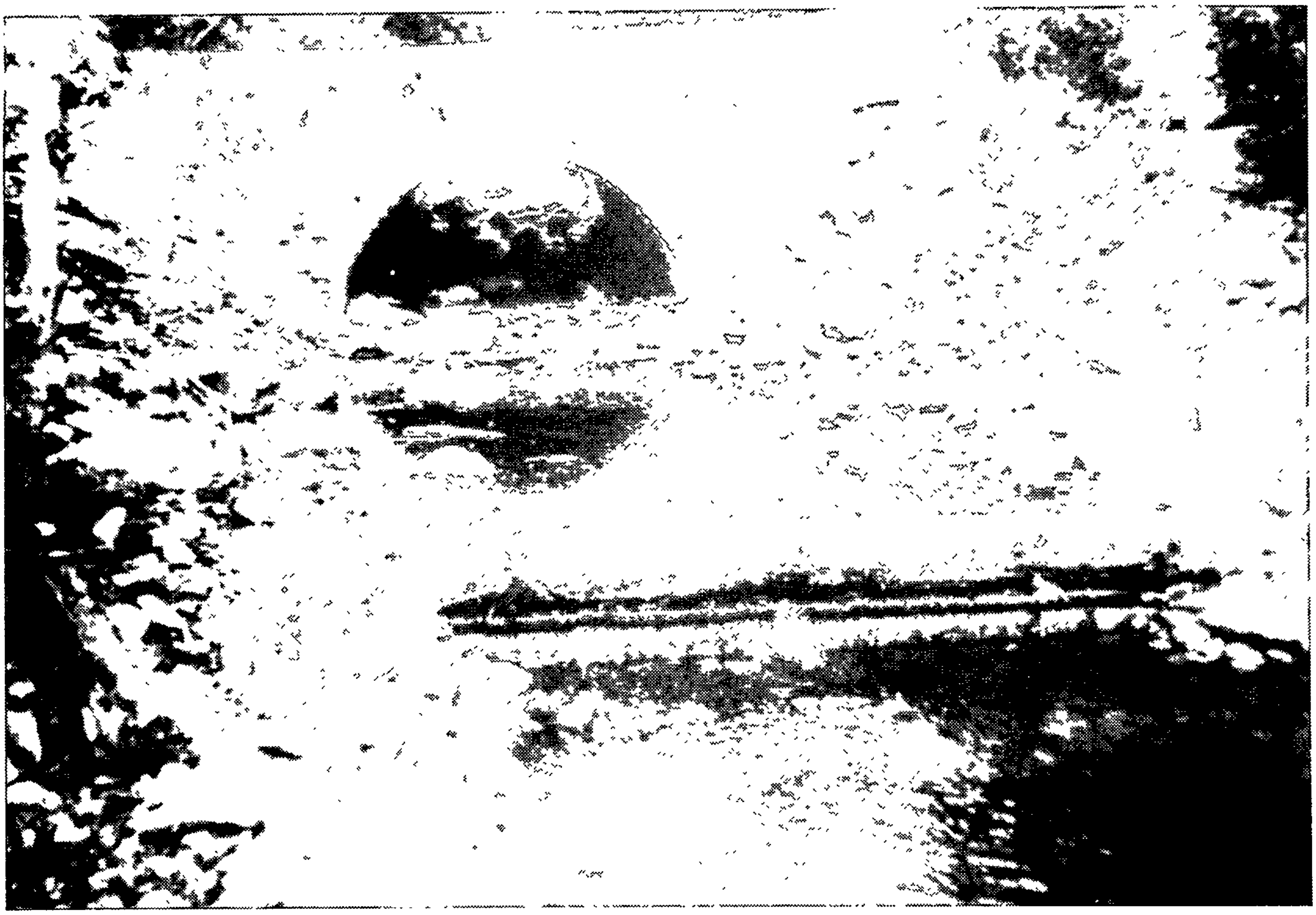


Figure 30. Correct perching problem.

riprapping the outlet.

Perching is not confined to higher gradient culverts but can occur at very low culvert gradients and at low water velocities. Any velocity increase above natural levels (for example, by decreasing the stream width) will tend to accelerate velocities in the culvert, even if the culvert is installed at or below natural stream grade. Perching can also be caused by improper installation where the outlet is higher than the natural streambed.

One way to anticipate and effectively prevent perching is to construct a culvert outfall basin to dissipate the energy of the water flow which many times is concentrated at the culvert outlet. The length and width of such a basin should be about twice the diameter of the culvert and the depth should be about 2 ft below the invert elevation of the culvert outlet. These outfall basins should be amoured with riprap large enough to prevent streambed scour. However, the most cost effective solution may be to design a pipe large enough in diameter that still does not increase velocities.

Inlet Drops, Figure 31.
Observation indicates that approximately 10 percent of the culverts subjected to detailed examination in Alaska were seen to have drops at the culvert inlet, Kane and Wellen, 1985. These drops can become a barrier to upstream fish migration at high or even moderate flows. In all cases they felt that these drops were due to deposition of material from either the natural streambed or adjacent roadway embankments. These drops could have been the result of several conditions:

1. When the deposition was from natural streambed material, it resulted from lower velocities at the upstream end of the culvert as the culvert was laid on a flatter grade than the stream.

2. The use of undersized pipe could have caused a backwater condition that promoted deposition.

3. Deposition from the adjacent roadway embankment occurred when riprap material rolled down the embankment to rest in front of the culvert inlet.

In any case, the deposition resulted in supercritical flow conditions creating hydraulic jumps within the culvert. Even at moderate flows fish passage can be significantly reduced.

To control velocity in culverts, many designers have advocated that a maximum gradient be used, Figure 32. In many cases this results in the culvert being installed at less than the stream gradient, particularly in mountain streams. This will result in lower velocities only if the culvert is enlarged to handle the same design discharge. However, such designs may result in reduced sediment carrying capacity and debris deposited at the upstream end of the culvert. Significant deposition can create the inlet drops discussed above if the designer does not consider the effects on sediment carrying capacity. In addition, the outlet end of the culvert needs to be installed at or below the streambed or a culvert perching problem can occur.

Several documents have been identified to provide further information should it be needed. One such publication is "Design of Depressed Inlet Culvert", Jordan and Carlson, June 1987. Figure 33.

Debris Control, Figure 34.
Streams at high flows often carry brush, large branches, whole trees, or other material. The accumulation of such debris at a culvert inlet can result in water overtopping the roadway, washing out backfill, or inundation of upstream land. More culverts have washed out due to debris plugging than to design inadequacies. Often, the

Figure 31. Inlet drops --- notice hydraulic jump.

end result is downstream destruction of fish habitat with sedimentation and loss of capital investment of roads and highways.

Should debris control be a consideration, the designer has three options for handling debris. First, the debris can be controlled upstream or at the inlet of the culvert. In this case, frequent maintenance may be required. A relief culvert placed higher on the embankment and in higher fills can often be installed as insurance that the entire embankment is not lost. Second, the designer may elect to try to pass the debris through the culvert. This may result in a larger culvert than needed just to pass the water flow. Third, as a last resort, the designer may elect to install a bridge where debris is so heavy that neither of the other options will work or if the values of downstream fisheries are so high that excess sedimentation cannot be allowed.

In performing a debris study the following factors should be considered:

1. Type of debris.

2. Quantity of debris.

3. Potential of the stream to carry debris based on factors such as water depth, channel width, and alignment.

4. Expected changes in type and quantity of debris due to future land use.

5. Streamflow velocity in the vicinity of the culvert.

6. Accessibility for periodic maintenance.

Publication	Suggested Maximum Gradient
Evans and Johnston (1972)	At or near zero
USDA - Forest Service (1979) R5	3% less than stream grade
State of Alaska, DOT&PF, Hydraulic manual	Flat grade
Morsel et al (1981)	0.5%
Dane (1987)	Less than 5% with baffles
Dryden & Stein (1975)	Prefer 0% gradient; less than 5% with baffles
Gebhards and Fischer (1972)	less than 0.5%

Figure 32. Suggested maximum gradients.

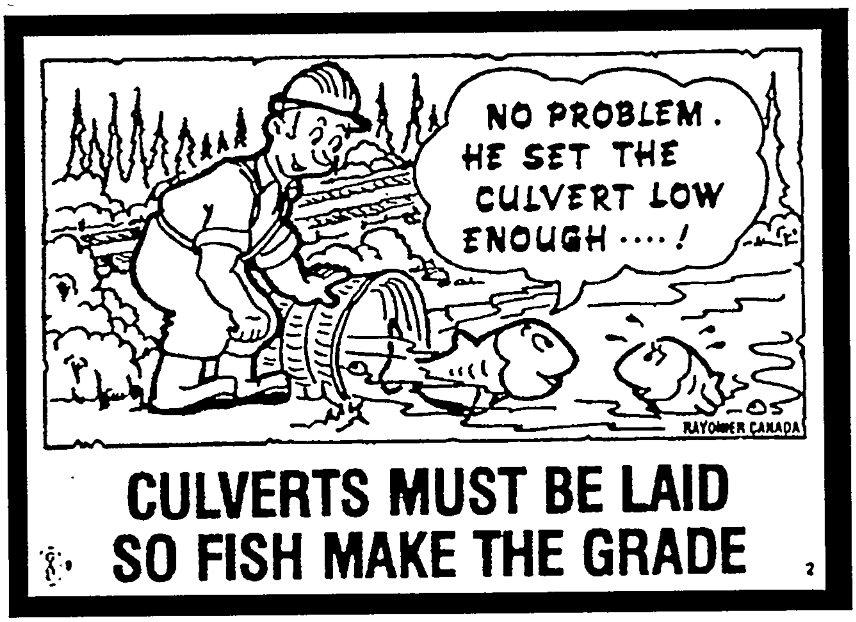


Figure 33.

Figure 34. Debris at culvert inlet..

7. Availability of water storage above debris catchments.

8. Assessment of damage due to debris clogging, if protection is not provided.

Hydraulic Engineering Circular (HEC), No. 9, "Debris Control Structures", published by the Federal Highway Administration, should be used when designing debris control structures. The designer should understand that debris control structures do not eliminate the need for maintenance. In fact, debris control structures will require a well thought out plan of periodic inspection.

A debris removal project extending hundreds of feet above and below a structure may well result in removal of streambed stabilizing material and fish hiding cover. The end result can easily be unstable streambeds, excess sediment, and a loss of fish habitat.

Aufeis

One of the most difficult phenomenon to assess for fish passage is that of the buildup of ice in stream channels or culverts. This event is termed aufeis. This process occurs naturally in small shallow headwater streams as well as in larger braided streams and rivers in cold climate. Culverts can increase the severity of the aufeis problem. In colder regions the ice can completely fill culverts resulting in the water overtopping the culvert and running down the roadway. The ice buildup reduces the cross-sectional area of culverts and can produce much higher water velocities than those indicated by the design, Kane and Wellen, 1985. Fortunately, aufeis does not normally occur during migration and is, therefore, a minimal problem for fish passage.

Culvert Alignment

Problems with fish passage can occur if culverts are not aligned with the natural stream channel. Sudden changes in stream flow direction can result in turbulence and erosion of the streambank and roadway excavation. When stream meanders are substantially cut off by culvert installations, the slope of the culvert and the resulting stream velocities will be greater than the original velocities. Such conditions are very conducive to scour of the culvert outlet.

To prevent scour or erosion at a culvert site the following points should be considered, Figure 35:

1. Avoid locating a culvert crossing at or near bends in the stream. The channel should be as straight as possible.

2. Avoid aligning the culvert so that culvert outflows are directed into a streambank. If a road crossing is not perpendicular to the stream, the culvert installation should be skewed.

3. The stream channel downstream from the culvert should be stable to avoid lowering natural control points in the stream and subsequent backcutting through the structure.

4. Cuts, fills, and other disturbed areas should be appropriately armoured during construction. Armouring can be accomplished by planting grass and brush where water will constantly attack the disturbed areas. Consideration of armouring should be given where improper culvert alignment cannot be avoided and banks are threatened by erosion.

5. Undermining of culvert inlets or outlets can be prevented by the construction of cutoff walls attached to the bottom of the culvert and extending perpendicular to the streambed. Use of aprons at the inlet or outlet should be avoided. Possibly a better solution to cutoff walls can be constructed of riprap keyways where the area immediately below the outlet is subexcavated and filled with subrounded riprap.

6. Good compaction around inlets is important and fills should be warped to cover as much of the pipe as possible. This will increase the inlet efficiency as well as reduce scour. Figure 36.

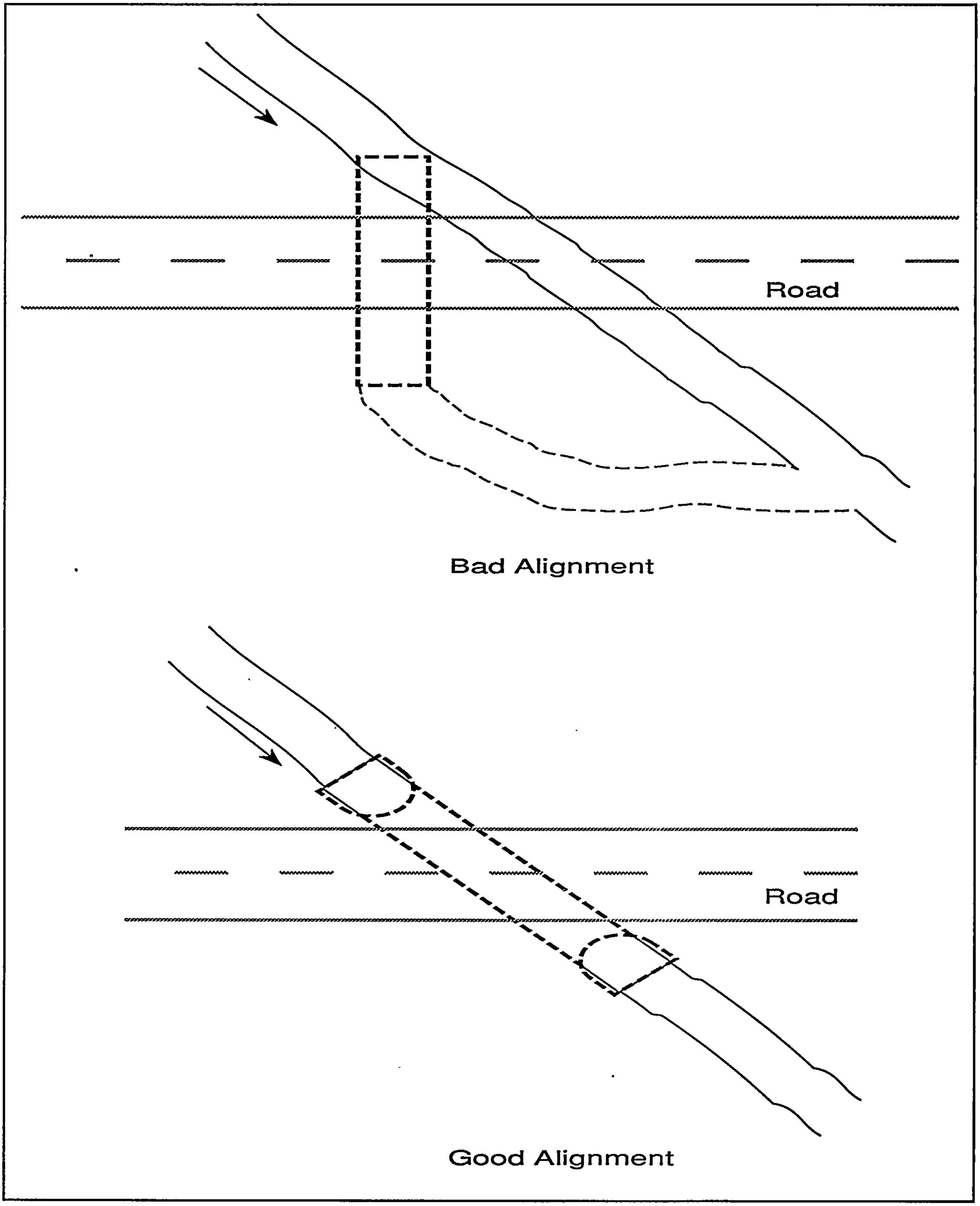


Figure 35. Locating culvert crossings.

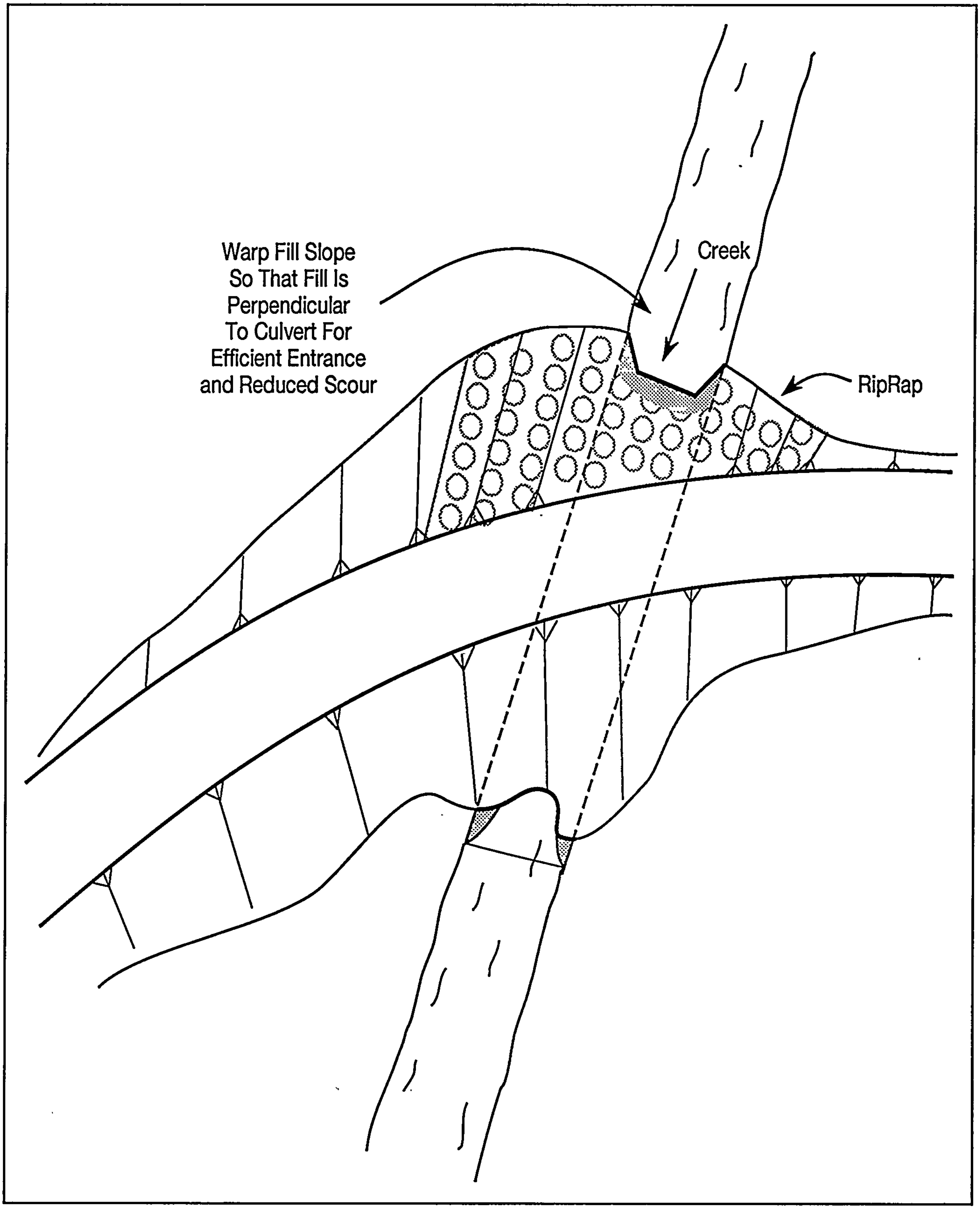


Figure 36. Typical section for warping fill slopes to increase hydraulic efficiency and to reduce scour.

SUMMARY

The success of fish migration through culverts is dependent on the swimming ability of the fish and the hydraulic conditions of the culvert. Properly designed and constructed culverts can minimize the impact on fish passage.

Because culverts are typically more economical than bridges, it is appropriate to evaluate when to use culverts and to predict the effects of such culvert installations. During the consideration of alternatives for structures for fish passage, culverts should not be automatically eliminated. This publication has tried to examine the aspects of culvert design and operation relative to the existing information that has been published in previous studies.

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. Any change in these conditions will result in a velocity change which could alter the sediment transportation capacity of the stream.

A truly successful culvert design would include matching the velocities of the fish's swimming zone in the culvert to the swimming capacity of the design fish. Unfortunately, not enough research has been completed to make this an acceptable criterion of culvert design. This approach is preferred because it is easier to reduce the velocities in the swimming zone by increasing boundary roughness than it is to reduce the mean velocity of the entire culvert.

This publication contains some relatively simple guidelines which can reduce the installation problems of culverts in streams containing migrating fish when combined with the expertise of an experienced fish biologist, engineer, and hydrologist.

APPENDIXES

APPENDIX A

DESIGN CONSIDERATIONS OF FISH PASSAGE THROUGH CULVERTS

A. BIOLOGICAL CONSIDERATIONS

1. Species of fish potentially impacted
    a. Age
    b. Velocity tolerances of fish over the design culvert length
    c. Time of migration
    d. Allowable delays (length of time)

2. Quality and quantity of upstream habitat

3. Presence of fish barriers upstream and downstream

4. Upstream channel stability and debris potential

5. Upstream management activities that may affect or impact fisheries

B. ENGINEERING CONSIDERATIONS

1. Road profile

2. Road cross section

3. Proposed culvert parameters
    a. Culvert length
    b. Type of inlet
    c. Proposed culvert alignment

4. Streambed foundation

5. Site access

6. Constraints
    a. Regulatory constraints (i.e. flood plains)
    b. Arbitrary constraints (i.e. allowable headwater depth)

7. Desired life expectancy of structure
    a. Corrosive soils
    b. Excessive streambed loads
    c. Options for repairing/replacing culvert once installed

C. HYDRAULIC CONSIDERATIONS

1. Design peak flows

2. Streambed parameters
    a. Gradient
    b. Cross section
    c. Roughness coefficient
    d. Hydrograph
    e. Bedload quantity

3. Debris considerations
    a. Amount and type
    b. Ice buildup

4. Upstream water storage

5. Upstream and downstream conditions that could affect culvert performance

Note: These design considerations can be formatted into a checklist for other agencies' needs.

APPENDIX B

GLOSSARY

abrade	Wear or scour by water and by the material transported by water.
adfluvial	Produced by river action. Also occasionally used in reference to fish that mature in lakes and migrate upstream into tributaries to spawn.
alviens	Newly hatched fish with the yolk sack still attached.
anadromous fish	Fish, such as salmon and some trout, that are born in freshwater rivers and tributaries, migrate downstream and mature in the ocean and return to freshwater to spawn.
apron	Erosion protection placed below streambed in an area of high velocity flow such as downstream of a culvert.
armouring	Lining of stream channel or banks with rock or other material to protect slopes from scour.
aufeis	Build up of ice in stream channels or within a culvert.
baffle	Obstruction, usually wood, concrete, or metal, placed inside a culvert to deflect and check and the flow of water.
bed load	Sediments, rocks, and boulders not in suspension rolled or dragged along a stream bottom.
bituminous	Material consisting of hydrocarbons mainly, as in asphalt or tar.
box culvert	Square shaped concrete or wood culvert usually assembled in the field.
burst speed	The highest rate of speed a fish can generate for a short period of time (such as several seconds).
cobble imbededness	The degree to which dominant stream substrates are buried by other materials such as sand or silt.
cofferdam	Temporary enclosure built in a water course and pumped dry to permit work on a structure by separating the work area from the water.
corrugations	Alternating series of grooves and ridges formed into a galvanized steel or aluminum culvert.
critical depth	Depth of flow at which specific energy is a minimum — water depth in a conduit at which under certain conditions maximum flow will occur. These other conditions are—the

conduit is on the critical slope with the water flowing at its critical velocity and there is an adequate supply of water. The depth of water flowing in an open channel or a conduit partially filled, for which the velocity head equals one-half the hydraulic mean depth.

critical flow — A condition that exists at the critical depth, and where the sum of the velocity head and static head is a minimum.

critical slope — The slope at which maximum flow will occur at minimum velocity. The slope or grade that is exactly equal to the loss of head per foot resulting from flow at a depth that will give uniform flow at critical depth.

critical velocity — Mean velocity of flow when flow is at critical depth.

cruising speed — The speed at which a fish can swim for an extended period of time (such as an hour or more).

culvert — Usually a factory assembled round-shaped conduit connected together with couplers or bands. It differs from a bridge in that it is usually constructed entirely below the road surface.

design discharge — A quantity of flow that is expected at a certain point as a result of a design storm. Usually expressed as a rate of flow in cubic ft^3 per second.

design frequency — The recurrence interval for hydrologic events used for design purposes. As an example, a design frequency of 50 years means a storm of magnitude that would be expected to recur on the average of once in every 50 years.

design life — The length of time that is economically sound for a structure to serve without major repairs.

embankment — A structure of soil, aggregate, or rock material constructed above the natural ground surface.

fish habitat — Resources and conditions essential for the production of fish including sufficient water quality and quantity, spawning and nursery and rearing areas and food supply areas all of which fish depend directly or indirectly for their processes.

fish migration — The movement of individual fish and/or fish populations for any purpose, including feeding, spawning, rearing etc.

fork length — The length of a fish measured from the most anterior part of the head to the deepest point of the notch in the tail fin.

gabion — A patented woven wire basket filled with rocks of such a size that they do not pass through the openings in the basket. Individual baskets are stacked in place like building blocks and filled with rock to form erosion resistant structures.

genetic segregation — The separation of a genetically distinct population from its original gene pool, or the separation of a portion of a population that may not possess the genetic range of the original population.

geotextile — Synthetic polyethelene fibers manufactured in a woven or loose non-woven pattern to form a blanket-like product.

gradient (slope) — The rate of rise or fall of a grade—expressed as a percentage or ratio as determined by a change in elevation to the length.

head - (static) — Height of water above any plane or point of reference. (The energy possessed by each unit of weight of a liquid. Expressed as the vertical height through which a unit of weight would have to fall to release the average energy possessed). Unit of measure is usually ft or m.

Relation between pressure head expressed in lbf/in^2 and lb/ft^2 is $\underline{lb/in^2 \times 144}$ for water at 68 F

Head in feet = Density in lb/ft^3 1 lb/in^2 = 2.31 ft

headcut — Process of erosion of the streambed back from the initial point of erosion.

hydraulic gradient — A line which represents the relative force available due to the potential energy available. This is a combination of energy due to the height of the water and internal pressure. In an open channel, the line corresponds to the water surface. In a closed conduit, if several openings are placed along the top of the pipe and open end tubes inserted, a line connecting the water levels in the tubes inserted represents the hydraulic grade line.

hydraulic jump — Abrupt rise in water surface depth. The surface of the jump is very rough and turbulent. This condition occurs when critical flow turns to subcritical flow. The resulting loss of energy is released into turbulent flow.

hydraulic radius — The cross-sectional area of a stream of water divided by the length of that part of its periphery in contact with its containing conduit; the ratio of area to wetted perimeter.

hydrograph — Plot of stream flow as time for a given drainage for a typical or specified rainfall distribution of some specified duration.

impoundment — The process of damming water. Also the resulting body of water from a dam or weir.

inver — That part of a culvert that is the lowest part of the internal cross section.

invertebrate — Animals that contain no backbone such as insects or crustaceans.

juvenile — Young fish, one that has not reached full maturity.

Manning's formula or equation — An equation for determining the quantity of flow whose factors are the hydraulic radius, cross section area of flow, and a coefficient of roughness.

maturation — The process of development into an adult.

morphology (stream)	The study of the form and structure of creeks, streams, and rivers.
nomographs	A graph or chart that reduces a mathematical formula to curves so that its value can be read on the chart's coordinates for any value assigned for the variables involved.
nursery	A rearing area for juvenile fish.
outfall	The discharge end of a culvert.
peak flow	The maximum instantaneous rate of flow during a flood.
perching	The tendency to develop a falls or cascade at a culvert outfall due to the erosion of the stream channel downstream from a culvert or drainage structure.
pipe arch	Multi-plate or structural plate culverts assembled on a treated timber or concrete foundation. Because of their size (normally in excess of 6 ft in diameter) and the fact they are placed on a foundation, they are normally field assembled in place. A series of interlocking steel plates are bolted together to make the required shape and length.
resident fish	A fish that spends its entire life in a limited range of habitats, such as fresh water. It should be noted that a resident fish can still be migratory.
riprap	Large cobbles or boulders placed along a stream or other water course to protect the banks from scour and erosion.
riverine pond	A pond or side channel area located off of the main river channel. This type of habitat is commonly used by fish for rearing and/or protection during adverse river conditions.
road alignment	The horizontal route or direction of a road. It is made up of straight line tangent sections and curves.
salmonid	Any of the fish belonging to the family Salmonidae such as whitefish, grayling, salmon, and trout. Most commonly used in reference to salmon and/or trout.
scour	Term used to describe soil erosion when it occurs underwater as in the case of a stream bottom or bank.
sediment	Eroded soil particles which are transported by wind or water and are deposited in a stream or lake.
spawning bed	A habitat used by fish for spawning.
structural plate	Corrugated steel plates or sheets, bolted together to form large pipes, pipe arches, marches, and other structures.
supercritical flow	The flow of water at a high velocity. It is usually defined as rapid, shooting, or torrential.

sustaining speed	The swimming speed fish can maintain for several minutes.
tailwater	The water just downstream from a structure.
ten-year flood	Maximum quantity of water flow per second expected at a particular water crossing, on a statistical average, once every ten years. It has a 10 percent probability of occurring in any given year. Other return frequencies are defined in a similar manner.
watershed	Region or area contributing to the supply of a stream or lake; drainage basis, catchment area.
weir	Small dam in a stream that causes water to back up behind it, and flow over or through it. Many times has a notch to control where the water flows over it.

APPENDIX C

Literature Review

NOTE : All summaries denoted with a ** are taken verbatim from Lynette Anderson and Mason Bryant. Fish Passage at Road Crossings: An Annotated Bibliography. Pacific Northwest Forest and Range Experimental Station, USDA - Forest Service. 1980. 10 p.

Adamovich, L.; Willington, R. P.; Lacate, D. Bibliography on forest roads and the environment. Fac. For. Univ. BC, Vancouver. Unpubl. ms. 1973. 25 p.

**A list is given of published and unpublished material on most aspects and effects of forest roads through 1973. Topics include esthetics, aerial photo interpretation, bridges, construction, cut and fill procedures, and various effects on fisheries.

Ashton, William S.; Carlson, Dr. Robert F. Determination of seasonal, frequency, and durational aspects of streamflow with regard to fish passage through roadway drainage structures. Institute of Water Resources, University of Alaska, Fairbanks, AK, State of Alaska, Department of Transportation and Public Facilities, Fairbanks, AK. November 1984. 51 p.

This report studied the streamflow data from 33 watersheds smaller than 100 sq. mi. throughout Alaska to develop methods to predict the magnitude and frequency of high and low flows for specific durations and seasonal periods of the year. Both high flows and low flows are important in the migratory habits of various fish species. This report provides the culvert designer with equations to predict such flows, other than the instantaneous peak flow, for use in designing culverts for fish passage.

Behlke, C.E.; Kane, D.L.; McLean, R.F.; Travis, M.D. Field Observations of Arctic Grayling Passage Through Highway Culverts. Research Paper presented at Transportation Research Board 68th Annual Meeting, Washington, DC. January 22-26, 1989. 13 p.

This report discusses six qualitative observations made during the completion of four field studies involving Arctic Grayling in Alaska from 1985 to 1988. These observations are: fish move upstream through a culvert along the boundary near the water surface where water velocity is significantly less than the average cross-sectional velocity; fish tend to swim oriented normal to the sloping culvert wall with their bellies very near the wall; skewed culverts have lower flow velocities along the "upstream" side of the culvert allowing for easier fish passage; red and white muscles used by fish for slow/fast swimming movements relate to fish responses to faster velocities at the culvert inlet and outlet and slower velocities along the culvert sidewalls; water noises attract upstream-migrating fish to natural and man-made fish passageways, and surface waves within culvert barrels caused by supercritical flow velocities retard fish passage. These observations were reported to provoke thought and to inspire future studies.

Belfore, D. A.; Gould, W. R. An Evaluation of Trout Passage Through Six Highway Culverts in Montana. N. Amer. Jour. of Fish Mgmt. (6 94) 1989. 437-445 p.

The authors examined non-anadromous rainbow, brown, cutthroat, and brook trout passage through six corrugated metal culverts in Montana. The trout were studied during natural upstream spawning runs from 1984-1986. Relationships between mean bottom velocities and passage length were derived for each species. The factors that produced strenuous passage for spawning rainbow trout was believed to be fairly representative for other trout species studied. The maximum recommended water velocities were about half of previous recommendations for anadromous fish. The authors did not find a relationship between fish length and culvert passage ability among the fish studied.

Bell, M. C. Fisheries handbook of engineering requirements and biological criteria. Fish. Eng. Res. Program. Corps. Eng., North Pac. Div., Portland, OR. 1973.

** A wide range of information on fisheries and engineering problems is included. Areas applicable to fish passage are discussed in several chapters, including passage around dams, fishways and other conduits, swimming speeds, and velocity barriers. Chapter 31 deals specifically with culverts and briefly discusses some of the hydraulic characteristics.

Some general guidelines for culvert installation are provided: culverts should be installed close to zero gradient; average velocities with a slope of 0.5 percent are 4.8 to 2.6 ft, which will allow fish to pass; culvert floor roughness should approximate natural streambed; and a minimum swimming depth of 12 in should be allowed. Darkness in a culvert is not a block to fish passage.

Blahm, T. H. Passage of salmon fingerlings through small tunnels. Trans. Am. Fish. Soc. 92(1): 1963. 302-303 p.

** Tests were conducted in an artificial channel to determine the optimum combination of water velocity and light that would be most effective for downstream passage of salmon fingerlings through small tunnels. Higher velocities (3.0 to 3.5 ft) in combination with downstream light induced the highest percentage of downstream passage.

Calhoun, A. J. Inland Fisheries Management, California Dept. of Fish and Game, Sacramento, CA. 1966. 546 p.

Carlson, Dr. Robert F. Seasonal, frequency, and durational aspects of streamflow in Southeast and Coastal Alaska. Water Research Center, Institute of Northern Engineering, University of Alaska - Fairbanks, Fairbanks, AK, State of Alaska, Department of Transportation and Public Facilities, Fairbanks, AK. March 1987. 40 p.

Five criteria are important to the design of culverts for fish passage: the hydrologic flow regime of the stream; the hydraulic properties of the culvert; the swimming abilities of the fish species; the time of year of fish migration for a given species; and the allowable delay in fish migration caused by high or low flows through a culvert. This report analyzes existing streamflow data from watersheds smaller than 100 sq. mi. in the southeast, the coastal southcentral and the Aleutian regions of Alaska. Significant basin and climatic characteristics for high and low flows was determined to be drainage area, mean annual precipitation, mean minimum January temperature, and percent of drainage area with forest cover and lake cover. The report develops equations and a method to predict the magnitude and frequency of high and low flows for specific durations and periods of the year. This allows the designer to estimate flow and frequency of a stream for a critical time of year (migration) and duration (delay factor) on a given stream.

This publication has some information for the fish biologist to use in determining allowable delays in fish migration. It also contains information on flow volumes to be used to calculate velocities.

Cederholm, C. J.; Scarlett, W. J. Seasonal Immigration of Juvenile Salmonids into Four Small Tributaries of the Clearwater River, WA. 1977-1981. Brannon, E. L. ; Salo, E. O., editors. Salmon and trout migratory behavior symposium. University of Washington, Seattle, WA. 1981. 98-110 p.

An annotated bibliography was not completed on this publication.

Clay, C. H. Design of fishways and other fish facilities. Dep. Fish. Can.,Ottawa, ON. 1961. 301 p.

** This handbook of fish-passage devices primarily deals with artificial and natural obstructions. Design criteria for fishways, vertical slot passages, entrances, baffles, and exits are discussed. Other chapter topics include fish locks, weirs, barrier dams, fish screens, and artificial spawning channels. A brief review of elementary hydraulics is contained in an appendix.

Collins, G. B.; C. H. Elling. Fishway research at the fisheries-engineering research laboratory. U.S. Fish and Wildl. Serv. Circ. 98. 1960. 17 p.

** Results of 4 years of research on fishway problems, rates of movement of salmonids ascending fishways, and spatial requirements of fish are given. Experiments to measure fishway capacity are described. The effect of fishway slope and length on fish performance and physiology were measured in "endless" fishways. Preference of salmonids for water velocities and light conditions revealed marked differences among species. Effects of light and water velocity on rates of passage through channels and fishways are described. Experiments on fingerling passage and the testing of full-scale prototype fishway designs are discussed.

Collins, G. B.; Gauley, J. R.; and Elling C. H. Ability of salmonids to ascend high fishways. Trans. Am. Fish. Soc. 91(1). 1962. 1-7 p.

** Ability and persistence of salmonids to ascend pool-and-overfall fishways were measured in experimental "endless" structures in which fishways of any height could be simulated. Rate of ascent of all fish tested increased after an initial period of experience in the fishway. Measurement of blood lactate in the exercised fish showed no evidence of fatigue. Practical significance of the data in relation to fishway design is discussed.

Dane, B.G. A review and resolution of fish passage problems at culvert sites in British Columbia. Fish. and Mar. Serv. Tech. Rep. 810. 1978. 126 p.

**Report includes guidelines for culvert design and installation, which describe salmonid passage requirements and hydraulic parameters. Five types of culverts are described. Their characteristics are compared with photos and sketches. The author describes type, cause, and effect of obstructions in the spawning/ rearing area, as well as effects of habitat and hydraulic instability. Recommendations are made for the installation of culverts to avoid conflict with fish use in the stream during construction. For a condensed version of this report, see Dane, Culvert guidelines: Recommendations for the design and installation of culverts in British Columbia to avoid conflict with anadromous fish. Fish. & Mar. Serv. Tech. Rep. 811.57p.

Dane, B. G. Recommendations for the Design and Installation of Culvert in British Columbia to Avoid Conflict With Anadromous Fish. Fish and Mar. Serv. Tech. Rep. 811, 1978. 57 p.

A summary report of the previously cited publication by Dane (Tech. Rep. 810).

Dass, P. Analysis of slot orifice fishways. M.S. thesis. University of Idaho, Moscow, ID. 1970. 101 p.

**Criteria for a slot orifice fishway are developed and the size and space of orifices can be designed to create flow conditions conducive to fish passage. The slot orifice fishway functions well in a wide range of discharges and should not have any serious silting problems. Values of drag coefficients for the slot orifice constrictions were evaluated by model studies.

Derksen, A.J. Canada Department of Natural Resources, Manitoba; Evaluation of fish passage through culverts at the Goose Creek Road Crossing near Churchill, MB.; April-May 1977; MS Report No. 80-4. 1980. 103 p.

This report is the result of on site studies at an existing site that has 5 culverts on a creek crossing with a major highway. Fish tagging, velocity measurements, discharge, and water temperatures were recorded at the crossing. It was determined that the culverts are a fish passage blockage. Species of fish included grayling, pike, suckers, burbot, and whitefish. Correlations are made between water velocity and fish swimming ability.

In general this article is limited to this specific site and fish species.

Dimeo, Art. Correcting Vertical Fish Barriers. ED & T 2613 Investigation of steeppass and fish ladders. USDA-Forest Service, Equipment Development Center, Missoula, MT. 1977. 28 p.

An annotated bibliography was not completed on this publication.

Dryden, R. L.; Jessop C. S. Impact analysis of the Dempster Highway culvert on the physical environment and fish resources of Frog Creek. Fish. and Mar. Serv., Can. Dept. Environ./Fish. Oper. Dir./Cent. Reg./Tech. Rep. Ser. CEN/T-74-5. 1974. 59 p.

**Improper culvert design and its effects on hydrology and fish populations of Frog Creek, Northwest Territories, Canada, are discussed. The effects documented are on migration of fish (northern pike, Esox lucius, and broad whitefish, Coregonus nasus) and streambank stability attributable to water velocities in excess of 1.5 m/s (5 ft). The causes were high flows through the culvert and energy dissipation at the outfall. Biological measurements made on northern pike and whitefish included age, growth, movement, and gonad development.

Dryden, R. L.; Stein J. N. Guidelines for the protection of the fish resources of the Northwest Territories during highway construction and operation. Fish. and Mar. Ser., Can. Dep. Environ./Fish. Oper. Dir./Cent. Reg./ Tech. Rep. Ser. CEN/T-75-1. 1979. 32 p.

** These guidelines are intended to aid highway designers; they are applicable to all water courses that flow for at least one period each year, as well as all highway-related stream alterations, including both temporary and permanent road crossings, culverts, right-of-way approaches, and gravel removal. The study was confined to Mackenzie Valley, Northwest Territories, streams and species. Statistical conclusions may be site specific, however, the biological and technical guidelines are universal in dealing with highway design and fish-passage problems.

Engel, P. Fish passage facilities for culverts of the Mackenzie Hwy. Dept. Environ., Hydraul. Div., Can. Cent. Inland Waters, Burlington, ON. 1974. 33 p.

**The study evaluated three types of fish passage facilities for large culverts-spoilers, offset baffles, and side baffles and the relation of hydraulic characteristics to swimming speeds of fish is described and modeled. Effectiveness of each design was proportional to gradient. Maximum recommended slope was 5 percent. Suggestions for application of elliptical and arch culverts to fish passage facilities are also made. Recommendations and limitations of each device are given. Problems with debris and sediment may occur. Ice may be more of a problem with side baffles. Data for swimming speed (burst), friction factors, and velocities are given, as are design diagrams.

Evans, Willis; Johnston, F. Beryl. Fish migration and fish passage. A practical guide to solving fish passage problems. USDA - Forest Service, Washington, DC. 1972 Revised 1980. 63 p.

This guide discusses the swimming ability of fish species in upstream and downstream migrations, and discusses natural and man-made barriers fish encounter in their migrations. Barriers include natural bed rock, debris jams, thermal barriers, short and long-term dams, culverts, fords, and bridges. Included is a procedure for designing new installations of stream crossing structures which includes checking into migration periods, stream flow, and site data. Inspection of and correcting existing culverts is discussed with an inventory and evaluation method used in R-5 to identify fish passage problems. A case history from R-6 of a fish passage problem with a successful solution is presented in detail. Graphs for water velocity and depth in circular, box, and arch culverts are in the Appendix. These graphs are for approximation only but are accurate enough for fish migration problems. The graphs are not intended for determining size and slope ofculverts. Hydraulic data for bottomless arches and bridges is not in this guide.

Overall, this is a good practical guide with adequate technical data to provide engineers and biologists information to aid in checking existing and designing new stream crossing structures.

Gauley, J. R. Effects of water velocity on passage of salmonids in a transportation channel. U.S. Dept. Int., Fish. and Wildl. Serv., Bur. Comm. Fish., Fish Bull. 66(1). 1966. 59-63 p.

**Passage times of chinook salmon, sockeye salmon, and steelhead trout through a test channel were compared at velocities of 1 and 2 ft. The test channel was 4 ft wide, 6 ft deep, and 100 ft long. Passage times did not differ significantly with water velocity for any of the three species. The two salmon species moved faster than steelhead trout at both water velocities. The author concluded that 1 ft is as suitable as 2 ft for fish passage.

Gauley, J. R.; Thompson C. S. Further studies on fishway slope and its effect on rate of passage of salmonids. U.S. Dept. Int., Fish and Wildl. Serv., Bur. Comm. Fish., Fish. Bull. 63(1). 1962. 45-62 p.

**Rates of passage of chinook and sockeye salmon and steelhead trout were studied in 1:16 and 1:8 slope, pool-and-overfall fishways. In general, the passage through the 1:8 slope fishway with a 1 ft rise between pools was as fast as, or faster than, in the 1:16 slope with a 1 ft rise. When the rise between pools was increased to 1.5 ft in the 1:8 slope fishway, chinook and sockeye passage was slower. The "Dalles type" wier crest (3.3 m, 4 ft pool width) in a 1:16 slope fishway appeared to accelerate chinook passage. Chinook and sockeye displayed seasonal differences in passage time.

Gauley, J. R.; Weaver C. R.; Thompson C. S. Research on fishway problems, May 1960 to April 1965. 3 d Prog. Rep. Fish. Eng. Res. Program, Corps Eng., North Pac. Div.. Portland, OR. 1966. 29-66 p.

** Research program sponsored by the U.S. Army Corps of Engineers to investigate design criteria for fish passage facilities for hydroelectric projects is reviewed. The primary objective was to provide basic information on the behavior of fish and what is required for fish passage. Major emphasis was on cost reduction of fish-passage facilities without reduction of efficiency to pass fish. Passage times for various salmonids through several fish-ladder designs and the response of salmonids to vertical and horizontal orifices in fishways are reviewed. Counting and identification studies at fishways are also discussed.

Gebhards, S.; Fisher J. Fish passage and culvert installations. Idaho Fish and Game Rep, 1972. 12 p.

** The authors list fish blocks resulting from improper culvert installation that occur at the outfall, within the culvert, and at the inlet. Criteria for installation, including timing of construction, design, and placement to insure fish passage, are given. Design criteria include gradient, velocity, and depth. Use of baffles, separator walls, and multiple installations are discussed. Velocities and distances impeding fish passage are graphed. A design for culvert baffles is also presented.

Harrison, M. B. Analysis of a skewed slot orifice. M.S. thesis. Univ. Idaho, Moscow, ID. 1972. 89 p.

** Design criteria for a skewed slot-orifice fishway exit are developed. The fishway exit can be constructed using these criteria in culvert wingwalls. The outlet terminates at a skew angle; it can be designed to create flow conditions necessary for fish passage. Values of slot-orifice contraction ratios ranged from 0.65 to 0.82 of the culvert width; culvert slope varied from 1.5 to 4.5 percent; skew angles ranged from 30 to 75 deg; and three lateral positions of the fishway channel were tested. Dimensional analysis was used to determine the significant design parameters. Design curves that display the relationship between the backwater ratio (H/h) and the Froude number are presented. The design curves and an equation, based on the momentum principle, are used to design two types of skewed-orifice exits. One problem uses the same contraction ratio, while the other uses different values of contraction ratio for the skewed-exit and normal-slot orifices downstream. Necessary criteria for suitability of flow for fish passage are also discussed.

Hosking, Hank. On-site monitoring of construction of Terror Lake Hydroelectric Project, Kodiak, AK. U.S. Department of the Interior, Fish and Wildl. Service, Western Alaska Ecological Services, Anchorage, AK. September 1984. 48 p.

This report describes the on-site monitoring procedures used by the U.S. Fish and Wildlife Service as a supplement to the fish and wildlife mitigation plan during construction of the Terror Lake Hydroelectric Project, Kodiak, Alaska. The report includes mitigation efforts taken to reduce adverse environmental effects to the land and wildlife, as well as to the fisheries resource. Actions taken to assure proper fish passage in identified fish streams are outlined in general, but they are not analyzed in detail. Suggested stricter mitigation measures are offered for future construction projects of this nature, including more detailed parameters for fish passage.

Jordan, Mark C.; Carlson, Robert F. Design of Depressed Invert Culverts. Water Research Center, Institute of Northern Engineering, University of Alaska - Fairbanks, Fairbanks, AK; State of Alaska, Department of Transportation and Public Facilities, Fairbanks, AK. June 1987. 64 p.

In an effort to improve fish passage, culverts are sometimes installed with buried inverts to allow partial backfilling with streambed material or riprap. The resultant lower flow velocities and greater invert turbulence presents less resistance to fish moving upstream through the culvert. This report studies the hydraulic characteristics of depressed invert culverts, and outlines a design procedure to be followed for such installations flowing under nonsubmerged conditions and set flush to a vertical headwall. The design procedure considers such features as culvert geometry, discharge coefficients, barrel losses, and velocity profile.

This is a good reference for the engineer to use for sample calculations for designing depressed inlets. There are also some good calculations on roughness.

Kane, Douglas L.; Wellen, Paula M. A hydraulic evaluation of fish passage through roadway culverts in Alaska. Institute of Water Resources, University of Alaska - Fairbanks, Fairbanks, AK. State of Alaska, Department of Transportation and Public Facilities, Research Section, Fairbanks, AK. August 1985. 54 p.

This report studied some 200 culvert installations in interior and northern Alaska, with approximately 100 culverts examined in detail to access hydraulic problems with regard to fish passage. The two major problems identified were high velocities and perching, while inlet drops due to deposited sediment, ice buildup (aufeis), culvert alignment and non-uniform culvert slopes were also noted. Numerous recommendations are made to control the hydraulic characteristics and installation of culverts so as to enchance fish passage. Also, the correlation between the water velocities in the occupied zone where fish naturally swim and the swimming ability of the design fish was noted as being a more realistic approach to basic culvert design when fish passage is a consideration. This report was one of the first of many fish passage studies conducted in Alaska in the 1980's.

Kay, A. R.; Lewis R. B. Passage of anadromous fish through highway drainage structures. Calif. Div. Hwy., Dist. 01 Res. Rep. 629110. 1970. 15 p.

** Authors discuss factors that impeded passage of migrating fish and establish design criteria for fish passage. Graphs and tables are included. A field investigation of 40 existing culverts was conducted and their fish-passage characteristics were evaluated.

Katopodis, C.; Robinson, P.R.; Sutherland, B.G. Canada Western Region of Fisheries and the Environment; Winnipeg, MB; A Study of model and prototype culvert baffling for fish passage; Fisheries & Marine Service Technical Report No. 828. 1978. 78 p.

This study looked at a highway crossing of the Redknife River in Northwest Territories, Canada. A system of spoilers and baffles were used to provide rest zones in the culverts. Mixed success was found for passage of grayling, long nosed suckers, pike, walleye, and other species while water velocity at the time of migration was the key factor. Generally, burst swimming speeds of these species were adequate to swim against the jet water flows at the baffles. Spoiler plates were found to be better against ice flows than the offset baffles. Culvert slopes less than 5 percent are recommended for reduced velocities. Downstream weirs are also recommended to aid fish in entering culverts.

In general this article is site specific for certain fish species but does offer helpful suggestions on the use of baffles in culverts.

Katopodis, C.; Robinson P. R.; Sutherland B. G. A study of model and prototype culvert baffling for fish passage. Can. Fish. and Mar. Serv. Tech. Rep. 828. 1978. 78 p.

** A hydraulic-model study tested and developed a set of offset and spoiler baffles to aid fish passage through culverts. Based on the model-study recommendations, they were installed at the Mackenzie Highway crossing of the Redknife River. Field testing showed the effectiveness of both baffle types is inversely proportional to culvert slope. Maximum recommended slope is 5 percent. A method of judging adequacy of baffles is provided. The problems created by ice, debris, and sediment are presented. The list of figures includes design dimensions, installation, and water-surface profiles for offset and spoiler baffles, as well as cross-sectional velocity distributions.

Lauman, J. E. Salmonid passage at stream-road crossings: A report with department standards for passage of salmonids. Oregon Dept. Fish and Wildl., Portland, OR. 1976. 78 p.

** The authors' review provides guidance for bridge and culvert projects, causes and solutions for fish-passage problems; excessive water velocity; inadequate water depth; excessive entrance jump are discussed. Structural guidelines for location, type, and size of fishway are included. Recommended velocities for adults and juveniles, as well as comprehensive tables and figures, are presented.

Leider, S. A.., Chilcote, M. W.; Loch, J. L. Movement and Survival of Presmolt Steelhead in a Tributary and the Main Stem of a Washington River. N. Amer. Jour. of Fish Mgmt. 1986. 6:526-531 p.

An annotated bibliography was not completed on this publication.

Long, C. W. Passage of salmonids through a darkened fishway. Fish and Wildl. Serv. Spec. Sci. Rep. Fish. 300, Washington, DC. 1959. 9 p.

** An experiment to produce specific information on rate of ascent of salmonids through a darkened fishway was conducted in a short, pool-and-overfall fishway without submerged orifices. The fish (98 percent steelhead trout) negotiated the 6 pool fishway significantly faster in near-total darkness than in light conditions approximating a bright, cloudy day.

Lowman, B. J. Investigation of fish passage problems through culverts. MTDC Proj. Rec. 2427, Missoula, MT. 1974. 17 p.

** The author reviewed problems related to culvert installation, requirements for fish passage including recommended velocities, and corrective measures. Baffles in culverts are discussed with replies from various agencies to a questionnaire on fish-passage problems and use of baffles in culverts. Economic value of spawning areas is reviewed in an appendix.

MacPhee, C.; Watts, F. J. Swimming Performance of Artic Grayling in Highway Culverts. Final Report to U.S.

Fish and Wildlife Service, Anchorage, AK, on contract No. 14-16-001-5207. 1976, 42 p.

No annotated summary was completed for this publication.

Mavis, F. T. The hydraulics of culverts. Pa. State Coll. Bull. 56. 1943. 34 p.

** Two hypotheses are tested: (1) When the culvert flows partly full and the inlet serves as a control section, the discharge is a function of the elevation of the headwater pond above the invert of the culvert; and (2) with the culvert flowing full the discharge is a function of the difference only between headwater/tailwater levels. The report includes extensive tests of culvert hydraulics; discharge of culverts flowing partly full, or flowing full and submerged; calculations for free discharge with outlet flowing full; and transitions between categories of flow. The paper includes sketches and tables.

McClellan, T. J. Fish passage through highway culverts. U.S. Dept. Trans., Fed. Hwy. Adm. and Oregon State Game Comm., Portland, OR. 1970. 16 p.

** A review of 62 culverts installed by several agencies in Oregon was made to determine the effectiveness of the installation to pass fish; evaluate which types were most effective, simplest, and least expensive to install and easiest to maintain. The review included round pipe, single and double culverts with baffles or other special devices, plated arches (with both open and closed bottoms), and a few nonculvert installations. The author concluded that the condition of the stream at inlet/outlet may override design in importance. Controlling factors for fish passage were velocity, length, slope, and headwater/tailwater conditions. Description of culverts reviewed, problems, and comments on fish passage are given. Evaluation forms with photographs are provided in the appendix.

McCrea, Robert. Lining Deteriorated Culvert Pipes on the Jones Valley Road, Engineering Field Notes-Engineering Technical Information System, Vol. 16, September-October 1984: USDA-Forest Service. 1984. 25-33 p.

This article covers the lining of existing culvert pipe with polyethylene pipe on an arterial road on the Shasta-Trinity National Forest in California in 1982. The alternative of lining the existing culverts was selected over excavation and replacement of the existing culverts. The author provides some cost figures for sleeving the existing culverts as compared with the conventional replacement of culverts as well as some tips on doing the job.

McKinnon, G.A.; Hyntka, G.A. Fish passage assessment of culverts constructed to simulate stream conditions on Liard River Tributaries, Canadian Technical Report of Fisheries and Aquatic Sciences, No. 1255. 1985. 120 p.

This technical report is the result of tests conducted in Canada on a road crossing over tributaries of the Liard River. The purpose was to check their construction guidelines to see how applicable they are. One of the main objectives was to determine the effectiveness of fish passage measures through culverts. Results of the tests dealt with the construction guidelines for installing culverts. Recommendations are made for reduction of erosion, timing of construction with respect to fish migration periods, and stream simulation concept in the culvert. Simulation was achieved by oversizing the culvert and placing riprap and gravel in the culvert.

This report deals with migrating grayling and longnose suckers. This report is site specific, and does not contain a significant measure of technical data.

McKinley, W. R.; Webb R. D. A proposed correction of migratory fish problems at box culverts. Wash. Dept. Fish. Fish Res. Pap. 1(4). 1956. 33-45 p.

** The authors discuss culvert standards and methods of culvert correction. Model culvert studies, fishway criteria, and an experiment on grading of baffles are included. Baffle arrangements; types, sizes, dimensions, and so on are discussed at length.

Metsker, Howard E. Fish versus culverts, some considerations for resource managers. USDA - Forest Service, Tech. Report ETR-7700-5. Ogden, UT. July 1970. 19 p.

This publication provides general guidelines for the resource manager in considering stream crossings. Considerations mentioned are crossing locations, channel gradients, water velocity, stream alignment, type and age of fish, identifying migration routes, fishery food source, and type of fish habitat. Barriers to migration are discussed which include culvert outfall area, insufficient water depth and light, and water velocity. Streambed stability importance is also presented for consideration as resting needs for fish. Swimming ability with respect to size and species is also discussed. The author suggests use of multiple culverts, outlet control, downstream weirs, and baffles to facilitate fish passage.

Overall, this publication is in general terms for the manager and does not provide technical data for the engineer and biologist.

Morsel, J.; Houghton, J. P.; Bell, M.; Costello, R. Fish Protection Strategies for the Design and Construction of the Alaska Segment of Natural Gas Transportation System. Report prepared by Dames and Moore for the Northwest Alaskan Pipeline Company, Anchorage, AK. 1981.

National Corrugated Steel Pipe Association. Installation Manual for Corrugated Steel Drainage Structures, Installation Manual-NCSPA 1977 revised 1987, Washington, DC. 1987. 93 p.

This manual gives practical information on the location and installation of drainage structures. It covers the general principles of location, excavation, preparation of foundations, handling, assembling, and backfilling corrugated pipes. Its purpose is to be a practical field guide for the satisfactory installation of corrugated pipes. It is not intended to be used as direct specifications for culvert installation.

Normann, J.M.; Houghtalen, R.J.; Johnston, W.J. Hydraulic design of highway culverts. Report no. FHWA-IP-85-15. U.S. Department of Transportation, Federal Highway Administration. September 1985. 235 p.

This publication provides information for the planning, hydrological design, and inlet improvements for culverts. It combines literature from several culvert design publications and puts them under one cover. Design nomographs, charts, and equations are provided. This publication is an excellent reference for culvert design.

Otis, M. B.; Pasko D. G. Suggested measures for minimizing damage to fishing streams from highway projects. New York State Conserv. Dept., Div. Fish and Game, Bur. Fish, Albany, NY. 1964. 4 p.

** The authors include a series of recommendations for streambank stabilization, bridge and culvert installation, gravel removal (generally not recommended), and streambank cover and shelter improvements.

Peterson, N. P.; Reid, L. M. Wall-base channels: their evolution, distribution, and use by juvenile coho salmon in the Clearwater River, Washington. Walton, J. M.; Houston, D. B., editors. Olympic Wild Fish Conference. Peninsula College, Port Angeles, WA. 1984. 215-225 p.

No annotated summary was completed for this publication.

Powers, Patrick D.; Orsborn, John F. Analysis of barriers to upstream fish migration. An investigation of the physical and biological conditions affecting fish passage success at culverts and waterfalls. Department of Civil and Environmental Engineering, Washington State University, Pullman, Washington, U.S. Department of Energy, Bonneville Power Administration, Portland, OR. August 1984. 120 p.

This research paper analyzes both natural and manmade barriers to the upstream migration of salmon and trout, and offers solutions to fish passage through barriers. Analytical methods are presented to study barriers using site geometry, hydrology, and hydraulics, the relationship between these factors and the swimming capabilities of fish are examined. Using this information, a classification system is developed to classify waterfalls, cascades, chutes, and culverts, based on four components: class, type, magnitude, and discharge, extending from general to specific. A degree of difficulty rating is also determined for each barrier class to rank the relative difficulty of a barrier for successful fish passage. This paper offers "parameter specific" solutions to assist fish past natural barriers without the installation of a typical fishway, and offers suggestions to improve fish passage through culverts.

Petroskey, C.E.; Holubetz, T.B. Idaho habitat evaluation for off-site mitigation record. Idaho Department of Fish and Game, Boise, ID. U.S. Department of Energy, Bonneville Power Administration, Portland, OR. June 1985. 245 p.

This report evaluates existing and proposed habitat improvement projects, including stream barriers for fish passing through the Clearwater River and Salmon River drainages. The stream habitat evaluation documented physical changes in habitat; measured changes in anadromous fish production attributable to habitat enhancement projects; measured changes in populations of resident fish species due to enhancement/ barrier elimination; and estimated enhancement effectiveness to establish the record of credit for mitigation. This evaluation was performed on 17 total streams in the two drainages and the findings are presented in this report, including stream habitat improvements and barrier elimination projects completed.

This report is effective in demonstrating the general effectiveness of stream habitat improvement and barrier elimination, but does not offer technical data for the implementation of these projects. This is more of a managerial guide.

Radke, Roger. Personal Communication.

Reihson, G.; Harrison, L. J. Debris Control Structures, HEC No. 9. Washington, DC Hydraulics Branch, Bridge Division, Office of Engineering, Federal Highway Administration, U.S. Department of Transportation. 1971.

This is a comprehensive publication on debris control structures. It outlines some of the options of dealing with debris problems, factors to consider in a solution for debris control, and some general guidelines to be used for designing debris control structures. This is a well written publication that is considered the authority for the design of debris control structures.

Saltzman, William; Koski, R. O. Fish Passage Through Culverts. Special Report, Oregon State Game Commission. 1971. 9 p.

Scarlett, W. S.; Cederholm, C. J. Juvenile coho salmon fall-winter utilization of two small tributaries of the Clearwater River, Jefferson County, WA. Walton, J. M. and Houson, D. B., editors. Proceeding of the Olympic wild trout symposium. Peninsula College, Port Angeles, WA. 1984. 227-242 p.

No annotated summary of this publication was completed.

Shoemaker, R. H. Hydraulics of box culverts with fish-ladder baffles. Natl. Res. Counc., Hwy. Res. Board Proc. 35. 1956. 196-209 p.

** Placement of transverse baffles in box culverts to provide fish passage has become increasingly necessary in recent years. Model studies were made to determine design factors for baffled culverts related to height and spacing, and to develop hydraulically efficient baffle shapes for use in culverts. The results of the studies, based on the treatment of baffles as roughness in a rectangular conduit, were obtained in the form of velocity-head coefficients; one dependent on and the other independent of friction effects.

Skeesick, D. G. The fall immigration of juvenile coho salmon into a small tributary. Oregon Fish Comm. Res. Rep. 2(1). 1970. 90-95 p.

** An upstream-downstream trap was monitored for 10 years; each fall, an upstream migration of large juvenile coho occurred. An average of 62.6 percent survived and returned downstream in the spring as smolts and they averaged 14 mm longer than native stock. The recapture rate of adults that had been upstream-migrant juveniles was 0.3 percent and for the native stock it was 0.8 percent. The author theorized that (1) the immigrant juveniles had spent the summer in the main stream where they grew rapidly; (2) they entered the tributary in the fall to escape high water in the main stream; and (3) as adults, they returned to their natal stream rather than to the study stream. Observations from two other river systems appear to substantiate the behavior pattern and suggest that other species may have similar habits.

Slatick, E. Passage of adult salmon and trout through pipes. U.S. Fish and Wildl.Serv. Spec. Sci. Rep.-Fish. 592. 1970. 18 p.

** This study determined that (1) if adult salmon and trout would use a pipe as a passageway, and (2) how the conditions at the entrance and within the pipe, such as diameter, length, illumination, and flow would influence passage. The pipes were 0.3, 0.6, and 0.9 in diameter and 27.4 to 82.3 m long. Chinook salmon, sockeye salmon, coho salmon, and steelhead trout passed through unilluminated pipes up to 82.3 m long. Only steelhead appeared to benefit from illumination. For distances up to 82.3 m, a 0.6 m diameter pipe was large enough to pass all salmon and trout. The fish would not readily enter a 0.3 m pipe until special conditions of water velocity and transition from pool to pipe was provided.

Slatick, E. Passage of adult salmon and trout through an inclined pipe. Trans. Am. Fish. Soc. 100(3). 1971. 448-455 p.

** The author examined a passageway at Bonneville Dam on the Columbia River, which required a descent and ascent by migrating adult salmon and trout. The influence of water velocities on fish passage was measured with velocities of 0.30, 0.76, and 1.22 m/s, and the relationship between performance and length of fish was determined by comparing median passage times of large and small fish. From 64 to 100 percent of the fish passed through the pipe in 45 min. Median passage times ranged from 3 to 23 min. Chinook salmon passed through the pipe most rapidly at the 0.76 m/s flow; coho salmon and steelhead trout passed through at 1.22 m/s.

Sockeye salmon passed through equally well at flows of 0.76 and 1.22 m/s. No significant differences were demonstrated between median passage times of small and large chinook salmon, sockeye salmon, coho salmon, or summer steelhead trout. Results of this experiment indicated that if proper flow conditions are provided, a large percentage of migrating adult salmon and steelhead will pass through an inclined pipe requiring a descent/ascent of about 5.2 m.

Smith, Wilbur and Associates. Draft Annotated Bibliography and Glossary of terms, FWHA Project DT FH61-88-C-0015, Falls Church, VA. 1988. 26 p.

This is a draft annotated bibliography for preparation of a manual and videotape for culvert repair practices. Final report will be published by the Federal Highway Administration.

Stuart, T. A. The Leaping Behavior of Salmon and Trout At Falls and Obstructions. Freshwater and Salmon Fisheries Research 28. Department of Agriculture and Fisheries for Scotland, Edinburgh. 1962. 46 p.

Tollefson, T. C. Facilities at culvert installations. Washington Dep. Fish. 1966. 8 p.

** Report includes basic recommendations for placement of culverts, use of baffles, downstream controls, separator walls, and multiple installations, plus drawings of these facilities.

Travis, Michael D.; Tilsworth, Timothy. Fish passage through Poplar Grove Creek culvert, Alaska. Research Paper included in Transportation Research Record 1075 - Roadside Design and Management, Transportation Research Board, National Research Council, Washington, DC. 1986. 48 p.

This research paper was included in a group of papers dealing with Roadside Management in the Transportation Research Record series. It documents experimental procedures to visually analyze Artic grayling passage through a 110 ft long by 5 ft diameter culvert in the Poplar Grove Creek, Alaska. Grayling passage was monitored during high flows to determine success percentages at measured flow velocities in the pipe. The study also requested information from the other 48 states and Canada concerning fish passage, and summarized their suggestions as follows: (a) early coordination should occur between highway and resource agencies during the design phase, (b) depress culvert inverts 1 to 2 ft below the natural streambed, (c) culverts having invert slopes greater than 1 percent should have a baffling system, and (d) the remaining culvert volume should be capable of handling a 50-year discharge flow.

USDA - Forest Service. Making culverts good fish passages. EDC, Missoula, MT. 1975. 4 p.

** The report covers factors influencing fish passage; velocity, length, resting pools, and water depth. Information is summarized on each topic, with some brief recommendations.

USDA - Forest Service. Fish/culvert roadway drainage guide. Engineering and Aviation Management Division, Alaska Region, Juneau, AK. Ser. R 10-42. 1978. 125 p.

** A guide for engineers, biologists, and hydrologists to aid in solving fish-passage problems, especially for juvenile salmon, trout, and char. Performance ratings of various culvert types, procedures for site selection, methods of determination of the design flow, and hydraulic charts and nomographs are included.

Watts, F. J. Design of culvert fishways. Water Resour. Res. Inst., Univ. Idaho, Moscow, ID. 1974. 62 p.

** Types of fish migration and typical fish-blockage problems associated with culverts are reviewed. Swimming capabilities of fish as a function of species, fish length, and water temperature are discussed. Also reviewed are: hydrological characteristics of streams and the importance of the timing of fish runs and peak discharge; procedure for analyzing culverts of corrugated metal pipe and pipe arches for recommended swimming velocities; slot-orifice fishways for box culverts placed perpendicular to the flow and skewed wingwall slot orifice; design aids developed for hydraulic analysis, and instream construction in or near prime fish habitat.

Watts, F. J.; Dass, P. C.; Liou, P.; Harrison, M. Investigation of culverts and hydraulic structures used for fishways and the enhancement of fish habitat. Water Resour. Res. Inst., Tech. Rep., Univ. Idaho, Moscow. ID.1972.7p.

** A method for the design of slot-orifice fishways for box culverts was developed. Characteristics for a satisfactory fishway are identified. Graphs for sizing slot-orifice fishways for a given performance capability of a fish are presented. The hydraulics of slot orifices constructed in the face of skewed wingwalls are explained. A table compiled from existing literature lists the swimming capability of various species of fish.

Welch, H.E. Canada Western Region Department of Fisheries and the Environment Winnipeg, MB. Swimming performance of Arctic Char from the Saqvaqjuac River, Northwest Territories; Fisheries & Marine Service Technical Report No. 854. 1979. 7 p.

This technical report is about research conducted on the Saqvaqjuac River in Northwest Territories, Canada to determine the maximum (critical) velocity char can maintain for 10 min. This information was needed to help in the design of culverts for fish passage and use of this report is limited to stream crossings when concern is for passage of Arctic char.

Wightman, J. C.; Taylor, G. D. Salmonid swimming performance in relation to passage through culverts. Fish Habitat Improv. Sect., Fish and Wildl. Branch, Minist. Recreation and Conserv., Victoria, BC. 1976. 50 p.

** The authors review literature on swimming performance of fish in culverts to establish standards for culvert design and installation to insure fish passage. Measured swimming abilities of game and non-game fish are explored, as well as factors affecting swimming performance, such as water temperature, dissolved oxygen, and previous exertion. The authors discuss baffles, downstream controls, and multiple installations. Appendixes include recommendations for proper culvert installation, graphs of swimming performances of anadromous fish, and methods of culvert modification.

Yee, C. S. and Roelofs, T. D. Planning Forest Roads to Protect Salmonid Habitat. Influence of Forest and Rangeland Management on Anadromous Fish Habitat in Western North America. USDA-Forest Service General Technical Report PNW - 109, Portland, OR. 1980, 26 p.

The publication reviews a variety of fish habitat considerations in planning and executing forest road development and construction. Particular emphasis is directed at evaluating and preventing sedimentation impacts and fish migration problems associated with roads.

Ziemer, G. L. Culvert design. Alaska Dept. Fish and Game. 1965. 2 p.

** Standards for design and placement of culverts in salmon streams are presented; a graph shows swimming capability of migrating salmon related to the horizontal distance between resting pools and the velocity of the water in the culvert.

Ziemer, G. L. Fish transport in waterways. Alaska Dept. Fish and Game. 1961. 2 p.

** The mechanics of fish passage at/in pipe culvert waterways under highways are given. Illustrations of stylized models demonstrate stress-level patterns of a migrating fish through time compared with normal performance, for example, the work required of a fish to navigate through a culvert where the upstream end head is less than one pipe-diameter. Hydrodynamics are examined for the following: total opposing force on swimming fish, gradient vector, drag force on the fish, weight of fish, angle of inclination of hydraulic gradient, length of fish, mass density of fluid, velocity of fish relative to the water, rate at which fish expends energy, transit time through culvert, length of culvert and velocity of fish relative to the channel. The report gives a checklist of controlling factors to consider when designing the culvert.