

**FISH PASSAGE THROUGH
RETROFITTED CULVERTS**

Final Report

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by

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16. Abstract Long term and short term studies of fish movement were conducted at several retrofitted culverts within Oregon. This was done to assess the effectiveness of retrofitting culverts with baffles to improve fish passage. The long term results showed that the baffle equipped culverts do in fact allow fish passage, even though the fish in the study areas did not appear to move a great deal in any part of the study reaches. The short term results indicated a definite improvement in the ability of juvenile steelhead trout to move upstream after the addition of certain baffle configurations. Measurements of hydraulic conditions showed that the baffles do create areas of lower flow velocity, deepen the flow, and create resting pools. These observations indicate that fish can and do move through culverts retrofitted with baffles and that the addition of baffles can improve the ability of juvenile fish (especially steelhead trout) to move upstream through a culvert.					
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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS				APPROXIMATE CONVERSIONS FROM SI UNITS			
Symbol	When You Know	Multiply By	To Find	Symbol	When You Know	Multiply By	To Find
<u>LENGTH</u>							
in	inches	25.4	millimeters	mm	millimeters	0.039	inches
ft	feet	0.305	meters	m	meters	3.28	feet
yd	yards	0.914	meters	m	meters	1.09	yards
mi	miles	1.61	kilometers	km	kilometers	0.621	miles
<u>AREA</u>							
in ²	square inches	645.2	millimeters squared	mm ²	millimeters squared	0.0016	square inches
ft ²	square feet	0.093	meters squared	m ²	meters squared	10.764	square feet
yd ²	square yards	0.836	meters squared	m ²	meters squared	1.196	square yards
ac	acres	0.405	hectares	ha	hectares	2.47	acres
mi ²	square miles	2.59	kilometers squared	km ²	kilometers squared	0.386	square miles
<u>VOLUME</u>							
fl oz	fluid ounces	29.57	milliliters	ml	milliliters	0.034	fluid ounces
gal	gallons	3.785	liters	L	liters	0.264	gallons
ft ³	cubic feet	0.028	meters cubed	m ³	meters cubed	35.315	cubic feet
yd ³	cubic yards	0.765	meters cubed	m ³	meters cubed	1.308	cubic yards
NOTE: Volumes greater than 1000 L shall be shown in m ³ .							
<u>MASS</u>							
oz	ounces	28.35	grams	g	grams	0.035	ounces
lb	pounds	0.454	kilograms	kg	kilograms	2.205	pounds
T	short tons (2000 lb)	0.907	megagrams	Mg	megagrams	1.102	short tons (2000 lb)
<u>TEMPERATURE (exact)</u>							
°F	Fahrenheit	(F-32)/1.8	Celsius	°C	Celsius	1.8C+32	Fahrenheit
<u>TEMPERATURE (exact)</u>							
°C							

*SI is the symbol for the International System of Measurement

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FISH PASSAGE THROUGH CULVERTS

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1.0 INTRODUCTION

Culverts and road crossings potentially create barriers that restrict or prevent movement and migration of all life stages of resident and anadromous fish. Increased flow velocities, shallow water depths, increased turbulence, and perched outlets are all problems that may restrict fish movement through culverts (*Fitch 1995*). These barriers impact both resident and anadromous fish populations by preventing movement at critical life stages and blocking access to critical habitats, potentially affecting genetic diversity and long-term survival of some species.

Fish movement and migration in streams vary greatly by species and depend on the life stage of the fish (*Groot and Margolis 1991*). Movement of anadromous juvenile salmonids and resident adult coastal cutthroat (*Oncorhynchus clarki clarki*) in coastal streams is poorly documented. In a study on Carnation Creek in British Columbia, researchers trapped juvenile coho salmon (*Oncorhynchus kisutch*) and steelhead trout (*Oncorhynchus mykiss*) at the mouth of a tributary. Upstream movements occurred predominantly in November and December, and downstream movements occurred from February through May. Most of the movements were associated with high flows and water temperatures above 6°C (42.8°F) (*Bustard and Narver 1975*). The extent of juvenile salmonid movements was not measured in this study, and in general is poorly understood. A study of a small coastal stream by Heggnes et al. 1991 found that the majority of the cutthroat trout population was static and resided within a home range of less than 22 m (72.2 ft). They also found that a small fraction (17.9%) of the population was more mobile and moved more than 50 m (164 ft), with some individuals moving more than 300 m (984 ft) upstream and downstream. This movement was stable during winter, spring, and summer. These studies indicate that juvenile and resident adult trout are active throughout the year moving up and downstream in response to a number of environmental factors.

If the benefits of moving to one or more new habitats outweigh the energetic costs of movement and the risk of predation, life history types that move should be favored (*Gross et al. 1988*). Resident stream fishes may increase their fitness by moving to find habitat needed to complete certain life history stages or to search for optimum habitat as present locations become unsuitable (*Fausch and Young 1995*). In small headwater streams where populations are often “sinks”, movement is required to drive metapopulation dynamics and even modest migration may promote persistence (*Fausch and Young 1995*). Some possible reasons for juvenile salmonid movement upstream are to find suitable over-winter areas in smaller tributaries with milder conditions, disperse from areas of high population density, or escape predators that are more prevalent in larger streams or rivers.

To navigate through their environment, fish use two muscle systems: red (aerobic) for longer-term, low intensity activities and white (anaerobic) for short, high-intensity activities (*Allen and Pyles 1999*). Prolonged use of the white muscle system leaves a fish exhausted and requires a long period of rest (*Webb and Weihs 1983*). Fish use these muscles to achieve three different swimming speeds: cruising, sustained, and darting or burst. Cruising speeds can be maintained for extended periods of time, whereas sustained and darting/burst speeds can be performed for

only minutes or seconds at a time, respectively (*Bell 1986*). Adult cutthroat trout have cruising, sustained, and darting speeds of about 0.9 m/s, 1.82 m/s, and 4.24 m/s (2.95 ft/s, 5.97 ft/s and 13.91 ft/s). Adult steelhead trout are strong swimmers with cruising, sustained, and darting speeds of about 1.52 m/s, 4.24 m/s, and 7.88 m/s (4.99 ft/s, 13.91 ft/s and 25.55 ft/s) (*Bell 1986*). Information about the swimming ability of juvenile cutthroat trout and steelhead trout is not abundant, but the swimming abilities of juvenile Coho salmon should be relatively similar. Juvenile wild and hatchery Coho salmon ranging in size from 40 to 70 mm (1.57 to 2.76 in) had burst speeds that averaged 0.64 to 0.73 m/s (2.1 to 2.4 ft/s) with a maximum of 1.04 m/s (3.41 ft/s) (*Powers 1996*). Sustained swimming speed stamina was tested in tanks with a velocity of 0.37 m/s (1.21 ft/s); fatigue times ranged from 17 to 28 minutes (*Powers 1996*). For most salmonid species, swimming ability is a function of body length (*Jones et al. 1974; Bell 1986*). White muscles are required to enter a culvert with a velocity or jump barrier, and red muscle groups would be used to swim through the remainder of the culvert length. If white muscles are required to swim the length of the culvert after entry, the fish may exhaust itself before successfully passing through longer culverts.

Culverts can create multiple problems that restrict the movement of salmonids upstream. Boulders, logs, pools and riffles, meanders, and other sources of friction provide zones of low water velocities where fish can rest in natural streams. Therefore, fish traverse only short distances through high velocities. In culverts, velocities are nearly uniform throughout their length and usually greater than in natural channels (*Katopodis et al. 1978*). Fish must traverse long distances against high water velocities with no resting areas. Baffles and other types of deflectors are used in culverts to create “hydraulic shadows” or low velocity areas where fish can rest before moving through the next high velocity zone.

Shallow water depths can also obstruct fish passage. This occurs when the culvert floor is wide and flat with no obstructions. Water disperses across the entire floor creating very shallow water depths, particular at low discharges. Retrofitted culverts increase the depth of flow through the culvert allowing easier passage for fish of all life stages.

The design of culverts in the past focused primarily on the diameter required to pass a high flow event of a given exceedance interval. In contrast, culverts designed for fish passage are based on water depth and velocity ranges that are passable by fish at high-flow and low-flow conditions (*Klingeman 2000*). These are determined from daily and seasonal flows for critical periods of fish passage, rather than from flood-peak frequencies. Most culverts have been designed for maximum hydraulic capacity rather than fish passage. Due to the significant capital investment in road networks and existing culverts, it is unlikely that every culvert that impairs fish passage will be removed and replaced with an adequate design. Thus, lower cost alternatives for making culverts passable for fish are attractive to resource managers (*Fitch 1996*).

The term “culvert retrofit” is used to describe modifications placed in the existing culvert and/or the stream channel in an attempt to remedy fish passage barriers and improve fish passage. Culvert retrofits are typically much more economical than full culvert replacements (*Fitch 1996*). Retrofits commonly used include baffles inside the culvert barrel. Baffles are normally transverse steel, concrete, or plastic linear elements installed in culverts to create hydraulic conditions suitable for fish passage over a range of flow levels (*Forman et. al 2003; Fitch 1996*).

Hydraulic performance characteristics have been related to laboratory determinations of swimming speeds and endurance capabilities of the fish species of concern for design purposes (*McKinley and Webb 1956; Shoemaker 1956; Katopodis 1991*). There is little information on whether fish can move through these culverts outside of a laboratory and which baffle design is the most efficient at passing fish.

There have been few studies of juvenile and resident fish passage through culverts outside of the laboratory setting. Fitch (*1995*) looked at nonanadromous trout passage in culverts in Virginia. However, due to small numbers of tagged fish, none of the fish were recaptured. Juvenile salmon swimming upstream in culverts use the low velocity zones located close to the culvert wall (*Barber and Downs 1996*). Apparently, roughness of the corrugated culvert wall provides a low velocity boundary zone where passage for these small fish is possible. Kane et al. (*2000*) used minnow traps baited with salmon eggs to assess juvenile salmonid movement through four different culverts in Alaska. Only one culvert had baffles. They found that all age classes of juvenile coho salmon successfully passed upstream through a 90 m (59.84 ft) culvert with 13 baffles and velocities of up to 1.52 m/s (4.99 ft/s). Kane et al. (*2000*) concluded that food (salmon eggs) was sufficient incentive for upstream juvenile movement in Alaskan streams. This study also tracked the path of juvenile movement through the baffled culvert with underwater video cameras. They concluded that juvenile fish did not leap over the baffles but swam through a slot between the culvert wall and the end of the baffle. They concluded that slots may be an acceptable technique for improving juvenile fish passage in culverts with baffles. In each case, Kane et al. (*2000*) concluded that juvenile fish look for the paths that minimize energy expenditure.

Total replacement of inadequate road crossings with a bridge or stream-simulation culvert is the most desirable solution, but not always financially or logistically possible. Retrofitting culverts with baffles and flow deflectors to make internal hydraulics more conducive to fish movement is a less expensive and less labor-intensive alternative. Although these retrofits are not long-term solutions, they potentially allow fish passage until it is financially and logistically possible to replace the existing culvert. While many of these problem culverts have already been retrofitted, the effectiveness of these interim retrofit approaches for improving fish passage has not been tested in the field.

This study was designed to assess the ability of fish to move through ODOT retrofitted culverts and to determine the relative effectiveness of different retrofit designs. The tested designs included 90°, 30°, and 45° baffles. These designs were the most common retrofit designs and covered a wide range of flow characteristics. The working hypothesis was that retrofitted culverts would not restrict the movement of juvenile trout through the culvert in either direction and there would be no difference between retrofit designs in their ability to pass juvenile trout.

2.0 METHODS

Two different studies were developed to determine juvenile cutthroat and steelhead trout movements through retrofitted culverts. A mark-recapture study documented long-term movement, and a controlled short-term movement study determined efficiency of different retrofit techniques. Seven culvert sites representing current retrofit techniques were selected for the fish tagging study. The small number of retrofitted culverts in the state prevented a replicated study of different designs in the field. A single culvert without retrofits was used as the basis for the short-term movement study.

2.1 MARK-RECAPTURE STUDY OF LONG-TERM MOVEMENT

Culvert sites were selected based on experimental requirements. Potential culverts were eliminated for the following characteristics: a perched outlet, close proximity to the mainstem river, potential barriers to fish passage up or downstream of the culvert, excessive length of culvert. Perched outlets of greater than 0.30 m (12 in) would block most juvenile fish from entering the culvert and prevent assessment of the culvert retrofit. Culverts that were in close proximity, less than 100 m (328 ft) to the mainstem river could potentially lose large numbers of tagged fish. This would result in the recovery of a small number of tagged fish. Potential barriers to passage above or below the culvert, such as large falls, beaver dams, or unmodified culverts, may not provide an accurate representation of juvenile fish movement. Regardless of retrofits, culverts longer than 30.5 m (100 ft) may impede fish movement due to the absence of light, while also imposing logistical research difficulties not found in shorter culverts.

Seven culverts that had previously been retrofitted by ODOT met the requirements of the study (presence of salmonids, appropriate habitat above and below the culvert, retrofitted culvert to improve fish passage). As a result, the seven study sites represented several retrofitting techniques, including steel baffles and racks. The following is a list of the seven sites and their locations:

- Hough Creek, Lincoln County, Siletz River Basin, T9S, R10W, Sec 10
- Stemple Creek, Lincoln County, Siletz River Basin, T8S, R10W, Sec 36
- Little Lobster Creek, Benton County, Alsea River Basin, T15S, R8W, Sec 3
- Hayden Creek, Benton County, Alsea River Basin, T13S, R7W, Sec 38
- Alder Brook Creek, Lincoln County, Salmon River Basin, T6S, R10W, Sec 25
- Canyon Creek (two culverts), Douglas County, Umpqua River Basin, T31S, R5W, Sec 2

The seven culverts selected for the long-term movement study represented a variety of culvert designs and retrofit techniques. Ninety-degree baffles are sometimes called weirs and usually span the entire width of the culvert, perpendicular to the culvert sidewalls. Angled baffles deflect the flow to one side of the culvert and are commonly set at a 30° or 45° angle to the culvert sidewalls. Angled baffles do not completely span the width of the culvert, leaving a gap along one sidewall. Descriptive characteristics of each of the seven culverts are reported in Table 2.1, and photographs and map locations are included in Figures 2.1 through 2.10.

Table 2.1: Characteristics of culverts used in field studies

		Little Lobster	Canyon #2	Canyon #3	Houg h	Stempl e	Hayde n	Alder Brook
Basin		Alsea	Umpqua	Umpqua	Siletz	Siletz	Alsea	Salmon
Culvert Type		RCBC	RCBC	CMP- CF	CMP	RCBC	RCBC	RCBC
Retrofit design		11 baffles	31 baffles	19 baffles	7 baffles	7 baffles	8 baffles	Rack
Length	(m)	24.5	83	84	26.8	16.5	14.5	11.7
	(ft)	80.4	272.3	275.6	87.9	54.1	47.6	38.4
Width	(m)	2.5	2.4	4.7	2.1	1.9	1.9	1.8
	(ft)	8.2	7.9	15.4	6.9	6.2	6.2	5.9
Height	(m)	2.5	2.4	4.3		2.5	1.2	1.9
	(ft)	8.2	7.9	14.1		8.2	3.9	6.2
Culvert Slope (%)		4.4	1.15	0.95	3.1	0.75	2.3	2.7
Upstream Slope (%)		9.6	1.7	1.5	2.3	0.4	1.8	3.7
Downstream Slope (%)		3.1	1.6	1.2	3	1.7	1.5	3.1
Upstream ACW	(m)	4.4	4.7	8.3	4.3	3.1	3.6	4.4
	(ft)	14.4	15.4	27.2	14.1	10.2	11.8	14.4
Downstream ACW	(m)	4.7	5.3	8.7	3.6	4.1	3.4	4.3
	(ft)	15.4	17.4	28.5	11.8	13.5	11.2	14.1
Mean Summer Flow	(m ³ /s)	0.05	0.19	0.38	0.08	0.15	0.02	0.2
	(ft ³ /s)	1.76	6.68	13.36	2.81	5.27	0.70	7.03
Max Summer Velocity	(m/s)	0.43	1.11	0.76	2.57	1.6	0.33	1.39
	(ft/s)	1.41	3.64	2.49	8.43	5.25	1.08	4.56
Maximum Depth in Culvert	(cm)	20	20	22	35	25	23	28
	(in)	7.87	7.87	8.66	13.78	9.84	9.06	11.02
Summer Jump Height	(cm)	28	40	10	0	11	20	0
	(in)	11.02	15.75	3.94	0	4.33	7.87	0
Pool Depth Below Jump	(cm)	19	110	100	24	30	40	45
	(in)	7.48	43.31	39.37	9.45	11.81	15.75	17.72

RCBC – reinforced concrete box culvert

CMP-CF – half corrugated metal pipe with a concrete floor

ACW – active channel width (upstream and downstream)



Figure 2.1: Little Lobster Creek



Figure 2.2: Canyon Creek #2



Figure 2.3: Canyon Creek #3



Figure 2.4: Hough Creek



Figure 2.5: Stemple Creek

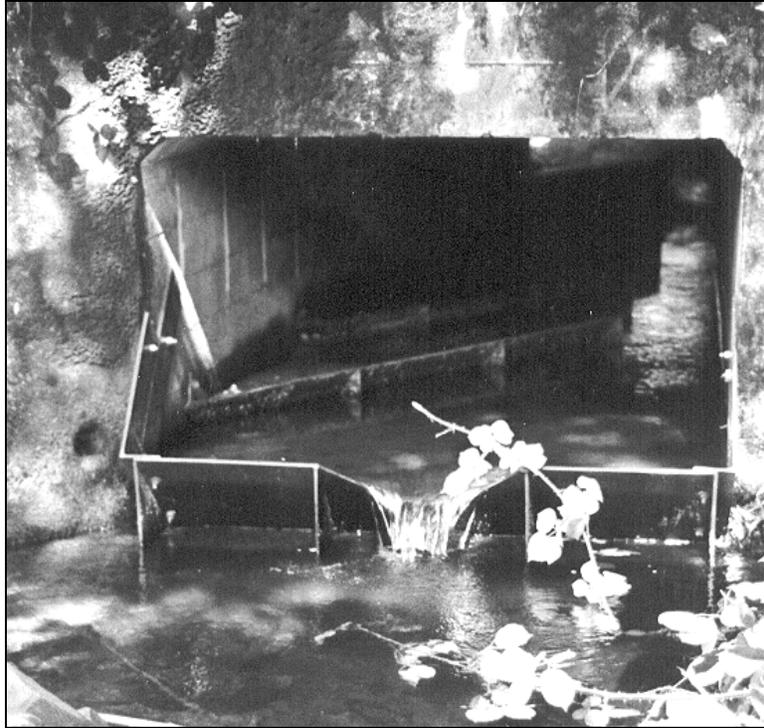


Figure 2.6: Hayden Creek



Figure 2.7: Alder Brook

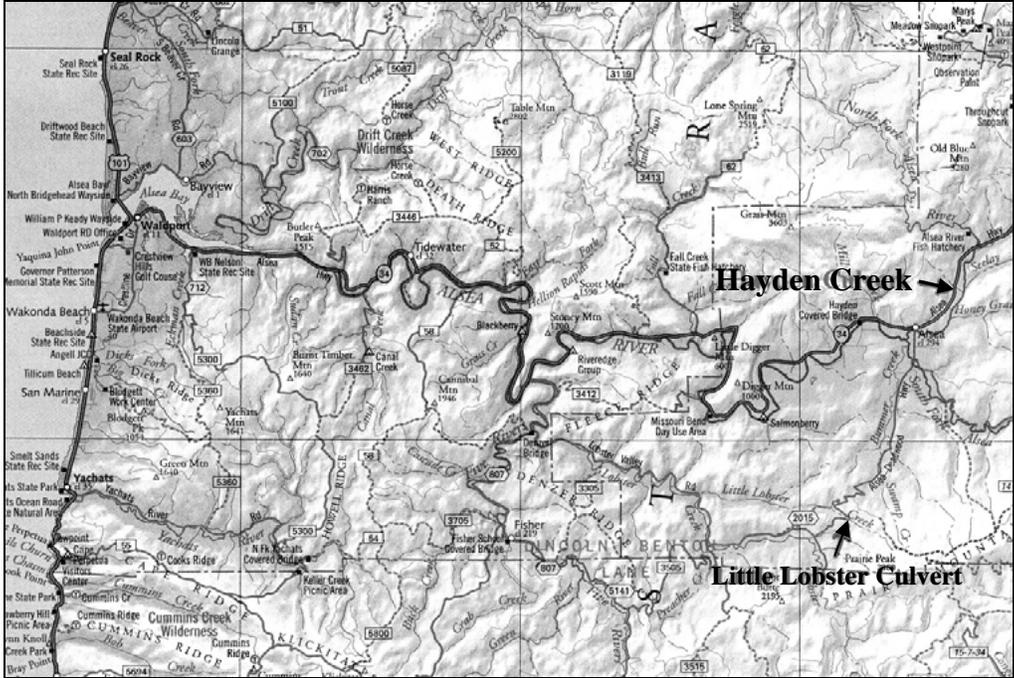


Figure 2.8: Locations of culverts on Hayden Creek and Little Lobster Creek.

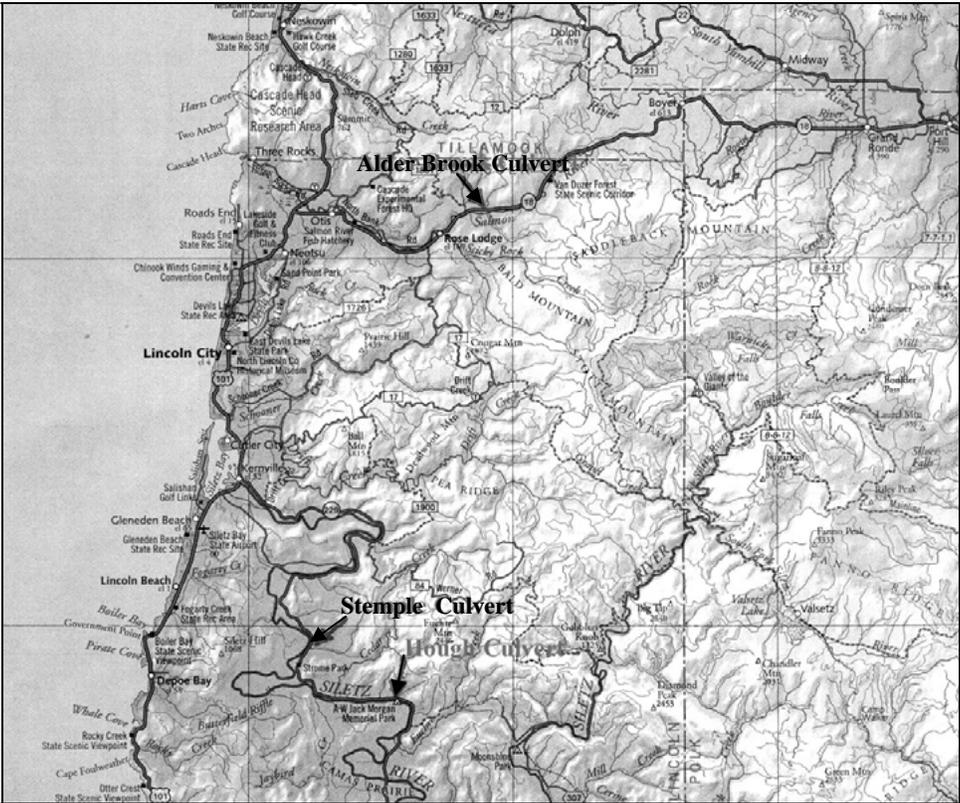


Figure 2.9: Locations of culverts on Alder Brook, Stemple Creek, and Hough Creek.

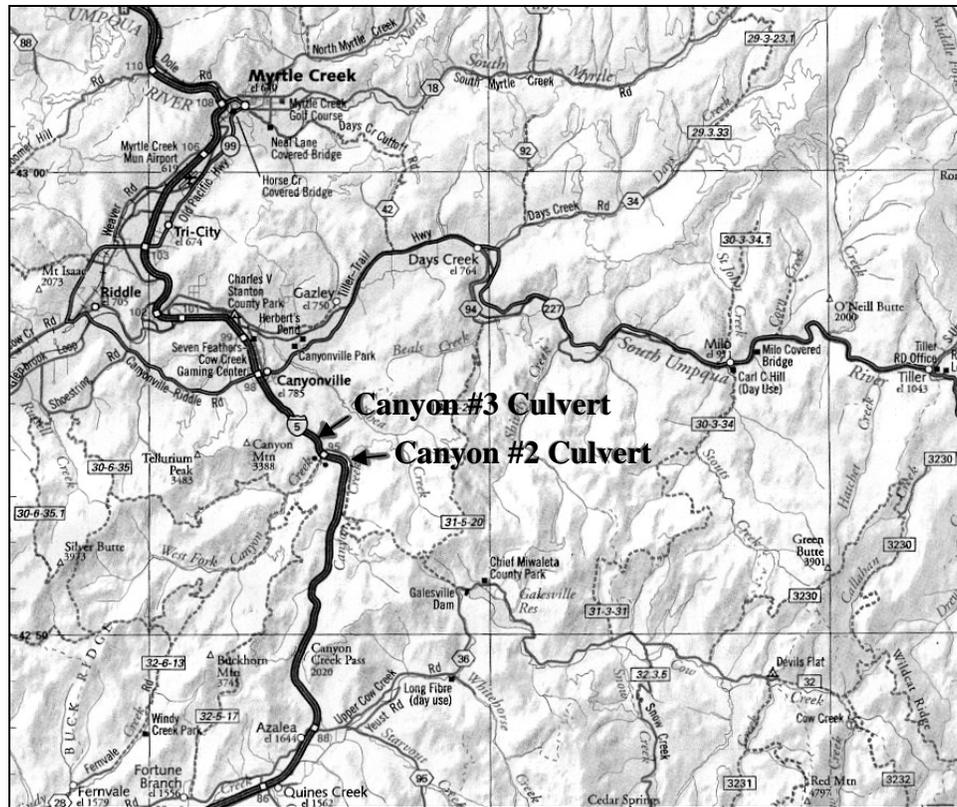


Figure 2.10: Locations of Canyon Creek culverts.

Study reaches for each site were set at a distance of 200 m (656.16 ft) upstream and downstream of the culvert with a total reach length of 400 m (1312.32 ft). Each site was divided into four 100 m (328.08 ft) sections, two above and two below the culvert. When the mainstem river was closer than 200 m (656.16 ft) downstream, the length of the reaches above and below the culvert were set equal to the distance to the river. Each of these reaches was then divided to create four study sections of equal length. A longer study reach was established on Little Lobster Creek because it had long sections of natural stream channel above and below the culvert. A reach of 400 m (1312.32 ft) downstream and 400 m (1312.32 ft) upstream was established. It was further divided into four 200 m (656.16 ft) study sections.

Block nets were placed at the upstream and downstream ends of each study section and left in the stream for one hour after electrofishing to prevent any unnatural movement. A Smith-Root Electrofisher was used to capture juvenile and adult cutthroat and juvenile steelhead trout to be tagged. Each captured fish was anesthetized with tricaine methanesulfonate (MS-222) and tagged with a small blue dot using a Panjet gun with alcian blue dye. The dye tag persists for 15 to 18 months and should only be placed on fish 80 mm (3.15 in) or larger¹ (*Thedinga and Johnson 1995*). A mark was placed at the base of each paired fin depending on the study section the fish was first captured in. Fish in the farthest downstream section were marked on the left

¹ Steve Johnson, conversation with author, 2001.

pelvic fin. Fish in the study section immediately below the culvert were marked on the right pelvic fin. A left pectoral fin mark was used on fish captured immediately above the culvert. The right pectoral fin was marked on fish captured in the farthest upstream section. Data recorded for each fish tagged included the previous tag location, new tag location, stream section, fork length, and species.

Study sites were sampled four times. The initial tagging was concluded on October 19, 2000 with subsequent mark-recaptures in March and August 2001, and June 2002. During each recapture, fish were examined for a previous tag. If a previous tag was found, the fish was retagged in the same location. If the fish did not have a previous tag, they were marked with the appropriate tag for that study section. All fish were released in the same section in which they were captured, regardless of tag location.

Velocity was measured with a Marsh-McBirney current meter. Average velocity was measured at 0.6 of the depth at 0.30 m (1 ft) intervals along a cross-sectional (transverse) or longitudinal transect. Discharge was calculated by multiplying the width, depth, and average velocity for each interval along a transect and summing the discharges for all intervals along the transect.

2.2 SHORT-TERM MOVEMENT CONTROLLED RELEASE STUDY

The second element of this study involved installing various baffle designs in a culvert with no previous retrofits. The study site was located on Big Noise Creek in Clatsop County, Oregon originating in the Clatsop State Forest at an elevation of approximately 1,200 ft (365.8 m) above sea level. The creek flows north under Oregon Route 30 at milepost 78.9 and joins Gnat Creek which eventually enters the Columbia River. Big Noise Creek is a second-order stream with a drainage area of 0.47 hectares (1.16 acres). The annual hydrologic pattern is low flows during the summer months and high flows during the winter months. December, January and February typically have the highest flows. The culvert that crosses under Oregon Route 30 is a reinforced concrete box culvert that is 30 m (98.42 ft) long, 2.4 m (7.87 ft) wide, and 2.4 m (7.87 ft) tall. The outlet is slightly backwatered by a logjam so there is no jump into the culvert. The slope of the culvert is 1.5 percent. Figures 2.11 and 2.12 show the culvert at Big Noise Creek.



Figure 2.11: Downstream end of culvert on Big Noise Creek, illustrating the lower fish trap.

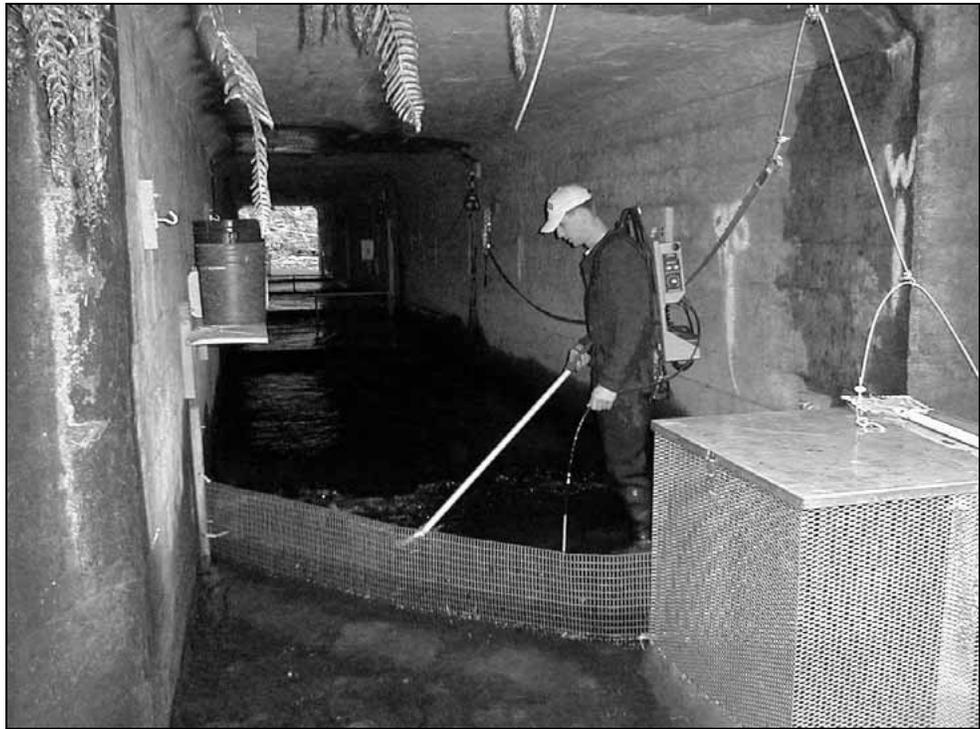


Figure 2.12: Downstream end of culvert on Big Noise Creek, illustrating backpack electrofishing for steelhead trout in lower section above the fish trap.

Juvenile steelhead trout from the Oregon Department of Fish and Wildlife, Big Creek Fish Hatchery were used for each release during summer and winter base flows. The juvenile trout were randomly selected from the hatchery raceways for each release. A new set of fish was used for each release to remove the possibility of learned behavior. The trout were transported via buckets approximately 10 km (6.21 mi) from the hatchery to the culvert, where they were allowed to acclimate in stream water for at least 30 minutes. Buckets were placed in the shade with aerators to ensure that the fish were stressed as little as possible before being placed in the culvert.

Fish traps, 0.9 x 0.9 x 0.9 m (2.95 x 2.95 x 2.95 ft) in size, were placed against one sidewall at each end of the culvert. A screen was attached to the other sidewall to divert fish into the trap. Drop screens that spanned the width of the culvert were placed 3.5 m (11.48 ft) on each side of the culvert center point. The drop screens could be lowered or raised from outside the culvert by a series of ropes and pulleys. A release cage was placed in the middle of the culvert between the two drop screens. The release cage had doors on the sides and front that could be opened by pulling ropes outside of the culvert as shown in Figure 2.13. Twenty acclimated juvenile steelhead trout were placed in the release cage and allowed to sit for three minutes. After this time, the doors on the cage were opened from outside the culvert, and the fish were allowed to move freely in the culvert for a period of three hours. The release time was chosen to allow two releases per day in the winter, and three releases per day in the summer.

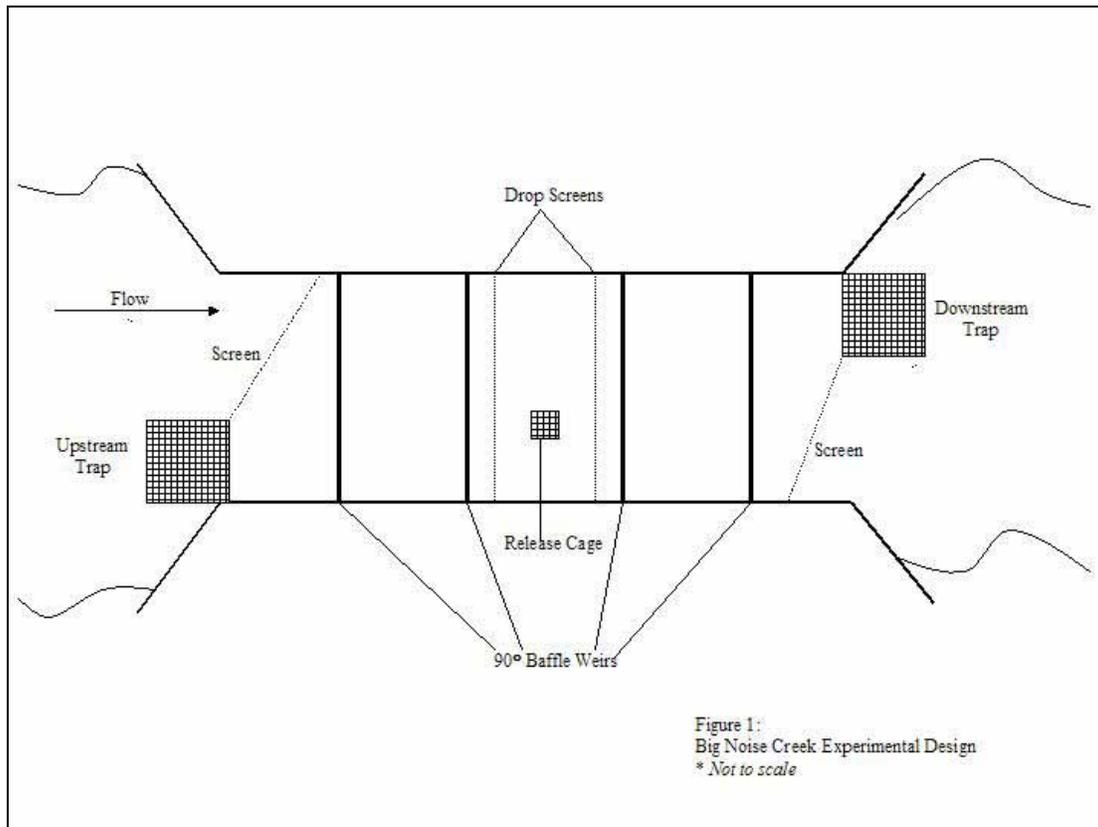


Figure 2.13: Experimental layout of fish traps and release cage in culvert on Big Noise Creek.

After the three hour period was over, the drop screens were released dividing the culvert into five sections; upstream through the culvert (upstream trap), upstream in the culvert, no movement (between drop screens), downstream in the culvert, and downstream through the culvert (downstream trap). Both traps were checked first, and the entrances to the traps were blocked after the fish were removed to prevent movement into the traps during collection of the other sections. A Smith-Root backpack electrofisher was used to capture fish that were not in the traps. Shocking started at the downstream end of the culvert and worked upstream, with fish from each section being placed into separate buckets. Each section had two to four passes with the electrofisher, until at least 80% of the fish were recaptured. The recaptured fish were anesthetized with MS-222 to measure length (fork length). After recovery, fish were released below a barrier falls downstream of the culvert.

Plastic baffles with a vertical back and a 45° upstream face were bolted to the floor of the culvert for each baffle configuration. Releases were divided into four groups for the winter study: control (no baffles), 30° and 45° baffles angled downstream, and 90° baffles. A field review of the project found that the research team misunderstood the designs used by ODOT for diagonal baffles. ODOT typically angles the 30° and 45° baffles in an upstream direction to create more depth between baffles. This is particularly important during low flow because the upstream baffles backwater the flow, providing more volume of water between the baffles for the fish. The summer study was expanded to include the four treatments (control (no baffles), 30° and 45° baffles angled downstream, and 90° baffles) plus additional treatments of 30° and 45° baffles angled upstream.

The 90° baffle design used 30 cm (11.81 in) tall plastic baffles, while all the 30° and 45° designs used 20 cm (7.87 in) tall baffles. The 90° baffle design consisted of 5 baffles with a spacing of 5.4 m (17.72 ft), the 45° baffle design had 12 baffles with a spacing of 2.1 m (6.8 ft), and the 30° baffle design contained 7 baffles with a spacing of 3.5 m (11.48 ft). The angled baffles had a 0.9 m (2.95 ft) gap between the end of the baffle and the culvert wall. Locations of the baffles for each design were marked on the culvert wall so that summer and winter releases would have the same baffle configurations. All of the baffle systems were designed by an ODOT engineer to be similar to the most common designs used in ODOT culverts.

Eight experimental releases were performed for each baffle design. The first four releases were conducted without incentives for replication, and the second four releases consisted of various incentives to attempt to increase trout movement upstream through the culvert. The four different incentives included lights, bait, overcrowding, and scare tactics. Artificial lights in the culvert were left on for the entire three-hour release in an attempt to move fish out of the normally shaded culvert. A screened bottle containing crushed hatchery pellets, salmon eggs, sand shrimp, and scented oils was placed just above the upstream trap to provide a positive “bait” incentive for movement up through the culvert. The overcrowding incentive involved leaving the lower drop screen down during the release so that the fish could only move upstream. The fright incentive consisted of moving from the downstream trap up with the electrofisher on a low setting and creating noise by hitting a steel bar with a hammer under water. Drop screens were lowered when they were passed to prevent “scared” fish from moving back downstream. The incentives did not attract fish and did not cause fish to move upstream through the culverts.

Therefore, the summer experimental releases for the control, 30°, 45°, and 90°, upstream baffle configurations did not include incentives.

3.0 RESULTS

3.1 LONG-TERM MARK-RECAPTURE

The long-term movement mark-recapture was an observational study with weak statistical power. The study culverts could not be randomly selected and were chosen based on attributes that would facilitate a mark-recapture study of this type. The data set for the statistical analysis was small due to the relatively few fish that moved between study sections. Observations from this study cannot be applied to a larger set of culverts but provide supplemental data for the short-term movement study.

3.1.1 Culvert Hydraulics

The seven study culverts were selected to be relatively similar, but they differed in several design characteristics and physical properties. Culvert types included five reinforced concrete box culverts (RCBC), one corrugated metal pipe culvert (CMP), and one half corrugated metal pipe with a concrete floor (CMP-CF). Culvert slopes ranged from 0.75% to 4.4% (Table 2.1). Stream channels ranged from 3.1 m to 8.7 m (10.17 ft to 28.54 ft) in width and stream slopes ranged from 1.2% to 3.1% downstream of the culverts. Maximum summer velocities ranged from 0.33 m/s to 2.57 m/s (1.08 ft/s to 8.43 ft/s) (Table 2.1).

Velocities in the culverts and the streams around them were compared in November 2000. In general, velocities were greater within the culverts than in the streams outside the culverts, as seen in Table 3.1. Both maximum velocity and average velocity inside the culvert was more than four times greater than velocities in the upstream and downstream reaches in Stemple Creek. Velocities inside the culvert were relatively similar to velocities in the surrounding stream reaches in Little Lobster Creek, both Canyon Creek sites, Hough Creek, and Alder Brook. Velocities in Hayden Creek were difficult to measure but appeared to be less than the velocities in the surrounding stream reaches.

Table 3.1: Velocities in retrofitted culverts at the seven study sites in November 2000.

Stream	Maximum Culvert Velocity		Average Culvert Velocity		Maximum Stream Velocity		Average Stream Velocity	
	ft/s	m/s	ft/s	m/s	ft/s	m/s	ft/s	m/s
Little Lobster Creek	1.42	0.433	0.21	0.064	1.22	0.372	0.17	0.052
Canyon Creek #2	3.63	1.106	1.48	0.451	1.99	0.607	0.43	0.131
Canyon Creek #3	2.49	0.759	0.36	0.110	3.22	0.981	0.38	0.116
Hough Creek	2.26	0.689	0.72	0.219	2.52	0.768	0.71	0.216
Stemple Creek	5.25	1.600	1.10	0.335	1.24	0.378	0.27	0.082
Hayden Creek	0.10	0.030	0.01	0.003	1.28	0.390	0.35	0.107
Alder Brook	4.55	1.387	1.37	0.418	3.67	1.119	0.81	0.247

3.1.2 Fish Movement in Field Surveys

Study sites were surveyed by snorkeling in order of priority. Number, length, and species of fish in pools were recorded. Snorkeling began with the pool immediately up from the mainstem river or 500 meters (1640.4 ft) downstream of the culvert, whichever came first. The same distance that was snorkeled downstream of the culvert was snorkeled upstream of the culvert.

The snorkel survey data were analyzed from above and below each culvert. Figures 3.1 through 3.5 depict longitudinal distributions of salmonids below each culvert and above each culvert. The lines for upstream and downstream reaches represent the cumulative number of salmonids observed as the reach was observed in an upstream direction. In a natural stream, it would be expected that each line would have relatively the same slope. Most of the distributions have smaller slopes on the upstream end of the culvert. Hough and Hayden Creek did not have enough snorkeling data to justify a longitudinal graph, but graphs are presented of each of the other culverts in Figures 3.1 through 3.5.

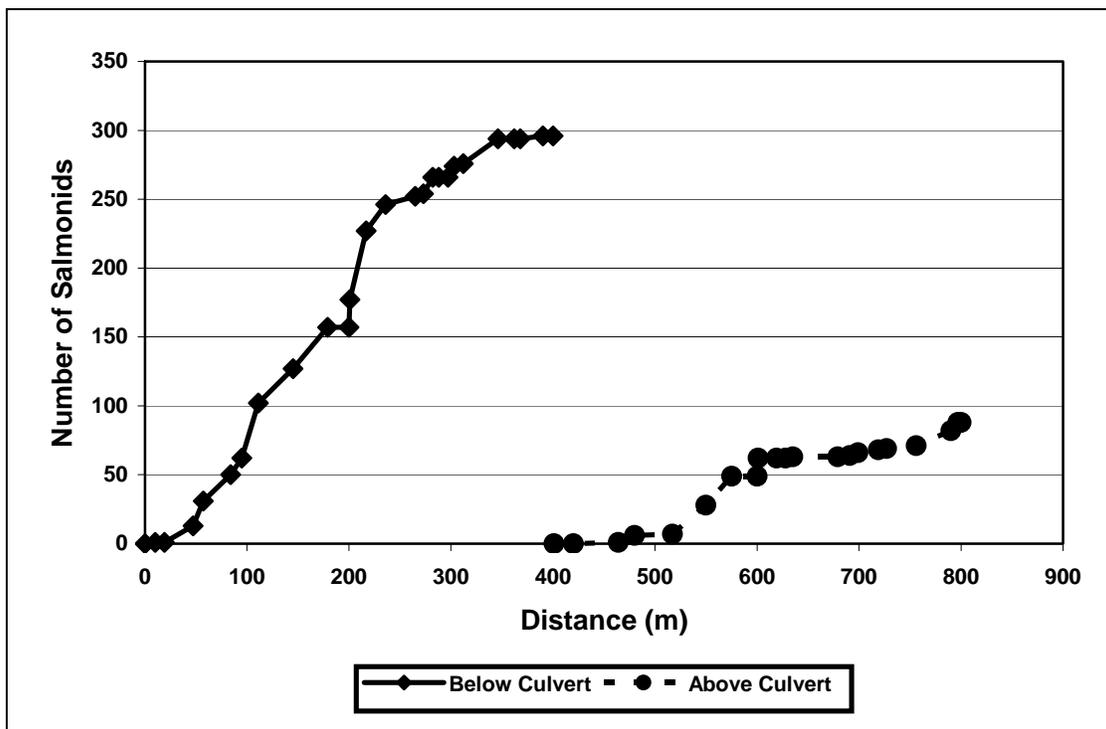


Figure 3.1: Longitudinal distribution of salmonids below and above the culvert at Little Lobster Creek.

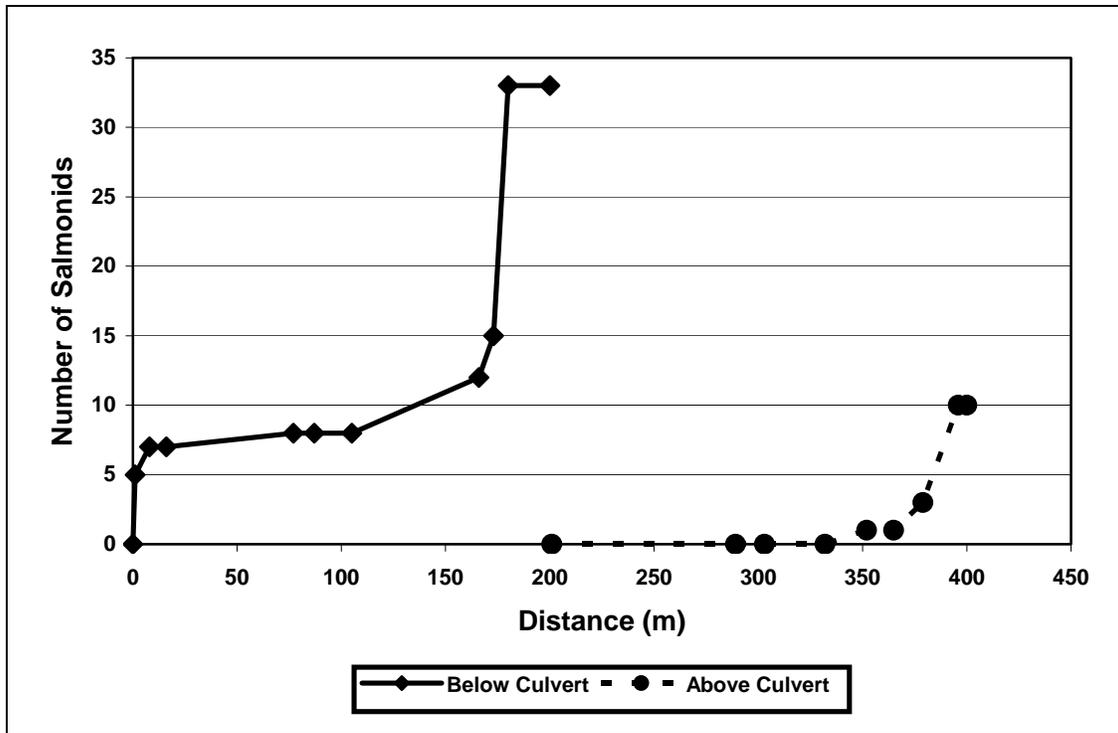


Figure 3.2: Longitudinal distribution of salmonids below and above the culvert at Canyon Creek Site #2.

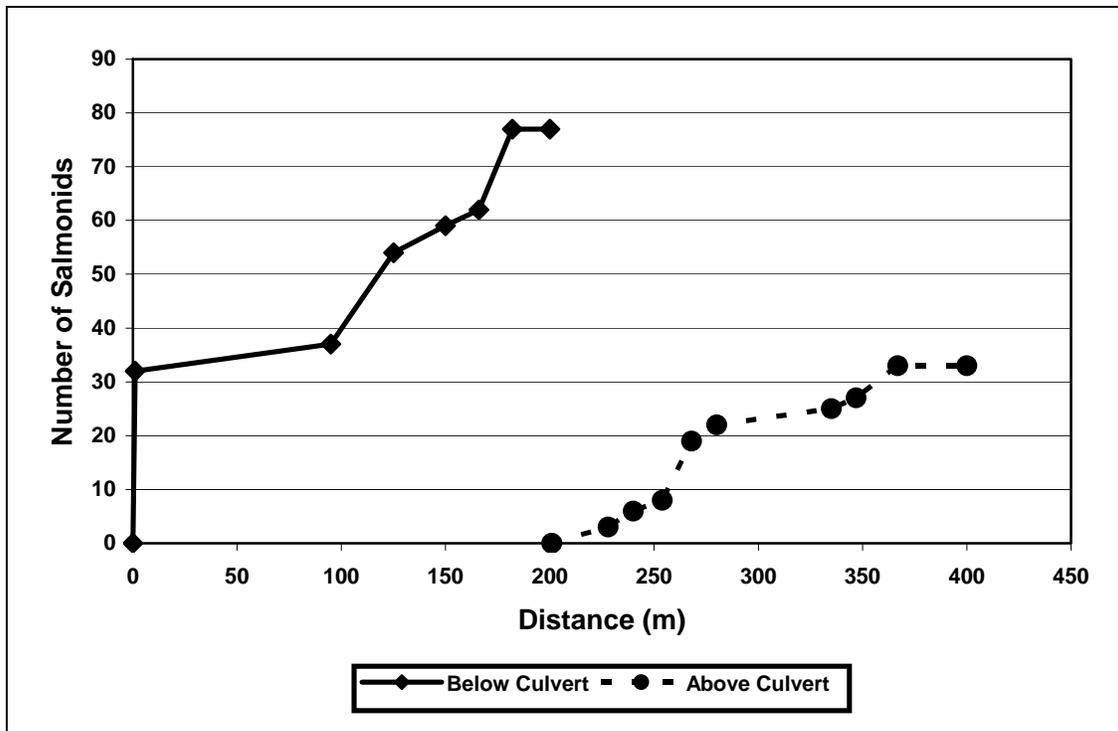


Figure 3.3: Longitudinal distribution of salmonids below and above the culvert at Canyon Creek Site #3.

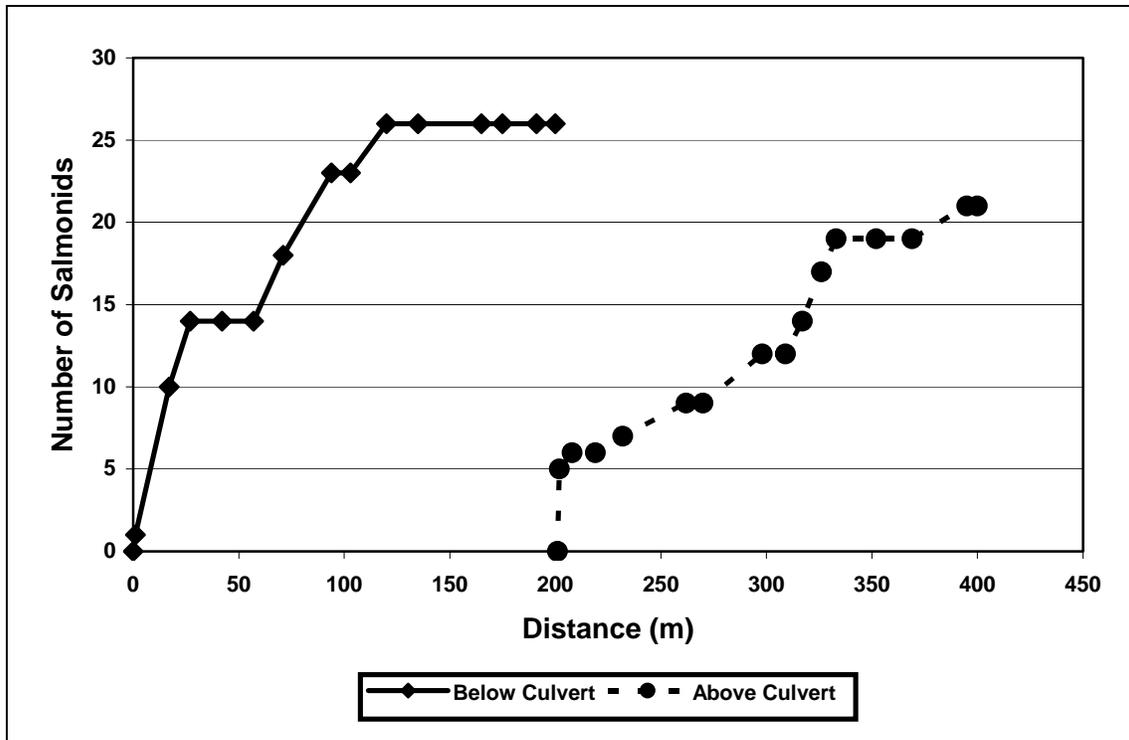


Figure 3.4: Longitudinal distribution of salmonids below and above the culvert at Stemple Creek.

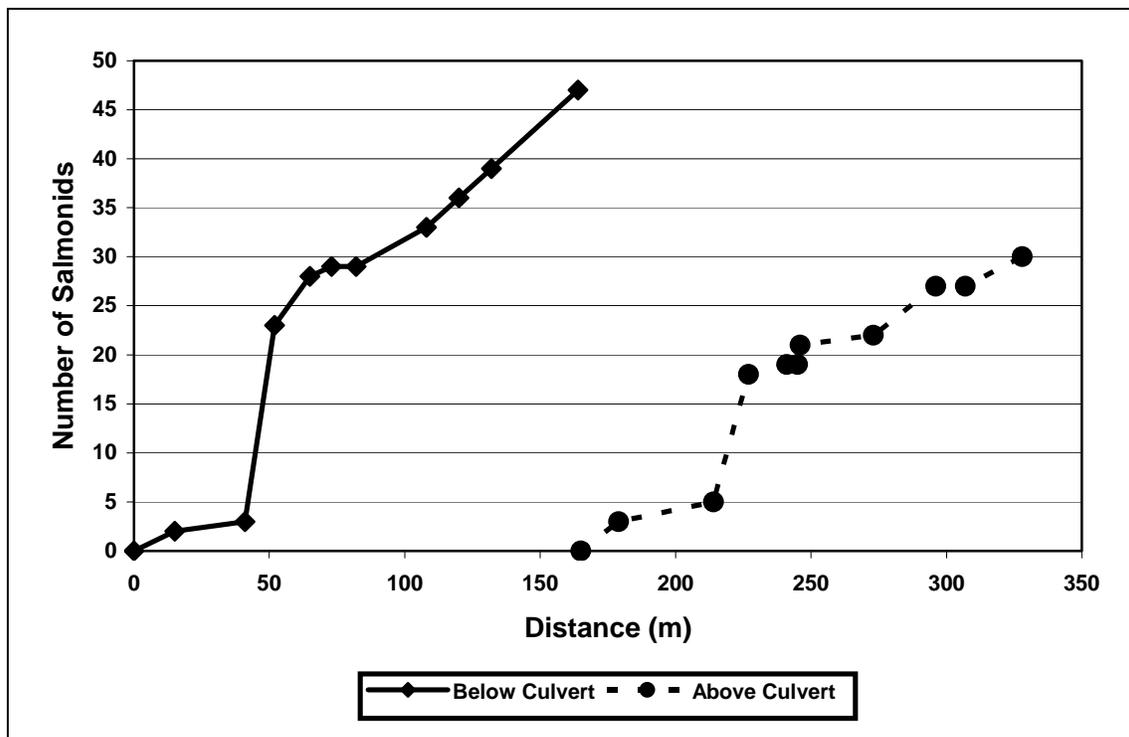


Figure 3.5: Longitudinal distribution of salmonids below and above the culvert at Alder Brook.

Fish were not observed for more than 50 m (164 ft) upstream of the culvert in Little Lobster Creek and Canyon Creek #2. Total numbers of fish observed upstream of the culverts were always less than the numbers of fish observed downstream of the culverts. These differences indicate that fish potentially move through the culverts, but the culverts possibly decrease upstream passage because of unfavorable flow conditions inside the culvert, unsuitable habitat upstream of the culvert, or lack of spawning habitat upstream of the culvert. There was no evidence that numbers of fish were disproportionately larger in the pools immediately below the culvert.

Fish movement within the study reaches can be compared in terms of the percent of recaptured fish that moved between study sections. The four classes of movement include downstream within, downstream through, upstream within, and upstream through. Percentages of fish that moved downstream or upstream within the study reach indicate that the fish moved within the study reach but not through the culvert. Percentages of fish that moved through the culvert either downstream or upstream indicate successful passage through the culvert.

General data on the total number of fish tagged, percent of tagged fish that were cutthroat and steelhead, percent of the tagged fish recaptured, and average size of a moving fish are reported in Table 3.2. In all, 1626 cutthroat and steelhead trout were tagged in the seven study reaches during the study (Table 3.2). Of those 1626 fish, 223 were recaptured for a total recapture rate of 13.7%. The total percent of fish that moved between sections was 17.9% or 40 fish out of the 223 recaptured. Twenty-percent of the fish that moved within the study reach were steelhead trout, while the remaining 80% were cutthroat trout. The average size of the fish for each movement category was 121 mm (4.76 in) for upstream through culvert, 138 mm (5.43 in) for downstream through culvert, 129 mm (5.08 in) for upstream within the study reach, and 128 mm (5.04 in) for downstream within the study reach. Figure 3.6 graphs the number of trout recaptured by stream and date of recapture.

Table 3.2: Percent of recaptured fish that moved for each study reach

	Total Fish Tagged	Percent Cutthroat	Percent Steelhead	Percent Recaptured	Mean Size (forklength)	
					(mm)	(in)
Little Lobster Creek	568	93	7	18	126	4.96
Canyon Creek #2	216	29	71	12	140	5.51
Canyon Creek #3	287	18	82	9	126	4.96
Hough Creek	109	81	19	9	106	4.17
Stemple Creek	134	100	0	13	103	4.06
Hayden Creek	80	100	0	9	120	4.72
Alder Brook	232	53	47	14	176	6.93
Overall	1626	80	20	13.7	13.1	5.17

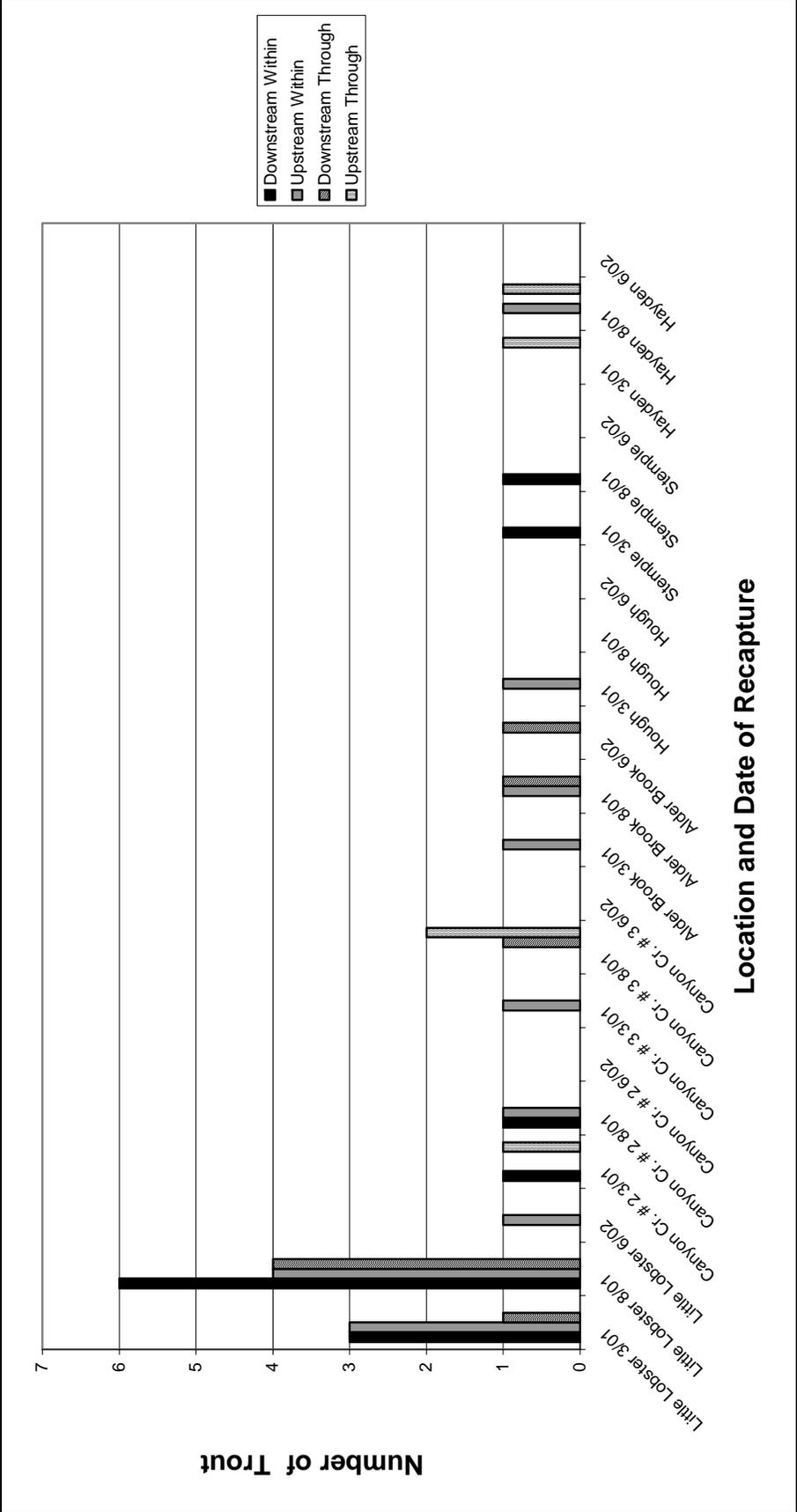


Figure 3.6: Number of trout that moved between sections for all study sites. Date of capture is indicated in figure axis. Movement between upper and lower sections of a reach above or below a culvert is indicated as movement “within” a reach. Movement through a culvert between downstream and upstream sections is indicated as movement “through” adjacent reaches.

A two-sample t-test was used to determine if there was a significant difference between the percent movements of trout within each stream (Table 3.3). Three comparisons were made for three possible types of movement: 1) downstream within versus downstream through, 2) upstream within versus upstream through, and 3) upstream through versus downstream through. Only Little Lobster Creek exhibited movement patterns that were statistically significant. The percent of fish that moved downstream through the culvert in Little Lobster Creek was significantly different than the percent of fish that moved upstream through the culvert (p-value = 0.01). All other comparisons were not statistically significant (p-value = >0.25).

Table 3.3: Mark-recapture data for each study reach

	Downstream		Upstream	
	Within	Through	Within	Through
Little Lobster Creek	8.7	4.8	7.5	0
Canyon Creek #2	7.7	0	3.8	3.8
Canyon Creek #3	0	3.8	3.8	7.7
Hough Creek	0	0	10	0
Stemple Creek	11.8	0	0	0
Hayden Creek	0	0	14.3	28.6
Alder Brook	0	6.1	6.1	0

3.1.2.1 Little Lobster Creek Culvert

The Little Lobster Creek culvert had the largest number of tagged fish move between the study sections, but did not have any fish move upstream through the culvert. The total number of tagged fish in Little Lobster Creek was 568 (528 cutthroat trout, 40 steelhead trout). All ten of the tagged steelhead trout juveniles that were recaptured remained within the study section in which they were tagged. All fish that moved were cutthroat trout, with an average size of 126 mm (4.96 in). Of the 22 recaptured cutthroat trout that moved; nine moved downstream between sections but not through the culvert, four moved downstream through the culvert, eight moved upstream between sections but not through the culvert, and zero fish moved upstream through the culvert.

3.1.2.2 Canyon Creek Culvert #2

Canyon Creek contained juveniles of both steelhead and cutthroat trout. The total number of tagged fish in this study reach was 216 fish (63 cutthroat trout, 153 steelhead trout). One cutthroat and three steelhead trout moved between study sections. The average size of these moving trout was 140mm (5.51 in). Two trout moved downstream within the study section but not through the culvert, zero moved downstream through the culvert, one moved upstream within the study sections but not through the culvert, and one trout moved upstream through the culvert. The cutthroat trout that moved upstream through the culvert between October 2000 and March 2001 had a fork length of 155 mm (6.10 in) at the time of recapture and moved from the study section just downstream of the culvert to the section just upstream of the culvert, a distance of at least 83 m (272 ft).

3.1.2.3 Canyon Creek Culvert #3

The total number of tagged fish in this study reach was 287 (51 cutthroat trout, 236 steelhead trout). One cutthroat and three steelhead trout moved between study sections. The average size of these moving trout was 126 mm (4.96 in). One trout moved downstream through the culvert, one moved upstream within the study sections but not through the culvert, and two trout moved upstream through the culvert. Two steelhead trout moved upstream through the culvert between March and August 2001. These two trout were the smallest fish that moved upstream through any of the culverts with fork lengths of 107 and 108 mm (4.21 and 4.25 in). Both trout moved from the farthest downstream study section. The steelhead trout that was 108 mm (4.25 in) moved up to the study section just upstream of the culvert, a distance of at least 184 m (603.67 ft). The 107 mm (4.21 in) steelhead trout moved up to the farthest upstream study section, a distance of at least 284 m (931.75 ft).

3.1.2.4 Hough Creek Culvert

Out of the 109 trout tagged in this study reach, 88 were cutthroat trout and 21 were steelhead trout. One cutthroat trout moved upstream between study sections but not through the culvert. It had a fork length of 106 mm (4.17 in).

3.1.2.5 Stemple Creek Culvert

In this study reach, 134 cutthroat trout were tagged. Two of these trout moved downstream between study sections but not through the culvert. The average size of the trout was 103 mm (4.05 in).

3.1.2.6 Hayden Creek Culvert

A total of 80 cutthroat trout were tagged in this study reach. Trout at this site only moved upstream and had an average size of 120 mm (4.72 in). One cutthroat trout moved upstream between study sections but not through the culvert and two trout moved upstream through the culvert. A cutthroat trout with a fork length of 125 mm (4.92 in) moved between October 2000 and March 2001, and a trout with a fork length of 111 mm (4.37 in) moved between March and August 2001. Each trout moved at least 15 m (49.21 ft).

3.1.2.7 Alder Brook Culvert

The total number of tagged fish in this study reach was 232 (122 cutthroat trout, 110 steelhead trout). Two cutthroat and two steelhead trout moved between study sections. The average size of these moving trout was 176 mm (6.93 in). Two trout moved downstream through the culvert and two trout moved upstream between study sections but not through the culvert.

3.2 SHORT-TERM CONTROLLED RELEASE

Winter tests were conducted between February 9 and March 15, 2002. Flows in the culvert during this time ranged from 1.5 to 5.1 m³/s (52.97 to 180.10 ft³/s). Discharge through the culvert at Big Noise Creek for each trial is reported in Table 3.4. All of the trout released could not be consistently recaptured because some of them moved inside the plastic baffles and were difficult to detect and remove. Even though some trout escaped, recapture rates for the winter and summer releases averaged greater than 95%. The average size of the hatchery juvenile steelhead trout in the winter trials was 179 mm (7.05 in), with a range of 116 to 246 mm (4.57 to 9.69 in).

Table 3.4: Steelhead trout recaptured by zone during winter flows.

Baffle Configuration	Trial #	Number of Fish Recaptured in Zone					Total Recaptured	Date	Flow	
		Below Culver t	Lower Culver t	Middle Culver t	Upper Culver t	Above Culver t			m ³ /sec	ft ³ /sec
90° Baffles	1	5	11	2	0	0	18	2/9/02	5.1	180.1
	2	4	0	5	2	4	15	2/9/02	5.1	180.1
	3	6	6	5	0	0	17	2/10/02	4.6	162.4
	4	5	5	7	2	0	19	2/10/02	4.6	162.4
45° Baffles	1	7	5	4	4	0	20	2/22/02	2.4	84.8
	2	9	6	2	2	1	20	2/23/02	2.4	84.8
	3	7	3	5	3	0	18	2/23/02	2.4	84.8
	4	8	7	2	2	0	19	2/24/02	2.4	84.8
30° Baffles	1	4	7	8	1	0	20	3/3/02	1.5	53.0
	2	13	4	2	1	0	20	3/4/02	1.5	53.0
	3	11	4	2	3	0	20	3/8/02	1.5	53.0
	4	10	10	0	0	0	20	3/9/02	1.5	53.0
None (Control)	1	10	9	0	0	0	19	3/14/02	4.7	166.0
	2	6	13	1	0	0	20	3/14/02	4.7	166.0
	3	0	19	0	0	0	19	3/15/02	4.7	166.0
	4	14	4	0	0	0	18	3/15/02	4.7	166.0

Experimental releases during summer flows were conducted between September 9 and October 4, 2002. General data about the releases is show in Table 3.5. Discharge during this season remained constant at 0.14 m³/s (4.94 ft³/s). The average size of the juvenile steelhead trout used in the summer trials was 127 mm (5 in), with a range of 80 to 156 mm (3.15 to 6.14 in). The size difference between the summer and winter trials was unavoidable due to juvenile growth rates in a hatchery setting. Two additional baffle configurations were tested during the summer trials because the flow patterns in the downstream angled baffles were similar to the control flow patterns. Angling the 30° and 45° baffles upstream increased the depth of water in the culvert and appreciably altered the flow patterns.

Table 3.5: Steelhead trout recaptured by zone during summer flows.

Baffle Configuration	Trial #	Number of Fish Recaptured in Zone					Total Recaptured	Date	Flow	
		Below Culvert	Lower Culvert	Middle Culvert	Upper Culvert	Above Culvert			m ³ /sec	ft ³ /sec
90° Baffles	1	0	6	14	0	0	20	9/9/02	0.14	4.9
	2	2	5	10	2	0	19	9/9/02	0.14	4.9
	3	4	2	12	4	0	20	9/10/02	0.14	4.9
	4	0	9	10	1	0	20	9/10/02	0.14	4.9
45° Baffles (Upstream)	1	13	5	0	0	0	18	9/23/02	0.14	4.9
	2	8	4	2	5	1	20	9/23/02	0.14	4.9
	3	9	5	2	1	3	20	9/24/02	0.14	4.9
	4	6	5	0	2	7	20	9/24/02	0.14	4.9
30° Baffles (Upstream)	1	4	5	7	2	0	18	10/2/02	0.14	4.9
	2	10	5	0	4	1	20	10/2/02	0.14	4.9
	3	7	3	6	2	1	19	10/2/02	0.14	4.9
	4	6	2	7	2	3	20	10/4/02	0.14	4.9
None (Control)	1	15	5	0	0	0	20	10/6/02	0.14	4.9
	2	18	2	0	0	0	20	10/6/02	0.14	4.9
	3	11	9	0	0	0	20	10/6/02	0.14	4.9
	4	16	4	0	0	0	20	10/7/02	0.14	4.9
30° Baffles (Downstream)	1	12	6	1	0	0	19	10/11/02	0.14	4.9
	2	14	4	0	0	0	18	10/12/02	0.14	4.9
	3	9	11	0	0	0	20	10/12/02	0.14	4.9
	4	15	2	2	0	0	19	10/12/02	0.14	4.9
45° Baffles (Downstream)	1	16	3	0	0	0	19	10/18/02	0.14	4.9
	2	13	5	1	0	0	19	10/18/02	0.14	4.9
	3	17	3	0	0	0	20	10/19/02	0.14	4.9
	4	8	9	3	0	0	20	10/19/02	0.14	4.9

3.2.1 Culvert Hydraulics

The experimental retrofit designs produced complex flow patterns within the culverts. All baffle designs resulted in lower maximum, minimum, and average velocities within the culvert as compared to the culvert without retrofitted baffles as seen in Table 3.6. In general, the baffles reduced the velocity profiles to about half of the velocities in the non-retrofitted culvert.

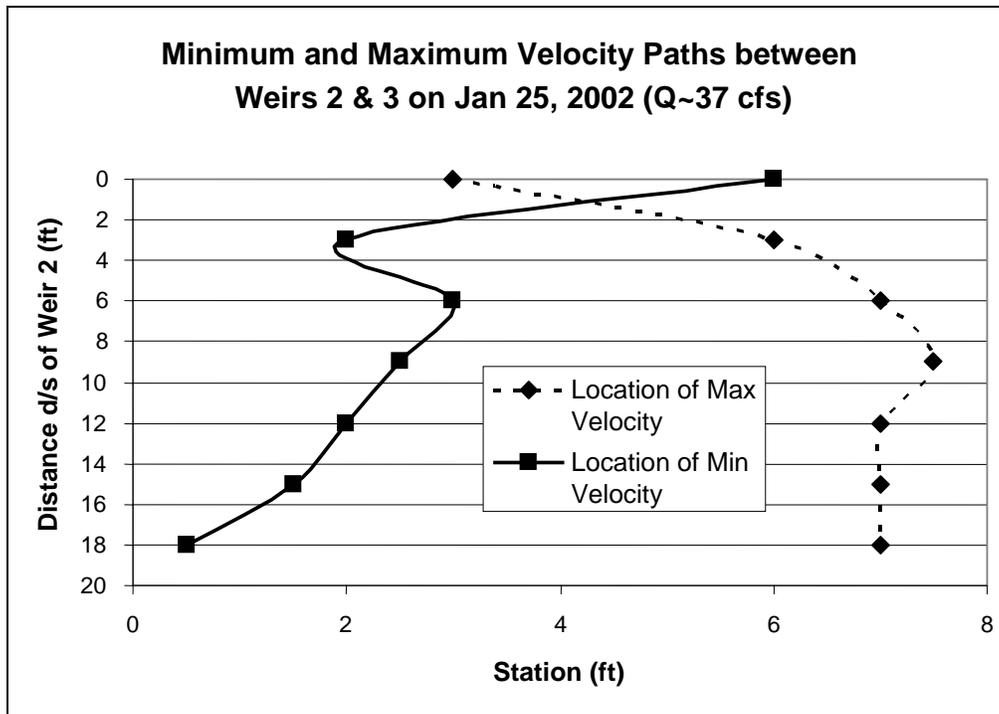
Table 3.6: Velocities within the culvert on Big Noise Creek for different baffle designs in winter 2002.

Retrofit Design	Date	Maximum Velocity		Minimum Velocity		Average Velocity	
		ft/s	m/s	ft/s	m/s	ft/s	m/s
None	March 19, 2002	5.69	1.73	2.04	0.62	4.06	1.24
30° Baffle	March 9, 2002	2.77	0.84	1.05	0.32	1.71	0.52
45° Baffle	February 24, 2002	3.41	1.04	1.81	0.55	2.71	0.83
90° Baffles (between baffles)	February 8, 2002	2.26	0.69	0.56	0.17	1.44	0.44
90° Baffles (top of baffles)	February 8, 2002	3.24	0.99	2.49	0.76	2.82	0.86

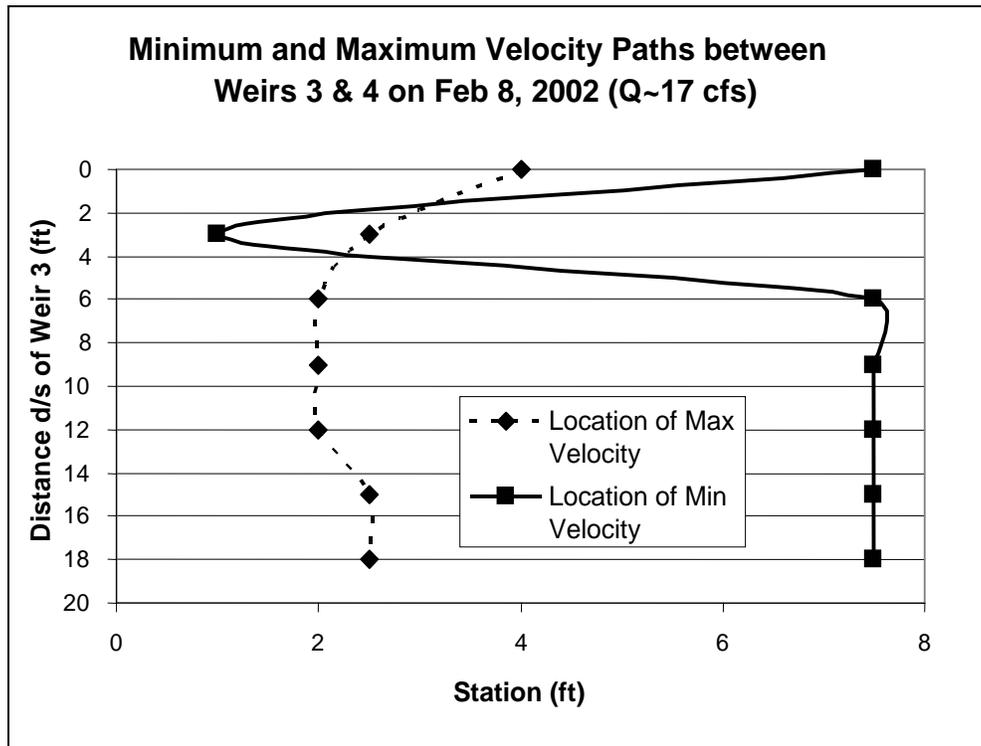
Baffles reduced velocities and created areas of low velocity and high velocity between them as shown in Figure 3.7. Velocities across the top of the baffles were much higher than velocities between the baffles as seen in Figures 3.8 and 3.9. In general, the velocities were twice as great

at the crest of the baffles as velocities in the sections between the baffles. The velocities were similar to average velocities found in the culvert without retrofitting (Table 3.6). The reduced velocities in the culvert, during the winter, fall within the swimming capacities of most salmonids (See Chapter 1.0).

Discharges during the experimental trials ranged from 0.14 to 0.48 m³/s (5 to 17 ft³/s) and were generally constant for a baffle design. Discharge during experimental releases for 90° baffles spanned the full range of observed discharges.

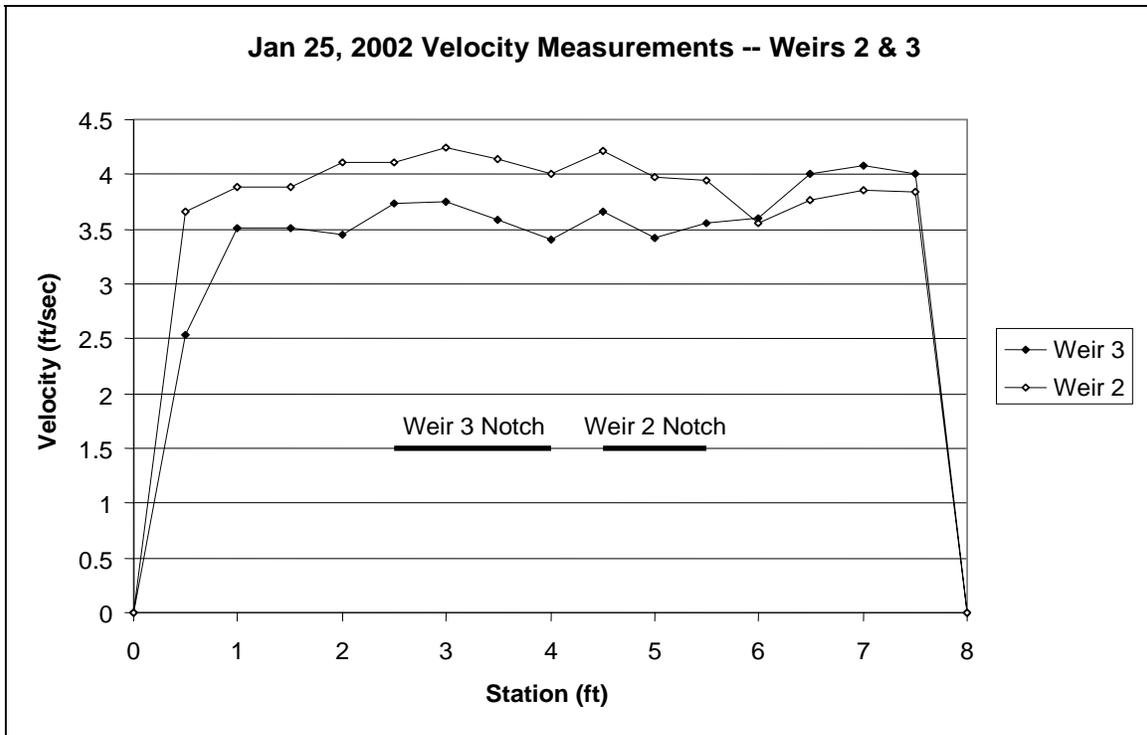


(a)

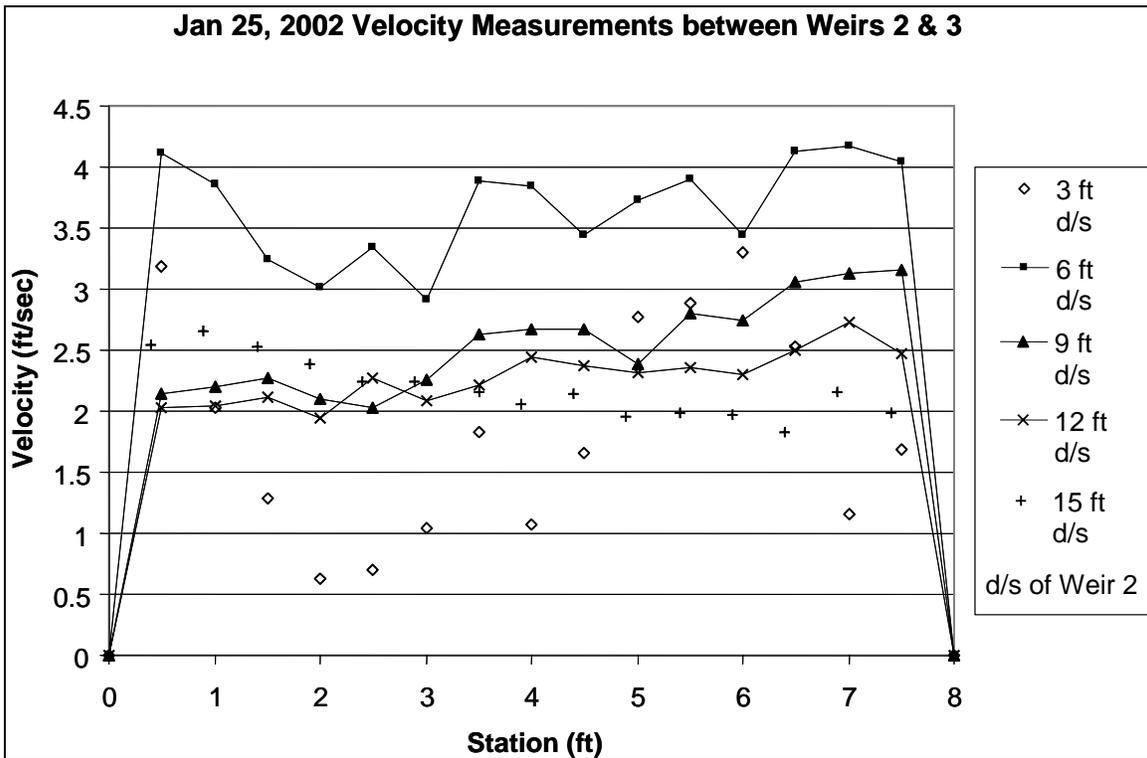


(b)

Figure 3.7: Paths of maximum and minimum velocities between baffles in the 90° baffle design in winter 2002. (a) Illustrates the paths between baffles 2 and 3 and (b) illustrates the paths between the next lower set of baffles.

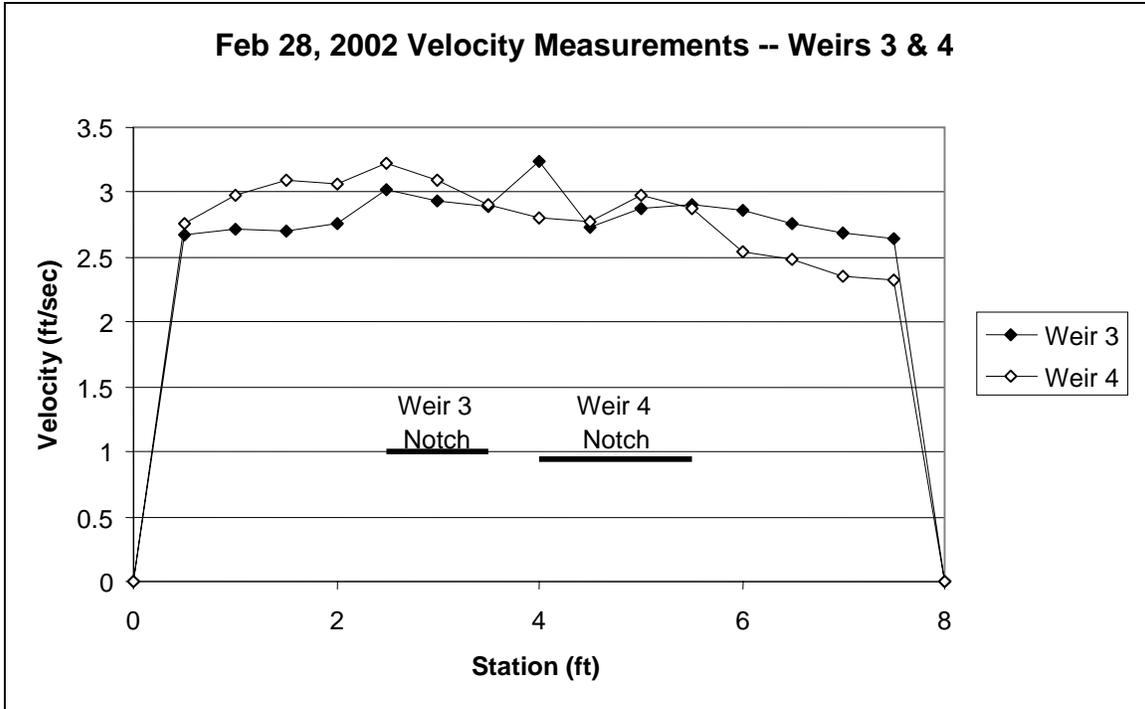


(a)

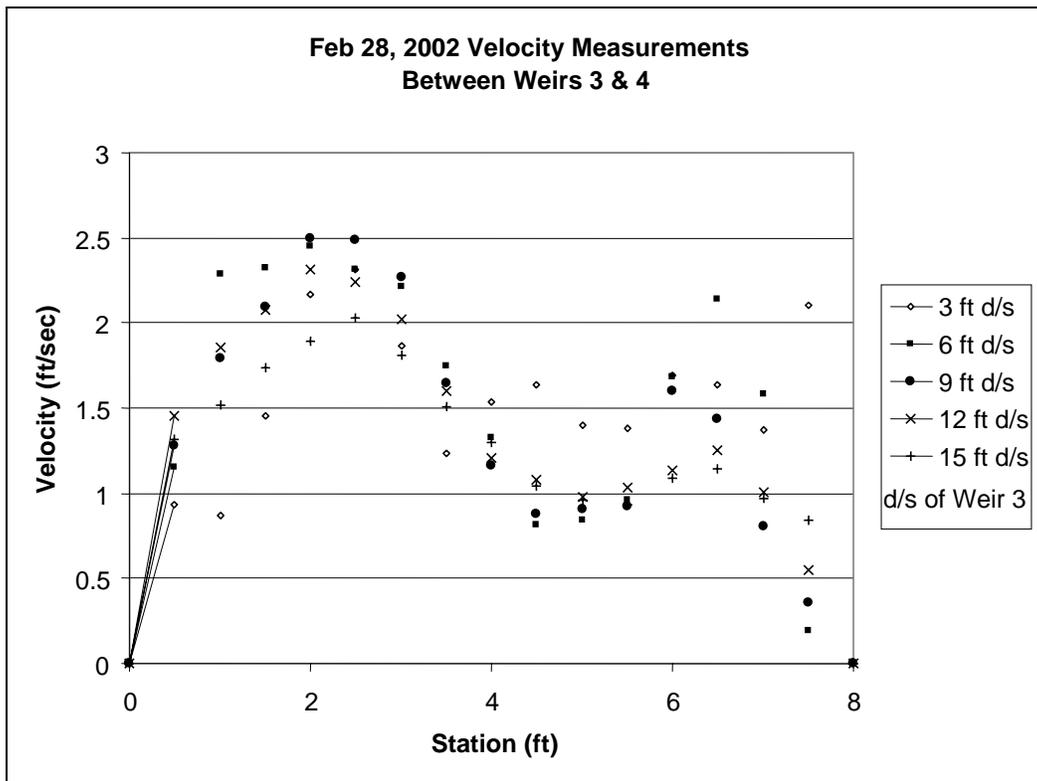


(b)

Figure 3.8: Velocities across the channel at the crest of baffles 2 and 3 (a) and across the channel at cross-sections between baffles 2 and 3 (b) in the 90° baffle design in winter 2002.



(a)



(b)

Figure 3.9: Velocities across the channel at the crest of baffles 3 and 4 (a) and across the channel at cross-sections between baffles 3 and 4 (b) in the 90° baffle design in winter 2002.

3.2.2 Fish Movement

Juvenile steelhead trout successfully navigated upstream through the culvert for all of the baffle designs tested during the winter and summer flows, except for the 30° baffles in winter flows. The smallest trout to make it completely through the culvert and into the upstream trap was 103 mm (4.06 in) and the largest was 194 mm (7.64 in), as shown in Figure 3.10.

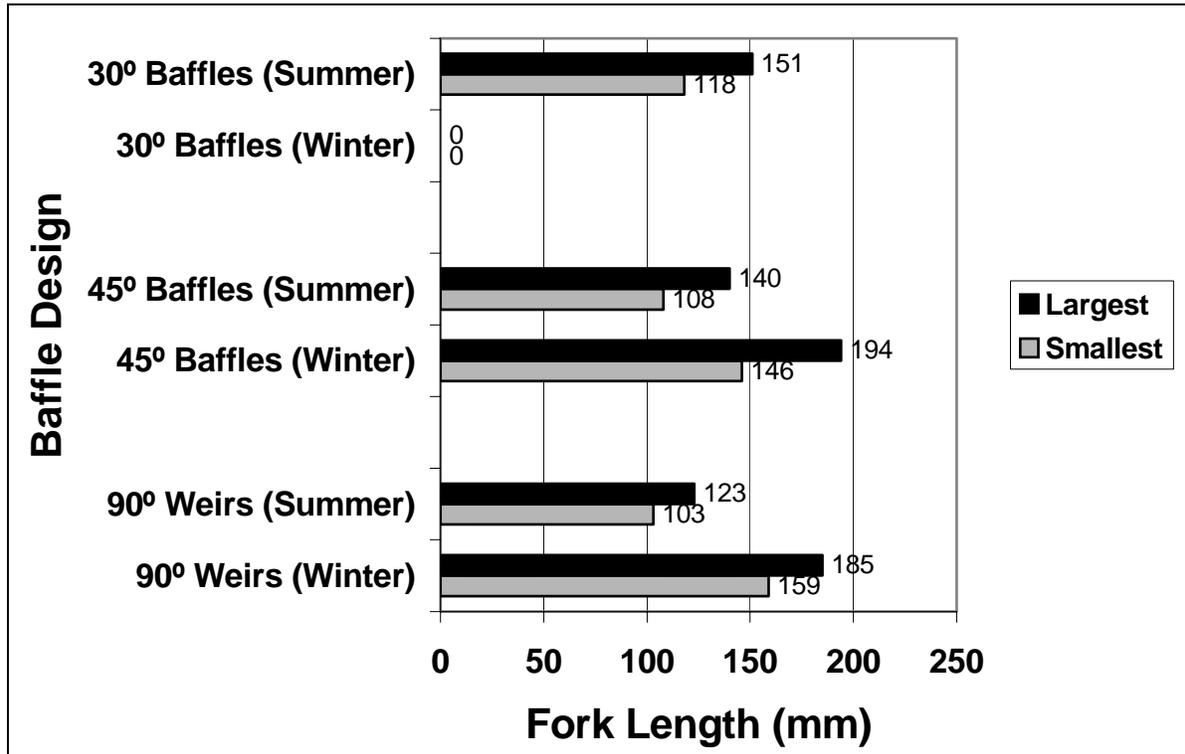


Figure 3.10: Sizes of steelhead trout that moved upstream during experimental releases under different baffle designs.

The percent of fish that maintained position or moved upstream was used as an indicator of the efficiency of each retrofit design. Adding baffles to the culvert increased the ability of steelhead trout to maintain their position within the culvert and allowed a small proportion to move upstream (Figure 3.11). None of the trout moved upstream in the culvert prior to adding baffles. Only 2% of the released fish remained in the middle section of the culvert and 98% moved downstream during control releases. When baffles were added, 29% of the trout maintained their position or moved upstream with the 30° baffle deflectors, 39% with the 45° baffle deflectors, and 38% with the 90° baffle baffles. Fish successfully passed through the culvert to the upstream trap with only the 45° and 90° baffles. Raw data from the individual releases are found in Table 3.4.

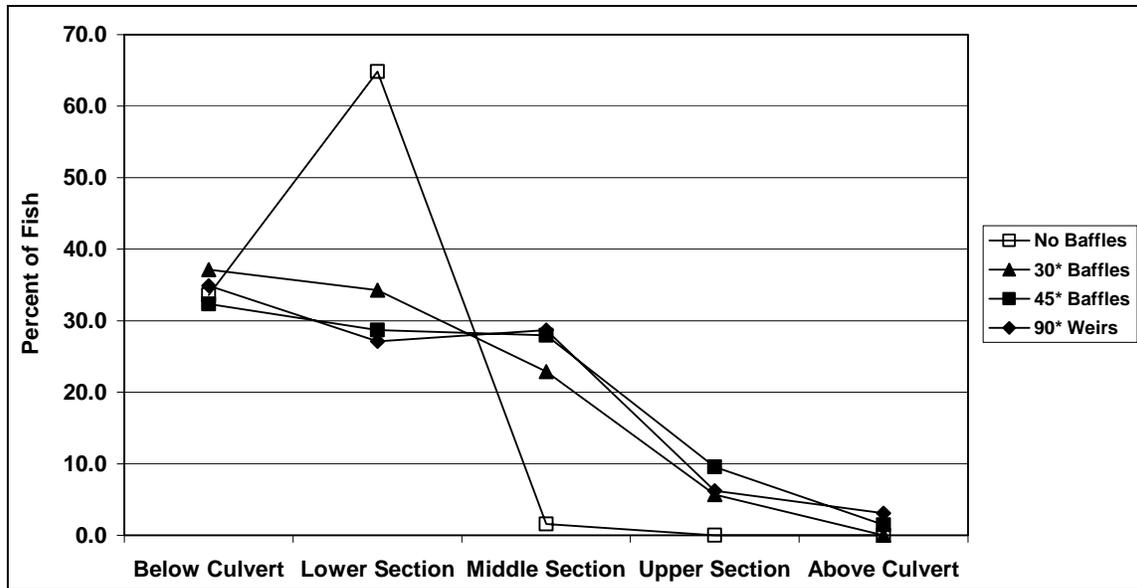


Figure 3.11: Fish movement through the culvert on Big Noise Creek during winter base flows.

During summer base flows, the addition of baffles also increased the ability of steelhead trout to maintain their position within the culvert and allowed a small proportion of trout to move upstream with certain retrofit designs, as seen in Figure 3.12. None of the trout maintained position or moved upstream in the culvert prior to adding baffles. In the control releases 100% of fish moved downstream in the culvert. Downstream angled baffles were also ineffective at allowing fish to maintain their position within the culvert. Over 95% of the released trout moved downstream with 30° and 45° baffles angled downstream. When the baffles were angled upstream, 27% of the trout maintained position or moved upstream with the 45° baffle deflectors, and 43% with the 30° baffle deflectors. The 90° baffles allowed 71.9% of juvenile trout to maintain position or move upstream. Fish successfully passed through the culvert to the upstream section with both the upstream angled baffles and 90° baffles. The 45° baffles angled upstream had the most fish move up through the culvert (10%). Raw data from the individual releases are found in Table 3.5.

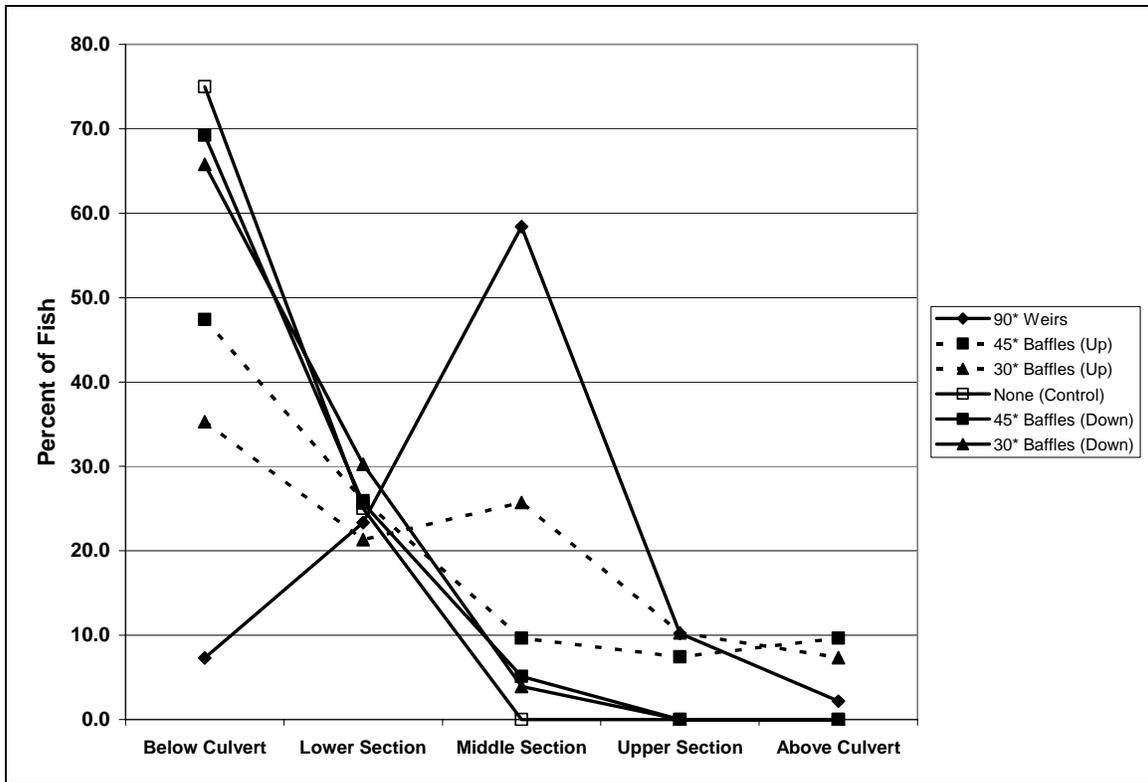


Figure 3.12: Fish movement through the culvert on Big Noise Creek during winter base flows.

3.2.3 Data Analysis

Logistic regression was used to statistically analyze the results of the release studies at the Big Noise Creek culvert. Logistic regression is similar to linear regression except that the data does not have to be normally distributed. The data from Big Noise Creek was not distributed normally because the responses are discrete instead of continuous. The results are discrete because responses are whole fish and cannot be a fraction of a fish. The five zones the trout could move to within the culvert were divided into two groups for analyses; trout that maintained position or moved upstream and trout that moved downstream. The resulting distribution is a binomial distribution. Since the data were not normally distributed, a link function was used to create a normal distribution. This link is similar to a transformation typical in linear regression methods. The link is the logit function which is $\log(\text{proportion}/(1-\text{proportion}))$. Once the regression coefficients have been calculated they must be back transformed into odds due to the logit link.

To analyze the data, a full mixed generalized linear model with both continuous data (flow rates) and categorical data (baffle configuration) was used. Flow data presented two problems. The flow rates were the same for all releases during the summer, so there is co-linearity between the two variables when comparing seasons. In other words, we can determine whether the season effects (temp, food availability, etc.) or the difference in flow are causing the observed effects. The co-linearity does not allow it to be discerned if flow is affecting movement, so flow during

the summer study could not be included in the model. During the winter studies, flow rates varied and were included in the model because they could be an explanatory variable for fish movement. When the winter flow rates were included in the model, flow was not a significant explanatory variable explaining fish movement (p-value=0.48), so it was removed from the model. Within the flow rates measured during the winter study (0.47 to 0.14 m³/s (16.6 to 4.94 ft³/s)), flow was not significantly related to movement of fish, but flow could be significant outside the range of rates that were measured.

When the regression coefficients are back transformed, resulting values are odds. Odds are represented by the omega symbol (ω). For example, if the odds of a baffle configuration were 6 to 1, then six fish moved downstream for every fish that maintained position or moved upstream. The lower the odds, the better a baffle configuration functioned at allowing trout to maintain position or move upstream within the culvert.

To compare baffle configurations to the control, or to each other, the odds ratio must be calculated. If two configurations have odds of ω_1 and ω_2 respectively, then the odds ratio is calculated as, $\phi = \omega_2/\omega_1$. If the resulting ratio was 3, then the odds of ω_2 are 3 times greater than the odds of ω_1 . If the odds ratio equals one, then the odds of the two separate events are equal. If the odds ratio does not equal one, then the odds may be significantly different. To test for significance, the value of the regression coefficients for each baffle configuration must be evaluated as to whether they are equal to zero. A Wald test was used to determine if the coefficient was significantly different from zero. The coefficients were calculated using maximum likelihood estimation and thus are asymptotically standard normal, which is why the Wald test was appropriate. The p-values were calculated using the least significant difference method.

3.2.3.1 Winter Baffle Comparisons

During winter base flows, movement through all of the retrofit designs were significantly different from the control. Trout generally maintained position or moved upstream. Under control conditions, the odds of a trout moving upstream were 75 to 1. In other words, 75 fish moved downstream for every fish that maintained position or moved upstream. The odds of the control were 48 times the odds of the 90° baffle baffles, 36 times the odds of the 45° baffles, and 20 times the odds of the 30° baffles. The odds ratios for all three retrofits compared to the control were significantly different from one (p-values <0.01). If the odds were equal to one, then there would be no difference between the control and the retrofit design. Table 3.7 shows that the 90° baffles had the best odds at 1.56 to 1.

Table 3.7: Statistical summary comparing each winter retrofit to the control

Configuration	Odds	Odds Ratio	p-value	SE	95% CI
Control	75.00 to 1	--	--	1	73.04 to 76.96
90°	1.56 to 1	48.2	<0.001	1.03	-0.46 to 3.58
45°	1.59 to 1	36.1	<0.001	1.03	-0.43 to 3.61
30°	3.71 to 1	20.2	0.002	1.04	1.67 to 5.75

The 90° baffles appear to be slightly better than other baffle configurations in allowing trout to maintain position or move upstream. The odds of the 45° baffle design are 1.36 times those of the 90° baffles, and this odds ratio was not significantly different from one indicating that the two designs were similar in their ability to allow trout to move upstream (p-value = 0.2). The odds ratio between the 90° and the 30° baffles indicates that the odds of the 30° baffles were 2.38 times larger. This ratio was significantly different from one indicating that there is a difference in trout response between the two designs (p-value = 0.01).

Finally, the odds ratio between the 45° and the 30° baffles indicates that the 30° baffles odds are 1.78 times the 45° baffles, this ratio was not significantly different from one (p-value = 0.06). The 90° and the 45° baffles were similar in allowing trout to maintain position or move upstream within the culvert, while the 30° baffles were significantly different from the 90° baffles, but not significantly different from the 45° baffles. Table 3.8 is a statistical summary of the winter baffle comparisons.

Table 3.8: Statistical summary comparing the winter baffle configurations to each other

Configuration	Odds Ratio	p-value	SE	95% CI
90° vs. 45°	1.34	0.2	0.35	0.67 to 2.01
90° vs. 30°	2.38	0.01	0.37	1.65 to 3.11
45° vs. 30°	1.78	0.06	0.37	1.05 to 2.51

3.2.3.2 Summer Baffle Comparisons

In summer, trout movement did not differ among the different baffle designs as compared to the control culvert conditions (odds ratios were not statistically significantly different). In the summer control releases, every trout moved downstream, so a large standard error resulted when comparing the control with the other configurations. Under control conditions the odds of a trout maintaining position or moving upstream were 121,016 to 1, in other words 121,016 trout will move downstream for each trout that maintains position or moves upstream. As with the winter trials, the 90° baffle baffles had the best odds at 0.53 to 1. This was the only set of trials to have more fish maintain position or move upstream than moved downstream. For every trout that moved downstream 1.9 trout maintained position or moved upstream within the culvert. The 45° and 30° baffles that were angled downstream, as in the winter trials, had the largest odds at 24.3 to 1 and 18.5 to 1 respectively. When the 45° and 30° baffles were angled upstream, they increased the depth of flow and altered the hydraulics within the culvert to allow better trout passage. This increase in fish passage is represented by the dramatically decreased odds for each retrofit. The 45° upstream angled baffles had odds of 2.4 to 1, and the 30° baffles had odds of 1.2 to 1. In other words, when the 45° baffles were angled downstream 24.3 trout moved downstream for every trout that maintained position or moved upstream; when the baffles were angled upstream the number of trout that moved downstream for every trout that moved upstream decreased to 2.4. This information is summarized in Table 3.9.

Table 3.9: Statistical summary comparing each retrofit to the control (summer)

Configuration	Odds	Odds Ratio	p-value	SE
Control	121,016.0 to 1	--	--	23.59
90°	0.53 to 1	229,066	0.3	23.59
45° upstream	2.39 to 1	50,607	0.32	23.59
30° upstream	1.20 to 1	101,069	0.31	23.59
45° downstream	24.33 to 1	5006	0.36	23.59
30° downstream	18.50 to 1	6541	0.36	23.59

In the experimental releases during the summer, the 90° baffles exhibited better fish passage than other configurations, as shown in Table 3.10. The odds ratio when the 90° baffles were compared to the 30° upstream baffles was 2.27. Again, this ratio indicates that the odds of the 30° upstream baffles were 2.27 times the odds of the 90° baffle baffles. This ratio is significantly different from one, signifying that there is a difference in the number of trout that maintained their position or moved upstream between the two designs (p-value = <0.001).

Table 3.10: Statistical summary comparing the summer baffle configuration

Configuration	Odds Ratio	p-value	SE	95% CI
90° vs. 45° up	4.53	<0.001	0.34	3.86 to 5.2
90° vs. 30° up	2.27	<0.001	0.33	1.62 to 2.92
90° vs. 45° down	46.06	<0.001	0.63	44.83 to 47.29
90° vs. 30° down	35.02	<0.001	0.56	33.92 to 36.12
45° up vs. 30° up	0.5	0.02	0.34	-0.17 to 1.17
45° up vs. 45° down	10.18	<0.001	0.64	8.93 to 11.43
45° up vs. 30° down	7.74	<0.001	0.57	6.62 to 8.86
30° up vs. 45° down	20.28	<0.001	0.63	19.05 to 21.51
30° up vs. 30° down	15.42	<0.001	0.56	14.32 to 16.52
45° down vs. 30° down	1.32	0.36	0.78	-0.21 to 2.85

The odds ratio between the 90° baffle baffles and the 45° upstream angled baffles was 4.53, which was significantly different from one (p-value = <0.001). The downstream angled baffles had a greater odds ratio than was observed for the 90° baffles. The 30° baffles had an odds ratio of 35.02, while the 45° baffles had an odds ratio of 46.06. These ratios are about one order of magnitude larger than when the baffles were angled upstream. They are significantly different from one, indicating a difference in trout response between the baffles and the downstream angled baffles (p-value = <0.001). The 90° baffles allowed the most fish to maintain their position or move upstream within the culvert during the summer trials.

After comparing the 90° baffles to all of the other designs, the 45° upstream baffles were then compared to the rest of the designs. The odds ratio between the 45° and the 30° upstream angled baffles was 0.5. The trout response was similar between these two designs because the odds ratio is not significantly different from one (p-value = 0.02). As with the 90° baffles, the downstream angled baffles had much higher odds ratios when compared with the 45° upstream baffles. The odds ratios for the 45° and 30° downstream angled baffles were 10.18 and 7.74 when compared to the 45° upstream baffles. These

ratios were significantly different from one (p-value = <0.001). The 30° upstream angled baffles also had significantly different odds ratios when compared with the 45° and 30° downstream angled baffles (p-value = <0.001).

There was essentially no difference in trout response between the two downstream angled baffles. When the 45° baffles were compared with the 30° baffles an odds ratio of 1.32 was derived, this was not significantly different from one indicating that the trout response was similar between the two designs (p-value = 0.36). The downstream angled baffles had a shallower depth of flow than the upstream angled baffles. This may have accounted for the differences in their ability to allow trout to maintain their position or move upstream inside the culvert compared to the upstream angled baffles.

3.2.3.3 Winter vs. Summer Baffle Comparisons

During the winter (variable flow) studies, all of the baffle designs were significantly better than the control (no baffles) at allowing trout to maintain position or move upstream within the culvert. The 90° baffles and the 45° baffles were similar in their ability to allow trout movement upstream. The 30° baffle design was significantly different from the 90° baffles, but not significantly different from the 45° baffles. The designs were in the following order from best odds to worst; 90° baffle baffles, 45° baffles, 30° baffles, and the control.

During the summer (constant low flow) trials, none of the baffle designs were significantly different from the control due to a large standard error. This error was a result of every fish moving downstream during the control releases. The odds of the control are four to six orders of magnitude larger than the various baffle designs, but could not be shown to be significantly different because not a single trout was able to maintain its position during the control releases. This was most likely due to extremely shallow water depths and high velocities within the culvert under control conditions. When the designs were compared to one another, the 90° baffles had the best odds of allowing fish to maintain their position or move upstream. The baffles were significantly different from all of the other designs. The 45° and 30° baffles that were angled downstream during winter flows were also angled upstream during summer flows to change flow characteristics. These designs were not significantly different from one another when angled the same direction, but the upstream angled baffles were significantly different from the same baffle designs angled downstream. The designs were in the following order from best odds to worst; 90° baffles, 30° upstream baffles, 45° upstream baffles, 30° downstream baffles, 45° upstream baffles, and the control.

The only baffle designs that were comparable between winter and summer flows were the 30° and 45° downstream angled baffles and the 90° baffles as seen in Table 3.11. The odds of a fish maintaining position or moving upstream within the culvert were 1.91 times greater during summer flows for the 30° downstream angled baffles. This value was significantly greater than one signifying a difference in fish response (p-value = 0.002). The odds for the 45° downstream angled baffles were 6.68 times greater during summer flows and were also significantly different (p-value = <0.001). The 90° baffles were more effective during the constant summer flows than during the variable winter

flows. The odds during the winter were 2.94 times greater than during the summer. The two odds were significantly different from each other (p-value = <0.001).

Table 3.11: Comparison of baffle designs between winter and summer flows

Configuration	Odds Ratio	p-value	SE	95% CI
30° Down Winter	--	--	--	--
30° Down Summer	1.91	0.002	0.65	1.49 to 2.33
45° Down Winter	--	--	--	--
45° Down Summer	6.68	<0.001	0.52	6.66 to 7.7
90° Baffles Winter	--	--	--	--
90° Baffles Summer	0.34	<0.001	0.34	-0.33 to 1.01

Each pair of identical baffle designs had significantly different abilities to allow trout to maintain position or move upstream between summer (constant, low) flows and winter (variable, higher) flows. Figure 3.13 compares the odds for each baffle design between summer and winter trials. The lower the odds the better the retrofit was at allowing fish to maintain their position or move upstream.

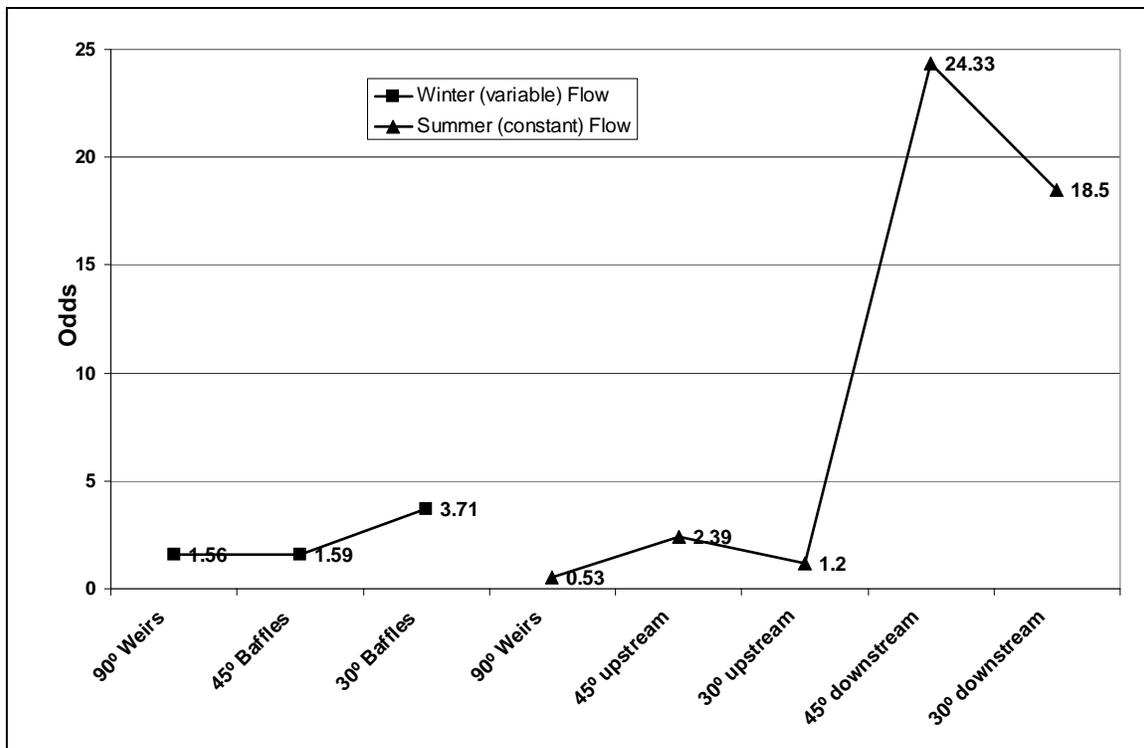


Figure 3.13: Comparison of odds ratios for movement with different baffle designs during summer and winter of 2002.

4.0 DISCUSSION

4.1 LONG-TERM EXPERIMENTAL STUDY OF FISH MOVEMENT

Although there were few findings of statistical significance in the tagging study, several important responses were observed. Cutthroat and steelhead trout moved upstream through three culverts in the study (Hayden, Canyon Creek #2, and Canyon Creek #3). The Hayden Creek culvert was 14.5 m (47.57 ft) long, had a 2.3% slope, a summer jump height into the culvert of 20 cm (7.87 in), and was retrofitted with 30° steel baffles. The Canyon Creek #2 culvert had a length of 83 m (272.31 ft), a slope of 1.2%, a summer jump height of 40 cm (15.75 in), and was retrofitted with 30° plastic baffles. The Canyon Creek #3 culvert was similar with a length of 84 m (275.59 ft), a slope of 1.0%, a summer jump height of 10 cm (3.94 in), and was retrofitted with 90° steel baffles. One movement up through the Canyon Creek #3 culvert is noteworthy. Between March and August 2001, a juvenile steelhead trout that was 107 mm (4.21 in) in length moved upstream through the Canyon Creek #3 culvert. This culvert was retrofitted with 90° steel baffles and is 84 m (275.59 ft) long with a 10 cm (3.94 in) jump into the culvert during summer flows. The minimum distance moved by this juvenile trout was 284 m (931.75 ft) within the 400 m (1312.32 ft) study reach.

The only statistically significant difference in movements was at Little Lobster Creek. The percent of fish that moved downstream through the culvert (4.8%) was significantly different from the percent of fish that moved upstream through the culvert (0%). This culvert could be a barrier to upstream movement because no trout were found to pass up through the culvert. During the course of the study, winter flows destroyed two large beaver dams upstream of the culvert. Many of the trout that were tagged in the upstream sections were found in the ponds behind these beaver dams. Some or most of these trout probably moved downstream after the collapse of the dams and the subsequent draining of the beaver ponds.

The relatively low recapture rates observed over the duration of the tagging study could be attributed to the size of the study reach and the length of the observation period. This is not unusual in studies of short reaches, and recent studies of fish in intermittent winter streams of the Willamette Valley observed less than 1% recapture.² Also, long-term studies of resident cutthroat trout in Mack Creek, a Cascade Mountain stream in the McKenzie River drainage, have observed that 20-35% of the trout tagged in 150 m (492.12 ft) reaches are captured the following year in the same reach. Resident cutthroat trout in this headwater Cascade Mountain stream would be expected to exhibit less movement than anadromous species in the Coast Range. If the tagged trout had larger home ranges than the study reach in which they were tagged, they could have easily moved outside the reach in between recapture dates. Another possible factor in the low recapture rates is that the stress of capturing and processing the juveniles could have caused delayed mortalities in some of the tagged fish. Finally, the electrofishing procedure is not 100%

² Randy Colvin, conversation with author, 2004.

effective in capturing all fish in a given reach. The streams selected for this study often had substantial amounts of large wood and other structures that made the capture of trout difficult. Future movement studies may look at alternatives to electrofishing such as telemetry or PIT-tag detector arrays.

With the exception of fish in Hayden Creek, less than 10% of the recaptured fish moved within the study reaches. Heggenes et al. (1991) theorized that only a small fraction of a fish population may be mobile while a larger fraction is sedentary. The exploratory behavior exhibited by this mobile fraction ensures a certain amount of spatial flexibility in the population. When fish mortality or habitat disturbances create vacant niches, this mobile fraction will occupy those vacancies (Heggenes et al. 1991). The findings of this study support Heggenes' theory of a small mobile fraction of the population. Although this mobile fraction is relatively small compared to the whole population, it is important to allow connectivity within the stream environment for these mobile individuals. These individuals drive metapopulation dynamics and allow sink populations to persist through migrations from source populations. By establishing connectivity throughout the stream system, the carrying capacity for the stream is increased by allowing the mobile fraction of the population to quickly fill open niches within the system.

4.2 SHORT-TERM EXPERIMENTAL STUDY OF FISH MOVEMENT

The short-term movement study at the Big Noise Creek culvert tested three baffle designs and a control within the same stream and culvert. Although variables such as temperature and flow could not be controlled, this design did allow almost all of the fish that were released to be recaptured. This part of the study provided greater statistical power than the tagging study while still maintaining an in-the-field setting.

Initially, various incentives were provided to facilitate trout movement through the culvert. The four incentives did not change trout movements and were not included in the statistical analysis. It should be noted that Dane (2000) found that food was an incentive for upstream movement of juvenile salmonids in Alaska. This was not the case in this study, as baiting the upstream trap did not change movements within the culvert. Scaring the trout resulted in random movements away from the stimulus and not a general upstream movement. Overcrowding resulted in most of the fish staying where they were released, and only a few fish moving upstream, but no more than without the incentive. Leaving the lights on in the culvert did not appear to change movements within the culvert.

Winter and summer releases included three retrofit design types (30° angled downstream, 45° baffles angled downstream, and 90° baffles) and a control (no baffles). A field review of the project found that the research team misunderstood the designs used by ODOT for diagonal baffles. ODOT typically angles the 30° and 45° baffles in an upstream direction to create more depth between baffles. This is particularly important during low flow because the upstream baffles backwater the flow, providing more volume of water between the baffles. The summer study was expanded to include the four treatments, plus additional treatments of baffles angled upstream at 30° and 45°.

During the larger, more variable winter flows, the 90° and 45° baffles had the best odds at allowing trout to maintain their position or move upstream within the culvert. The 30° baffles were significantly different than the two other designs, but were still better than the control. All of the baffle designs during the winter were significantly different than the control. These results indicate that movement up through a culvert similar to the Big Noise Creek culvert is only possible when that culvert has some structure within it. Without baffles, the streamflow within the culvert was shallower with a uniform velocity, and areas of hydraulic shadow (resting areas) were non-existent. When baffles were installed the streamflow within the culvert became deeper with more variable velocities and areas of hydraulic shadow were frequent. Under these conditions juvenile steelhead trout were more likely to maintain their position or move upstream rather than immediately heading downstream.

During the lower volume, constant summer flows, the hydraulic conditions under control conditions were even worse. The depth of flow was less than the height of a juvenile steelhead trout, and again there were no areas of hydraulic shadow. Although not statistically significant from any of the baffle designs, the odds of a trout maintaining position or moving upstream under control conditions was 4 to 6 orders of magnitude larger than any of the baffle designs. As in the winter studies, the 90° baffles had the best odds of allowing steelhead trout to maintain their position or move upstream. The odds for the 90° baffles were significantly different from the other designs. Although the 45° and 30° downstream angled baffles allowed passage during winter flows, the summer flows were too low and the depth of the water in the culvert was in many cases less than the height of the juvenile steelhead trout. The odds greatly increased during summer trials from 1.59 to 24.33 (45°) and 3.71 to 18.5 (30°). The baffles were tested when they were angled upstream to see if any changes in movement were identifiable. The depth of flow increased, but other hydraulic characteristics were similar. The odds of a steelhead trout maintaining position or moving upstream dropped an order of magnitude to 2.39 (45°) and 1.2 (30°) when the baffles were angled upstream. Unfortunately, the winter trials were already concluded, so the upstream angled baffles could not be tested under variable winter flow conditions.

Many of the juvenile trout were captured or observed in the small gaps between the plastic baffles and the culvert wall and even inside of the baffles (the ends of the baffle were not closed to flow). Dane (2000) observed juveniles moving through gaps between baffles within a culvert and the culvert wall rather than leaping over the baffles. Leaving small gaps between the baffles and the culvert wall and leaving the ends of baffles open to flow may facilitate juvenile fish passage through the culvert. Juvenile steelhead trout seem to prefer to follow the culvert wall and move through gaps, rather than leap over obstructions. Not once during this project were juvenile trout observed leaping within the culvert.

4.3 RECOMMENDATIONS AND CONCLUSIONS

Several conclusions can be made based upon the research from this study:

- Culvert retrofitting using baffles increases the probability of salmonids moving upstream through a culvert during low flow and high flow.
 - Salmonids were observed to move through retrofitted culverts in field studies.
 - Baffles increased the likelihood of fish moving upstream in experimental trials in a culvert in Big Noise Creek.
- Ninety-degree baffles and 45° upstream baffles are more effective in increasing upstream fish movement than other baffle designs evaluated in this study.
- Additional research with adult salmon in both field trials and experimental culverts would increase the understanding of the effectiveness of retrofitted culverts for passage of resident and anadromous salmonids.
- Based on this study, an expanded list of additional culvert literature was developed and is presented in the Appendix

4.4 FUTURE RESEARCH

This research project focused on existing retrofitted culverts. In an attempt to overcome the lack of statistical design caused by the small number of available culverts and the high variation in retrofit designs used in these culverts, the short-term releases were conducted at Big Noise Creek to provide a common setting for comparing different baffle designs.

Future studies should incorporate a larger study area than the one used in this study to capture mobile fish with larger home ranges. The use of PIT tags would also be useful to identify individual fish and determine if the trout that are moving, are the same or different fish in the population. Large PIT antennas that are left in the stream would allow more continuous observations of fish movements through a culvert. Large PIT antennas would also allow researchers to determine the timing of juvenile fish movements both daily and seasonal. Once mobile fish are identified via PIT tags, it would then be possible to use radio tags to follow these fish's movements throughout the year. The use of large PIT antennas and radio telemetry tags would expand on the observations made during the tagging portion of this study. Future studies similar to the controlled release portion of this study should incorporate other species of fish and different culvert retrofit options (such as different baffle designs and stream simulation culverts). PIT tags would also be helpful with a similar controlled release study to test the same fish multiple times to see if they move upstream or downstream consistently.

Future studies could expand on several aspects of the approaches used in this study:

- Research could include different species of salmon and trout.

- Before and after studies could be incorporated into new projects for retrofitting culverts to improve fish passage.
- Additional research with adult salmon in both field trials and experimental culverts would increase the understanding of the effectiveness of retrofitted culverts.
- Experiments could be designed to monitor movement through natural stream reaches. Natural unimpeded movements could be compared with: 1) movement through natural impediments (wood, boulder obstacles, falls or steps of different heights) and, 2) obstacles or barriers created by culverts and retrofitted culverts.

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APPENDIX

ADDITIONAL CULVERT LITERATURE

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