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Evaluation of a Small Diameter Baffled Culvert for Passing Juvenile Salmonids

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Abstract

A 90-cm-diameter culvert with off-set baffles was set at a 10-percent gradient in an artificial stream channel on Admiralty Island, Alaska. Coho salmon, Dolly Varden Char, and cutthroat trout, all less than 120-mm fork length, were able to move up the 9-m culvert. Additional work is needed to determine an upper discharge limit and to evaluate field installations.

Keywords: Fish habitat, culvert construction, road building (forest/logging), salmonids.

Introduction

Small streams are frequently important nursery areas for juvenile coho salmon *(Oncorhynchus kisutch* [Walbaum]), Dolly Varden Char (*Salvelinus malma* [Walbaum]), and cutthroat trout (*Salmo clarki* Richardson) throughout the Pacific Northwest and Alaska. Although juvenile salmonids are generally territorial, redistribution within available habitat occurs throughout the year. Access to upstream areas is particularly important during seasonal migrations.

Poorly constructed road crossings of small streams can block upstream movement of juvenile salmonids. In many cases problems can be avoided by installing a bridge or culvert of the correct size (Bell 1973, Evans and Johnson 1974, Lowman 1974, Watts 1974). Culverts installed at gradients greater than 1 percent usually cause a velocity barrier to juvenile salmon moving upstream; therefore, installations with gradients less than 1 percent are recommended (Bell 1973). In some places, particularly in areas of bedrock with steep slopes, installing culverts at recommended gradients may not be feasible. Where gradients are more than 1 percent, baffled culverts (fig. 1) may facilitate fish passage to nursery areas above road crossings.

The concept and function of the baffled culvert is similar to most fishways in that the baffles create a series of short high velocity runs between the baffles and a series of low velocity backwater areas behind the baffles. These areas allow the fish to swim in short bursts and then rest. This study examined the ability of coho salmon, Dolly Varden, and cutthroat trout to ascend a small diameter, 90-cm (36-in), baffled culvert set at a gradient of 10 percent.

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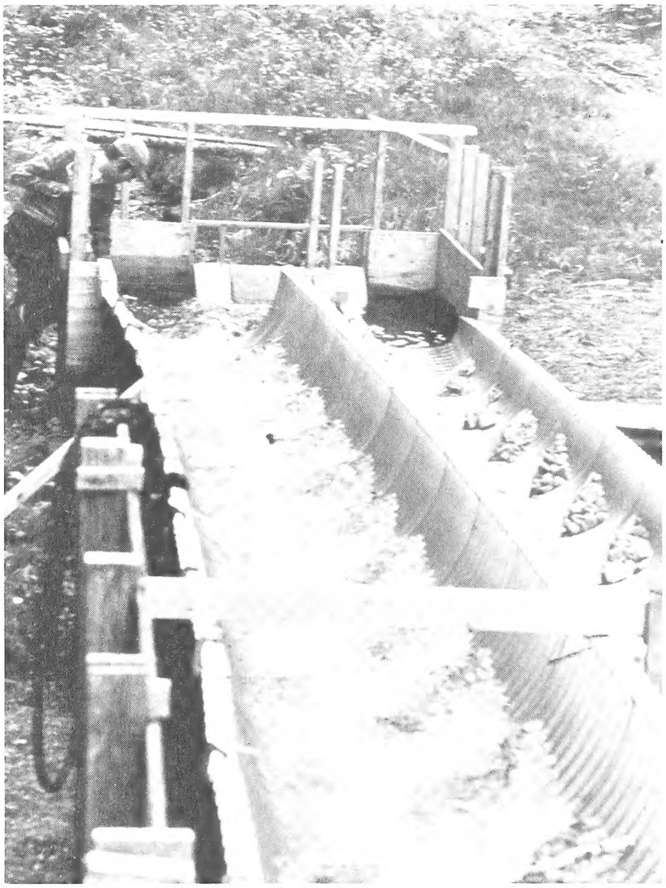

Figure 1.—Baffle culvert installation.

Several studies have examined the effectiveness of baffled culvert designs, but they dealt with larger culverts and adult fish (McKinley and Webb 1956, Tollefson 1966, Gebhards and Fisher 1972). McKinley and Webb (1956) suggested that flat-bottomed baffled culverts should be at least 1.2 m (4 ft) wide and have a minimum diameter of 1.5 m (5 ft.) Optimum fish passage occurred when flows were just over the baffles. Passage decreased with increasing flows.

McKinley and Webb (1956) proposed a series of designs and found the offset baffle similar to that shown in figure 1 to be the most effective. In general the offset design has been adopted by most resource agencies when a baffled culvert was used (Lowman 1974).

Results from a questionnaire circulated by W. A. Evans (see Lowman 1974) to 13 resource agencies concerning the use of baffles in culverts showed that: (1) baffled culverts were not in widespread use, (2) they were frequently a corrective device rather than a primary installation, (3) the design primarily used was that of McKinley and Webb (1956), (4) there had been no recent evaluations of baffled culverts, and (5) many felt that additional attention should be given to alternate solutions to baffled culverts, while others felt additional studies on baffled culverts were needed.

McClellan (1970) reviewed 62 existing culverts, but did not include a field evaluation of baffled culverts. It appears that baffled culverts are not frequently used, nor have they been thoroughly investigated as solutions to fish passage at road crossings of small, high-gradient streams.

Methods

The study was conducted in 1978 at the Young Bay research facility of the USDA Forest Service on Admiralty Island in southeast Alaska. The facility is described in detail by Meehan and Swanston[1]. A baffled culvert 9 m (30 ft) long and 90 cm (36 in) in diameter was installed at a gradient of 10 percent below an artificial stream channel (fig. 2).

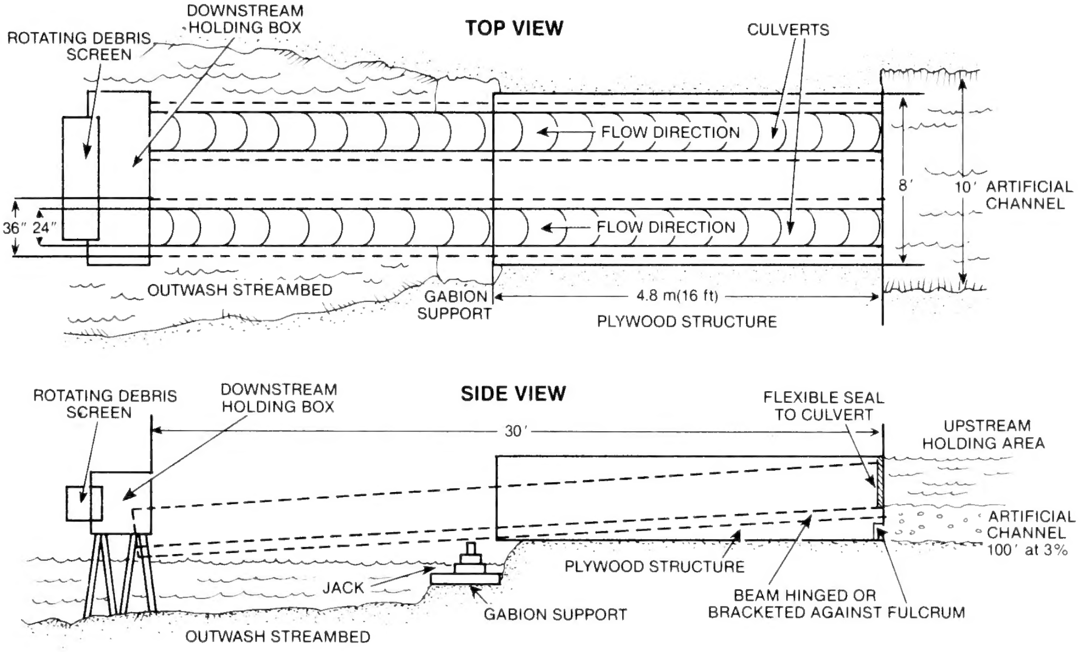

Figure 2.—Baffled culvert installation; top view to show inlet and outlet structures.

The baffles shown in figure 1 were bolted to the bottom of the culvert before the culvert was installed. The spacing can be changed, although this was not done in this study. On August 29 an additional baffle was placed at the outlet lip of the culvert during a test with coho salmon less than 55 mm in length. In a permanent installation the baffles may be either bolted or welded to the culvert.

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[1] Meehan, W.R., and D.N. Swanston. 1972. Development and use of a fish habitat research facility at Young Bay, Alaska. 60 p. Unpublished report, on file at Forestry Sciences Laboratory, Juneau, Alaska.

An inlet flume brought water from an adjacent stream into a stilling pond above the artificial channel. The discharge from the stilling pond to the artificial channel was controlled by an outlet dam that diverted excess flows back to the stream. Discharge from the stilling basin into the artificial channel was recorded continuously by a Fisher-Porter stage recorder at a V-notch weir. Velocities in the culvert were changed by changing the pond level at the outlet dam; however, because of leaks along the artificial channel, the discharges at the V-notch weir and in the culvert did not correspond.

An offset self-cleaning baffle system similar to that described by McKinley and Webb (1956) was installed at 60-cm (2-ft) intervals along the 9-m length of the culvert (fig. 2). Baffle dimensions and placement are illustrated in figure 1.

The culvert emptied into a plywood holding box (fig. 2) which was designed so the lip of the culvert was beneath the water in the box. Water from the holding box was filtered at the outlet by a rotating debris screen. Some fish escaped through the outlet at high flows. There was no device to prevent movement of fish from the upstream artificial channel back down the culvert.

Juvenile coho salmon, Dolly Varden, and cutthroat trout used in the study were taken from two nearby streams. All fish, with the exception of a few larger (110- to 120-mm) Dolly Varden, were less than 100-mm fork length. All fish were measured (fork length) and marked with a freeze brand (Bryant and Walkotten 1980) before being placed in the downstream holding box.

Fewer than 20 fish were used during the first trial in June and early July. In mid-July, 80 fish of all three species were stocked in the downstream holding box. The number of fish and species composition varied depending upon the catch from the nearby stream. Fish were not selected for size, but ranged from 40 mm to 120 mm in length. In late August, coho salmon young of the year, average length 49 mm, were tested.

The culvert and artificial channel were drained daily, and all fish above and below the culvert were counted and remeasured. The upstream opening of the culvert was blocked to prevent fish above the culvert from escaping back down the culvert when it was drained. Fish in the culvert, if any, retreated to the holding box which was not drained. The percent of each species successfully moving up the culvert was computed for each day[2]. All fish were returned to the downstream holding box after enumeration. Fish lost either through mortality or escapement were replaced from a nearby stream. All fish were replaced at approximately 1-week intervals.

Tests were conducted intermittently from late June to mid July. From mid July to mid August daily tests were run. At the end of August, young of the year's coho were tested for a 1-week period.

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[2] $S_i = ({}^{n}i/N_i)\ 100$

Where S_i = % of each species i successfully moving up the culvert.

n_i = Total number of species i above the culvert.

N_i = Total of each species in the test day.

Results

During initial trials in June and early July, Dolly Varden and cutthroat trout were able to negotiate the culvert. With increased stocking, the number and percent of fish moving up the culvert increased (fig. 3). In a number of trials, no fish were found above the culvert.

No significant differences (t-test) were found between average length of fish above the culvert and those remaining below the culvert. This was true for any species. Lengths ranged from 50 to 120 mm.

When coho salmon with an average fork length of 49 mm were used in late August, none passed up the culvert until a baffle was placed at the lip of the culvert outlet. After the baffle was installed on August 29, coho salmon began moving upstream. Discharge levels were below 14 liters/s (.5 cfs).

Although some fish of all species and sizes were able to negotiate the culvert at discharge levels examined, more Dolly Varden than coho salmon or cutthroat trout were successful (fig. 3). The percent of coho and cutthroat found above the culvert varied, but seldom exceeded the percent of Dolly Varden when all three species were present.

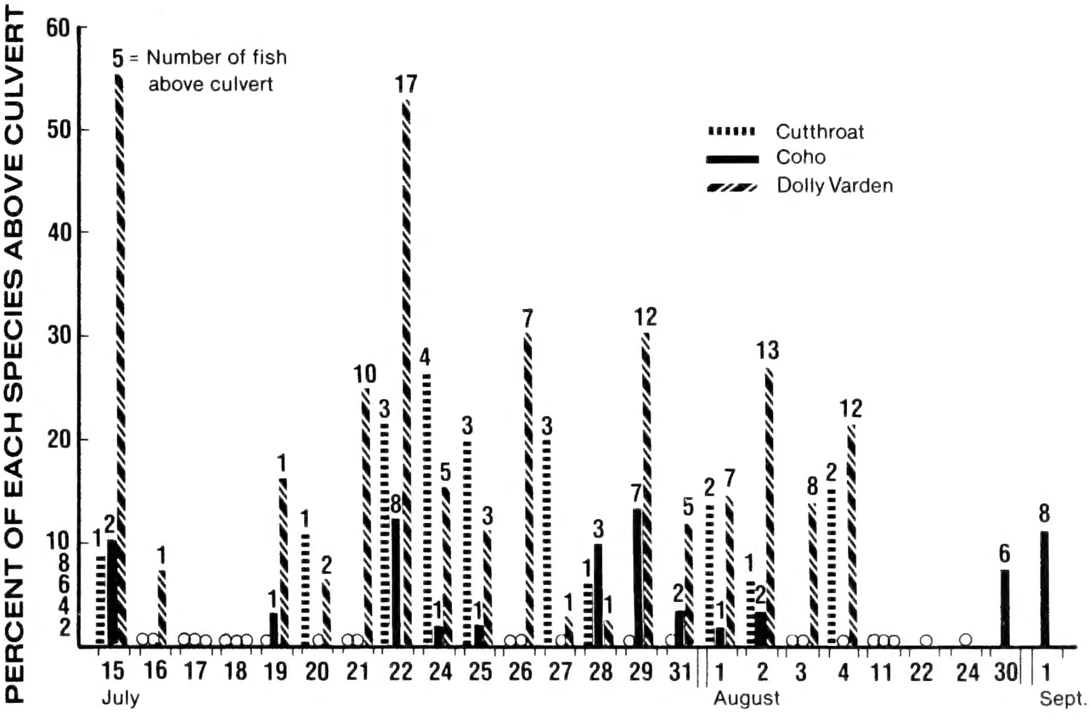
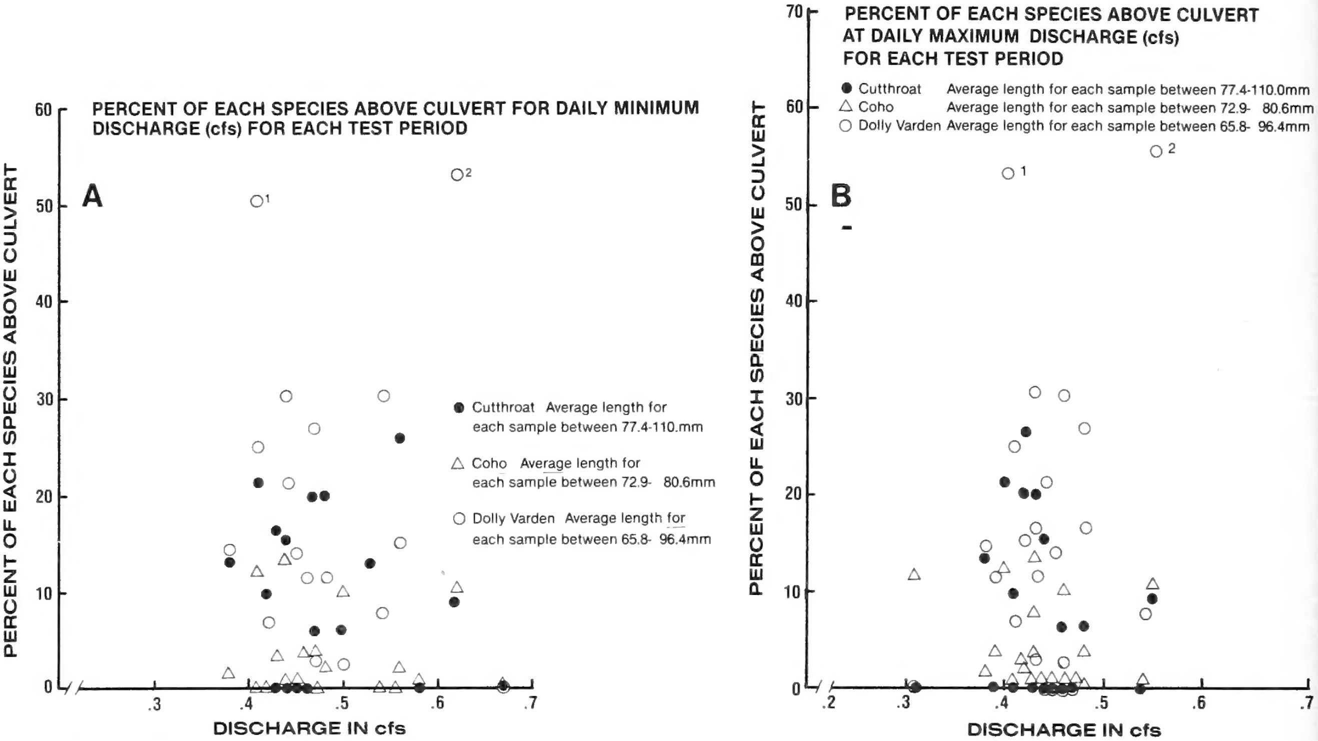


Figure 3.—Number and percent of fish by species found above the culvert daily from July 15 to September 1.

The maximum discharge at the V-notch weir ranged between 10 liters/s (.3 cfs) and 19 liters/s (.68 cfs)[3]. Most days the maximum discharge was between 10 liters/s and 16 liters/s, (.4 cfs and .6 cfs). Within the range of discharges most commonly examined, between 10 liters/s and 16 liters/s, discharge did not appear to affect fish movement up the culvert. There did not appear to be any relationship between daily discharge, expressed as maximum or minimum, and the percent of species composition of the fish moving up the culvert (fig. 4a, b).

Below 5.23 liters/s (.2 cfs) water in the culvert was too shallow for the baffles to operate. At a discharge greater than 17 liters/s (.65 cfs)—approximately 14 cm of water depth in the culvert—no fish moved up the culvert, but this occurred in only one trial period. Additional tests are required to determine an upper discharge limit.



1) Point represents 17 out of total of 32 Dolly Varden
2) Point represents 5 out of total of 9 Dolly Varden

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Figure 4.—A. Percent of each species above the culvert at daily maximum discharge (cfs). B. Percent of each species above the culvert at daily minimum discharge (cfs).

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[3] The discharges in the culvert were not accurately gauged, but were somewhat less than at the weir because of leaks along the artifcial channel. A discharge of 16 liters/s (.6 cfs) represented about 10-12 cm of water in the culvert.

Discussion

The factors that limit fish passage during a given time period are the maximum water velocity through the culvert and the darting speed of the fish. Because darting speed is frequently three to four times greater than sustained swimming speed, velocities that might block fish swimming at a sustained speed may be tolerated in a baffled culvert. Bell (1973) warns that "when designing upstream facilities, velocities must be kept well below darting speeds for general passage." Many of the constraints applied to fishways also apply to baffled culvert installations; the most important is the design at the pipe outlet.

Two potential problems with baffled culverts may occur at the outlet: (1) velocities and (2) scour of the stream bottom. Both can be avoided by proper design. Within the discharge ranges that were examined, a baffle section at the lip of the culvert disrupted the outlet velocity enough to allow passage of small juvenile salmonids. If hydraulic energy is not dissipated at the outfall, the streambed will scour, resulting in a drop off at the outfall that will effectively block upstream passage.

The results presented here represent a relatively narrow range of velocities and discharges, particularly for southeast Alaska streams which can increase tenfold in discharge during peak storms. This presents problems not only for fish passage, but also for hydraulic design. An oversize baffled pipe might accommodate high flows, but not operate at low summer flows. An undersize pipe might wash out at high flows. A thorough hydraulic analysis of the stream should be made to insure proper design and installation. An upper discharge level for successful passage of juvenile salmon was not determined in this test, but it appears that discharges of more than 5 cm of water over the top of the baffles will act as velocity barriers. Further work is needed to determine this level.

Gravel and fine material accumulated in the baffles of the Young Bay culvert but did not seem to interfere with the operation of the baffles or to prevent fish from ascending the culvert. Accumulations were light and appeared to wash out with the discharge levels used during the study. Further work is required to examine the self-cleaning characteristics of a field installation and the suitability of small diameter culverts to pass adult coho salmon, which frequently spawn in small headwater streams.

Literature Cited

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

Bryant, M.D. and W.J. Walkotten.
1980. Carbon dioxide freeze-branding device for use on juvenile salmonids. Prog. Fish Cult. 42:55-57.

Evans, W.A. and F.B. Johnson.
1974. Fish migration and fish passage: a practical guide to solving fish passage problems. USDA For. Serv., Reg. 5, San Francisco, CA.

Gebhards, S. and J. Fisher.
1972. Fish passage culvert installations. Idaho Dept. Fish and Game, Boise, mimeo report, Jan. 1972.

Lowman, Ben J.
1974. Investigation of fish passage problems through culverts. USDA Forest Service, Equip. Dev. Cent. Proj. Rec. ED&T 2427, Missoula, MT.

McClellan, T.J.
1970. Fish passage through highway culverts. Fed. Hwy. Admin., U.S. Dept. Transp., and Ore. State Game Comm., Portland, OR.

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

Tollefson, T.C.
1966. Facilities at culvert installations. Wash. Dept. Fisheries Processed Rep.,Olympia, WA.

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

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