Fish Passage at Road Crossings in a Montana Watershed

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16. Abstract

A basin-wide assessment of fish passage through culverts was performed in the upper Seeley Lake watershed in western Montana. The watershed has many small streams that support a variety of trout species, predominately cutthroat trout and brook trout, but with some bull trout and brown trout too. A total of 47 culverts were studied, and at these culverts the FishXing model and a screening tool that is a composite of several flowchart-based models were used to predict fish passage success. At a subset of 21 culverts, fish were collected above and below the culvert to check for population differences with respect to species, size, and abundance. At another subset of 10 culverts, fish passage was directly assessed using fish traps. Results indicate that the FishXing model and the composite screen are conservative estimators of fish passage in culverts. The direct passage assessment indicated that more fish passage occurred during low flow than was expected, and the population (above/below) sampling results gave little evidence to indicate that many of the culverts were functioning as barriers to fish passage. However, there was evidence that fish passage was restricted at many of the culverts at low flow. High flow was not examined in detail at the field sites in this study.

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Conversion Factors

length: miles (mi) x 1.609 = kilometers (km)
length: feet (ft) x 0.3048 = meters (m)
length: inches (in) x 2.540 = centimeters (cm)
velocity: feet per second (ft/sec) x 0.3048 = meters per second (m/s)
flow rate: cubic feet per second (cfs or ft^3/sec) x 0.02832 = meters cubed per second (m^3/s)

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Introduction

Providing adequate fish passage through culverts has been a topic of growing concern for fisheries biologists, engineers, and hydrologists over the last two decades (*1, 2*). The movement of fish throughout a watershed is vital for a number of life history requirements (*1, 2, 3, 4*), and maintaining migratory corridors is critical for the stability and persistence of many fish populations (*3, 5*).

Restriction or blockage of fish movement by culverts may have important consequences to fish populations. The most obvious problems are associated with the direct loss of habitat upstream of the barrier, which is often critical for spawning and other seasonal habitat requirements. Less obvious are the problems related to habitat fragmentation and the isolation of populations. Loss of connectivity with neighboring populations due to migratory barriers has been recognized as an important factor influencing local extirpation (*6, 7, 8*), yet the extent to which culverts fragment populations is largely unknown. Conversely, culverts may also serve as barriers to interchange between native and nonnative species and thereby serve to protect native species from nonnative species encroachment (*9, 10 ,11*).

Previous studies of fish passage in culverts have focused primarily on the blocking or delaying of upstream spawning runs of large migratory adult salmonids (*12, 13*). However, recent information suggests that spawning and non-spawning movements of smaller salmonid and nonsalmonid species may be much more prevalent and extensive than previously thought. For example, in a literature review conducted to determine the state of knowledge on the movement and passage of juvenile and adult salmonids through culverts, Kahler and Quinn concluded that upstream movement was common among all species, age classes, and seasons (*14*). Thus, movement of all species and life stages must be considered in developing and evaluating culvert passage design criteria.

High water velocities, inadequate water depths, and excessive outfall heights are recognized as the main features of culverts that impede or block fish passage (*1, 2, 15, 16*). Because these hydraulic conditions differ markedly with discharge, it is important to consider the full range of hydrologic conditions that may occur during the course of the year when assessing fish passage conditions. For example, at high flows, excessive water velocities within the culvert may impede upstream movement, whereas at low flow, inadequate water depth or high outfall height may restrict passage. Other physical factors that may influence fish passage include inlet drops (*1, 2, 4, 17*), plunge pool conditions (i.e. air entrainment and pool depth), turbulence within the culvert (*15*), ice or debris blockage (*1*), lack of resting pools downstream or upstream (*16*), and culvert alignment relative to the stream channel (*2*).

The swimming and jumping abilities of fish in relation to the aforementioned physical factors interact to determine the ability of a fish to pass upstream through a culvert. Fish species and size are the primary controllers of swimming and jumping ability, but other factors such as water temperature, dissolved oxygen, motivation to move upstream, sex, physical condition, disease, and sexual maturity (*1, 12, 18*) are also involved. Most research to date has focused on the capabilities of large-bodied salmon and trout, and little is known about the swimming and jumping abilities of nonsalmonid fishes and of juvenile and small-bodied resident salmonids. As a result, the accuracy of fish passage models incorporating these abilities is unknown.

A number of different approaches have been used to investigate fish passage through culverts, each with distinct advantages and limitations. Direct approaches monitor movement of marked fish through culverts and relate passage ability to culvert hydraulics and fish species and size (*13, 19, 20*). This type of approach is successful at determining both the passage status of the culvert and the passage capabilities of the species of interest, but it is labor intensive and therefore only practical for assessing a small number of culverts over a short period of time.

Indirect approaches to assess fish passage generally focus on either the physical conditions around and within the culvert or on fish population characteristics at the culvert site. FishXing (*21*) is a widely used software program that combines culvert characteristics (slope, length, roughness, etc.) and stream discharge to model the hydraulic conditions in and near the culvert. The hydraulic conditions are then compared with the swimming and jumping abilities of fish to assess the passage status. However, the limited knowledge regarding the swimming and jumping abilities of many species and size classes potentially limits the accuracy and applicability of the model. Although this type of analysis may be useful for assessing a large number of culverts with a relatively small amount of field data collection, a thorough review of the literature has revealed that the accuracy of this method for predicting fish passage has not been extensively evaluated.

Species abundance, size structure, and presence can also be used as an indirect approach to evaluate fish passage. For example, population surveys performed upstream and downstream of a perched culvert indicated that cutthroat trout (*Oncorhynchus clarki*) density was 64% lower upstream than downstream and the size structure was skewed to a higher proportion of large fish downstream of the culvert, suggesting that it was functioning as at least a partial barrier to upstream movement (*22*). Natural and man-made barriers are known to limit the upstream distribution of fish (*6, 7, 8, 10, 23*), thus species absence above a culvert may also imply that the culvert is a barrier to upstream passage. This upstream and downstream approach can provide valuable information about how culverts affect the abundance, size structure, and distribution of fish populations.

Most previous studies have focused on fish passage at only a few culverts and thus the extent to which culverts impede fish passage across large drainage basins is largely unknown. A comprehensive assessment of culverts is necessary in order to prioritize sites for maximizing fish passage improvement. In this study, a tiered approach was used, combining assessments made using FishXing and a flowchart-based screening tool, species abundance, size structure, and presence above and below culverts, and direct assessment using marked individual fish to assess fish passage at culverts throughout a large drainage basin.

Study Area

The study area included all the streams in the upper Clearwater River drainage that have culverts at road crossings. The drainage area was defined for this study by the area upstream of the Seeley Lake outlet (Figure 1). This area was chosen as the study location due to the large number of culverts of different types located throughout the watershed, varied land ownership and road types, a diverse fish assemblage, and an array of stream types and sizes. The watershed is located in northwestern Montana and encompasses approximately 143 square miles of private, federal, and state lands. The basin is bordered by the Swan Mountains on the east and the Mission Mountains to the west, both comprised of mainly carbonate sedimentary rocks. The valley and mountains were both heavily glaciated during the Quaternary period and subsequently glacial till and stream deposits are found extensively throughout the drainage.

The Clearwater River flows 29 miles in a southerly direction through a series of 8 lakes to the confluence with the Blackfoot River. There are two large manmade fish barriers on the Clearwater River (Figure 1) that were installed to limit the distribution of exotic species that were introduced into the lakes. Consequently, they block the upstream movement of all species. Large, low gradient streams characterize the lower reaches in the valley bottom with bridges comprising nearly all of the road crossings. Ascending from the valley floor, the middle and upper reaches are characterized by small, high gradient streams that are crossed repeatedly by timber harvest and forest access roads. Most of the road crossings use culverts in the middle and upper reaches of the drainage.

The fish assemblage in the Clearwater River drainage is comprised of approximately 20 different species of fish. Many of these species have been introduced into the low elevation lakes and the main stem of the Clearwater River for recreational purposes. Native species that were encountered during this study were westslope cutthroat trout (*Oncorhynchus clarki lewisi*), bull trout (*Salvelinus confluentus*), and slimy sculpin (*Cottus cognatus*). Non-native species encountered were brook trout (*Salvelinus fontinalis*), brown trout (*Salmo trutta*), and brook stickleback (*Culaea inconstans*). Of particular concern regarding passage through culverts are the native bull trout and westslope cutthroat trout (*24*). The bull trout is listed by the U.S. Fish and Wildlife Service as threatened under the Endangered Species Act (*25*) and the westslope cutthroat trout is classified as a Species of Special Concern in the state of Montana (*26*).

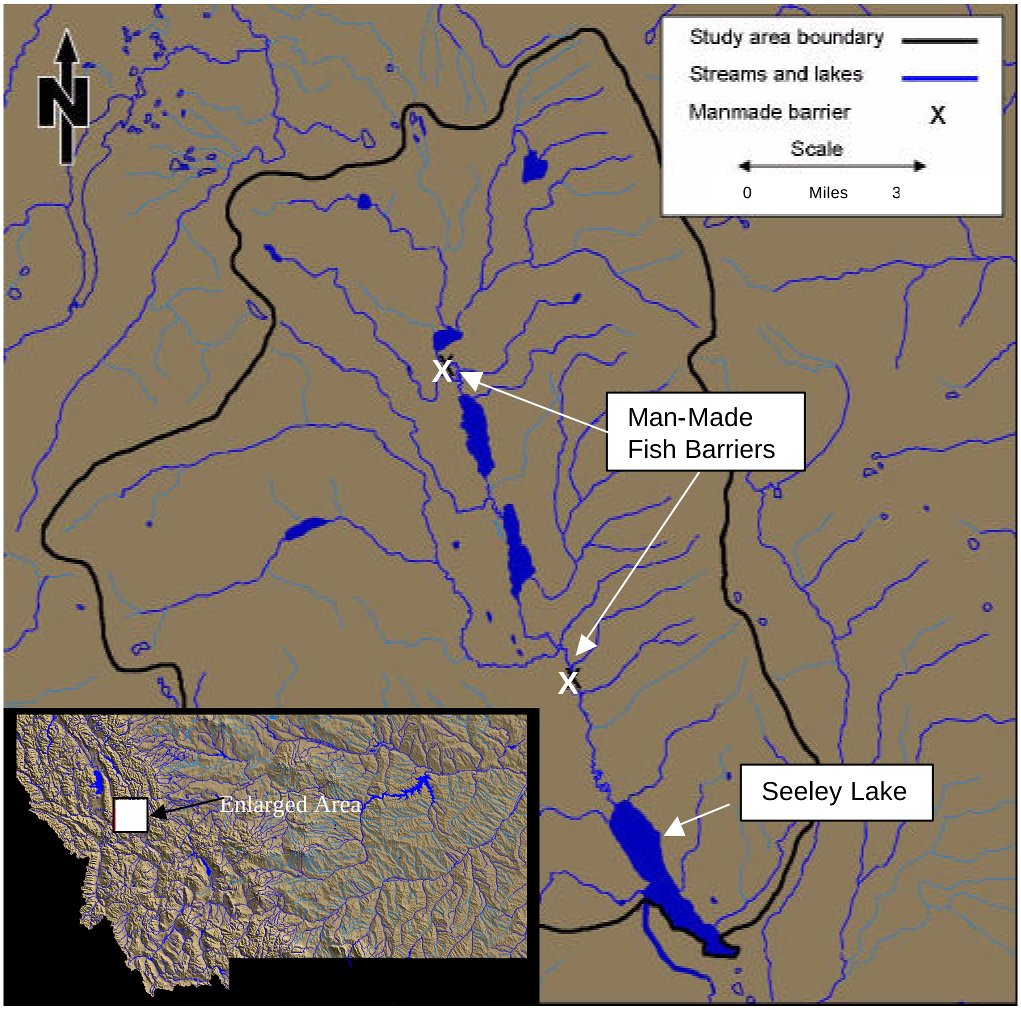

Figure 1. The study area in the upper Clearwater River basin.

There were 47 culverts included in the study. Tables 1 and 2 and Figure 2 provide the location and a summary of all the physical descriptions of each culvert in the study. The culverts were mostly on roads maintained by the US Forest Service or Missoula county. One culvert has since been replaced with a bridge (484 - Clearwater Main Stem) due to hydraulic failure. Culverts studied were of a variety of materials, shapes, slopes and features. The mean culvert width was 4.35 ft (the median width was 4 ft) and the average length was 40.2 ft (the median length was 38.7 ft). Culvert slopes ranged from an inverse grade of -0.85% to a steep culvert with a slope of 16.55%. The average slope of the culverts studied was 4.25% (the median slope was 3.24%).

Seven culverts had natural substrate beds while the remaining 40 culverts had the culvert material as the channel floor. In 20 culverts the tail water exit was at-grade, 18 culverts had tail-water falling into a plunge pool, and the remaining had tail water falling or cascading onto rocks.

Table 1. A summary of characteristics of each culvert in the study (continued in Table 2).

Stream Name	**Culvert ID Number**	**Situation**	**Latitude (N Deg Min)**	**Longitude (W Deg Min)**	**Type of Culvert**	**Culvert Material**	**Corrugation Dimensions w (in) x h (in)**	**Culvert Width (ft)**	**Culvert Diameter (ft)**	**Culvert Length (ft)**	**Culvert Slope (%)**	**Outlet Drop Height (ft)**
Uhler Cr.	481	Private	N 47 17.622	W 113 35.507	c	sspp	6.00 x 2.0	5.00	5.00	34.4	1.30	0.00
Uhler Cr.	482	Private	N 47 17.628	W 113 34.929	c	sspp	2.67 x 0.5	4.00	4.00	40.7	0.90	0.30
Colt Cr.	483	USFS	N 47 19.702	W 113 35.802	c	stee		5.17	5.17	35.7	3.90	0.50
Clearwater Main Stem	484	USFS	N 47 21.180	W 113 34.937	c	sspp	6.00 x 2.0	5.50	5.50	36.8	2.47	0.50
E. Fork Clearwater	485	USFS	N 47 21.752	W 113 32.350	o	sspp	6.00 x 2.0	13.30		39.6	0.80	0.00
Unnamed Tributary to Bertha Cr.	486	USFS	N 47 22.206	W 113 35.257	s	acmp	2.67 x 0.5	6.50		41.0	5.50	0.20
Richmond Cr.	487	USFS	N 47 19.601	W 113 34.622	s	sspp	3.00 x 1.0	6.00		38.8	4.40	0.00
Richmond Cr.	488	MDT US 83 (25)	N 47 19.524	W 113 34.717	s	conc		5.00		93.9	2.40	0.00
Unnamed Cr. 1/4 N. of Richmond Cr.	489	MDT US 83 (25)	N 47 19.802	W 113 34.838	s	conc		6.00		86.7	1.30	0.00
Unnamed Cr. 1/4 N. of Richmond Cr.	490	USFS	N 47 19.788	W 113 34.629	s	acmp	2.67 x 0.5	4.80		30.5	4.90	0.00
Trib. to Westfork Clearwater	491	Private	N 47 18.991	W 113 38.925	c	acmp	2.67 x 0.5	3.50	3.50	36.6	6.00	1.20
Bertha Cr.	492	USFS	N 47 22.594	W 113 39.256	c	sspp	2.67 x 0.5	3.00	3.00	36.6	2.10	1.00
Unnamed Tributary to Marshall Cr.	493	Private	N 47 17.476	W 113 38.286	c	acmp	2.67 x 0.5	3.00	3.00	30.7	2.10	0.10
Archibald Cr.	494	USFS	N 47 11.474	W 113 32.145	s	acmp	3.00 x 1.0	4.50		30.7	1.50	0.40
Fawn Cr.	495	Private	N 47 12.890	W 113 35.479	s	sspp	2.67 x 0.5	4.50		35.0	3.40	0.20
Sheep Cr.	496	Private	N 47 13.603	W 113 37.621	s	sspp	2.67 x 0.5	4.80		41.2	7.10	0.20
Unnamed Trib. to Inez Cr.4	498	Private	N 47 18.428	W 113 33.003	s	sspp	2.67 x 0.5	4.90		38.7	1.63	0.00
Inez Cr.5	499	Private	N 47 18.845	W 113 32.375	c	acmp	2.67 x 0.5	3.20	3.20	28.5	6.70	0.10
Unnamed Trib. to Camp Cr.	500	Private	N 47 16.862	W 113 32.448	s	acmp	2.67 x 0.5	3.40		38.8	7.60	0.80
Rice Cr.3	601	USFS	N 47 12.857	W 113 31.283	s	acmp	2.67 x 0.5	5.00		26.6	-0.30	0.00
Inez Cr.	602	USFS	N 47 18.084	W 113 32.780	s	sspp	2.67 x 0.5	4.60		42.7	4.80	0.00
Camp Cr.	603	USFS	N 47 17.927	W 113 32.172	s	sspp	2.67 x 0.5	5.30		39.6	9.20	0.20
Findell Cr.	604	USFS	N 47 16.016	W 113 32.248	c	sspp	2.67 x 0.5	3.50	3.50	45.0	9.90	0.90
Findell Cr.	605	MDT US 83 (20)	N 47 15.620	W 113 32.963	b	conc		4.00		41.7	4.90	0.00
Fawn Cr.	606	Private	N 47 12.003	W 113 36.495	s	acmp	2.67 x 0.5	4.00		35.6	2.00	0.00
Benedict Cr.	607	USFS	N 47 14.800	W 113 31.846	s	sspp	2.67 x 0.5	4.20		42.8	5.00	0.70
Benedict Cr.	608	MDT US 83 (19)	N 47 14.768	W 113 32.313	b	conc		6.00		32.7	3.20	2.00
Benedict Cr.6	609	Private	N 47 14.768	W 113 32.313	c	acmp	2.67 x 0.5	2.00		20.3	1.00	0.00
Rice Creek	610	USFS	N 47 12.928	W 113 31.239	s	sspp	2.67 x 0.5	4.50		47.8	5.74	0.00
Rice Creek	611	MDT US 83 (17)	N 47 12.947	W 113 31.230	s	conc		4.00		70.0	1.30	0.00
Rice Creek	612	State	N 47 13.84	W 113 30.543	s	acmp	2.67 x 0.5	3.50		40.8	12.20	0.15
Auggie Creek	613	USFS	N 47 12.425	W 113 29.775	s	sspp	2.67 x 0.5	4.80		40.7	6.07	0.16
Auggie Creek	614	MDT US 83 (15)	N 47 11.842	W 113 30.138	c	conc		4.00	4.00	72.6	2.44	0.00
Seeley Creek	615	MDT US 83 (14)	N 47 10.934	W 113 29.097	b	conc		4.00		32.0	0.78	0.12
Seeley Creek	616	USFS	N 47 10.979	W 113 28.887	s	sspp	2.67 x 0.5	4.50		45.4	2.70	0.12
Seeley Creek	617	Private	N 47 11.027	W 113 28.760	c	conc		2.30	2.30	12.3	1.14	0.00
Seeley Creek	618	USFS	N 47 12.629	W 113 27.285	s	sspp	2.67 x 0.5	3.50		36.5	-0.85	0.00
Uhler Creek	619	USFS	N 47 19.839	W 113 38.125	s	sspp	2.67 x 0.5	4.80		28.2	2.94	1.62
Murphy Creek	620	USFS	N 47 15.807	W 113 32.027	c	sspp	2.67 x 0.5	3.00	3.00	40.6	7.37	2.11
Murphy Creek	621	USFS	N 47 15.812	W 113 31.770	c	sspp	2.67 x 0.5	3.00	3.00	46.9	10.58	1.01
Murphy Creek	622	MDT US 83 (20)	N 47 15.175	W 113 32.625	b	conc		4.00		32.6	1.45	0.62
Sawyer Creek	623	MDT US 83 (18)	N 47 14.115	W 113 31.978	b	conc		6.00		36.2	3.24	0.00
Richmond Creek	624	Private	N 47 20.388	W 113 32.638	c	acmp	2.67 x 0.5	2.10	2.10	31.2	5.64	0.18
Richmond Creek	625	Private	N 47 20.298	W 113 33.032	c	acmp	2.67 x 0.5	2.10	2.10	24.8	1.12	0.60
Trib. to West Fork Clearwater	626	Private	N 47 15.438	W 113 36.184	c	scmp	2.67 x 0.5	3.00	3.00	41.2	3.29	1.75
Trib. to West Fork Clearwater	627	Private	N 47 15.452	W 113 36.446	c	scmp	2.67 x 0.5	3.00	3.00	55.4	16.55	0.07
Trib. to West Fork Clearwater	628	Private	N 47 15.339	W 113 37.228	s	acmp	2.67 x 0.5	3.50		32.5	10.56	0.47
Average								**4.35**	**3.43**	**40.20**	**4.25**	**0.39**
Standard Deviation								**1.74**	**1.01**	**14.77**	**3.59**	**0.56**

Situation:
USFS sites are on US Forest Service lands
MDT sites were all on US 93 with closest mile marker shown in parenthesis.
State site was on USFS road passing through a State section

Type of Culvert:
c - circular pipe
b - box culvert
s - squashed circle or ellipse
o - open bottom arch

Culvert Material:
acmp - annular corrugated metal pipe
scmp - spiral corrugated metal pipe
sspp - structural steel plate pipe
conc - concrete
stee - reused steel tank

Table 2. A summary of characteristics of each culvert in the study (continued from Table 1).

Stream Name	Outlet Config-uration	Maximum Inlet Velocity (ft/sec)	Maximum Outlet Velocity (ft/sec)	Minimum Inlet Depth (ft)	Minimum Outlet Depth (ft)	Continuous Substrate	Upstream Gradient (%)	Down-stream Gradient (%)	Average Bankfull Width (ft)	Constric-tion Ratio
Uhler Cr.	ag	1.90	2.60	0.40	0.40	no	0.30	2.20	10.40	0.48
Uhler Cr.	fp	n/a[4]	n/a[4]	0.50	0.50	no	1.00	5.70	5.70	0.70
Colt Cr.	fr	n/a[4]	n/a[4]	0.80	0.50	no	4.40	6.50	11.50	0.45
Clearwater Main Stem	fp	2.40	3.20	0.70	0.50	no	1.40	3.10	16.90	0.33
E. Fork Clearwater	ag	3.20	3.10	0.30	0.40	yes	1.60	1.90	14.90	0.89
Unnamed Tributary to Bertha Cr.	ag	3.90	0.50	0.30	0.40	yes	5.20	3.80	5.60	1.16
Richmond Cr.	ag	1.50	2.80	0.10	0.10	no	7.00	5.70	5.00	1.20
Richmond Cr.	ag	1.60	1.80	0.25	0.20	no	3.80	6.40	5.60	0.89
Unnamed Cr. 1/4 N. of Richmond Cr.	ag	2.60	1.80	0.10	0.20	no	2.50	4.50	5.40	1.11
Unnamed Cr. 1/4 N. of Richmond Cr.	ag	3.90	0.80	0.10	0.30	no	5.40	3.60	5.20	0.92
Trib. to Westfork Clearwater	fp	1.50	4.80	0.25	0.20	no	16.50	11.20	5.90	0.59
Bertha Cr.	fp	1.30	4.00	0.70	0.40	no	0.90	3.50	6.80	0.44
Unnamed Tributary to Marshall Cr.	fp	0.20	1.20	0.05	0.05	no	5.00	3.30	3.50	0.86
Archibald Cr.	fp	0.20	1.00	dry	dry	no	0.60	1.50	3.90	1.15
Fawn Cr.	fp	0.50	3.50	0.15	0.10	no	4.30	4.00	8.20	0.55
Sheep Cr.	fp	n/a[3]	n/a[3]	dry	dry	no	9.10	9.70	8.50	0.56
Unnamed Trib. to Inez Cr.4	ag	2.20	0.10	0.20	0.30	yes[5]	3.90	3.80	5.80	0.84
Inez Cr.5	fp	n/a[1]	3.83	n/a[1]	0.15	no	6.90	14.40	6.00	0.53
Unnamed Trib. to Camp Cr.	fr	4.30	4.90	0.10	0.10	no	9.60	10.00	6.60	0.52
Rice Cr.3	ag	n/a[2]	0.50	0.40	0.10	yes[5]	5.10	2.60	5.20	0.96
Inez Cr.	ag	1.20	1.90	0.20	0.10	no	2.30	2.40	6.50	0.71
Camp Cr.	cr	1.30	5.40	0.30	0.15	no	12.10	19.30	7.90	0.67
Findell Cr.	fr	1.90	4.50	0.10	0.10	no	7.60	10.80	5.00	0.70
Findell Cr.	ag	n/a[3]	1.80	0.05	0.10	no	4.30	3.10	4.00	1.00
Fawn Cr.	ag	n/a[2]	n/a[2]	0.50	0.70	no	0.84	1.00	3.00	1.33
Benedict Cr.	fp	2.30	2.00	0.10	0.10	no	5.00	6.60	5.40	0.78
Benedict Cr.	fp	1.10	1.60	0.10	0.10	no	4.00	7.30	5.10	1.18
Benedict Cr.6	ag	0.90	1.10	0.60	0.70	yes	3.70	0.70	5.70	0.35
Rice Creek	ag	0.31	1.42	0.50	0.20	yes	2.47	4.38	5.25	0.86
Rice Creek	ag	1.69	0.68	0.20	0.20	yes	3.98	5.53	5.95	0.67
Rice Creek	fr	1.70	2.12	0.05	0.05	no	6.53	9.10	5.45	0.64
Auggie Creek	fp	0.52	1.10	0.05	0.05	no	5.81	5.47	3.75	1.28
Auggie Creek	ag	n/a[3]	n/a[2]	0.05	1.00	no	4.10	3.96	3.70	1.08
Seeley Creek	fp	1.97	2.24	0.30	0.25	no	2.05	2.49	6.50	0.62
Seeley Creek	fp	1.56	3.55	0.60	0.25	no	2.12	1.55	6.70	0.67
Seeley Creek	ag	1.57	3.72	0.50	0.30	no	1.28	1.99	6.35	0.36
Seeley Creek	ag	0.30	0.27	0.50	0.50	no	2.77	4.47	4.55	0.77
Uhler Creek	fp	n/a[1]	n/a[1]	0.10	0.05	no	1.30	8.63	7.25	0.66
Murphy Creek	fr	n/a[1]	1.63	0.10	0.05	no	6.95	14.10	6.25	0.48
Murphy Creek	fr	n/a[1]	2.59	0.10	0.05	no	8.24	7.20	5.80	0.52
Murphy Creek	fp	n/a[3]	n/a[3]	0.03	0.03	no	4.69	7.68	5.10	0.78
Sawyer Creek	ag	n/a[1]	0.83	<0.05	0.05	no	5.59	4.85	5.15	1.17
Richmond Creek	fp	0.61	2.81	0.20	0.15	no	3.43	8.77	3.20	0.66
Richmond Creek	fp	0.89	0.10	0.20	0.10	no	3.35	11.38	3.40	0.62
Trib. to West Fork Clearwater	fr	0.44	1.17	0.10	0.10	no	8.70	n/a[4]	8.15	0.37
Trib. to West Fork Clearwater	fp	n/a[3]	n/a[2]	0.04	0.04	no	13.20	10.75	8.75	0.34
Trib. to West Fork Clearwater	fr	n/a[2]	n/a[2]	0.10	0.05	no	11.10	17.87	6.20	0.56
Average		**1.61**	**2.18**	**0.26**	**0.23**		**4.94**	**6.28**	**6.31**	**0.74**
Standard Deviation		**1.09**	**1.44**	**0.21**	**0.21**		**3.52**	**4.35**	**2.69**	**0.27**

Outlet Configuration:
ag - at grade
fp - falls into pool
fr - falls onto rocks
cr - cascades onto rocks

Notes:
n/a[1] - debris blockage
n/a[2] - velocity too low to measure
n/a[3] - depth too shallow to measure
n/a[4] - unknown difficulty
yes[5] - nearly continuous

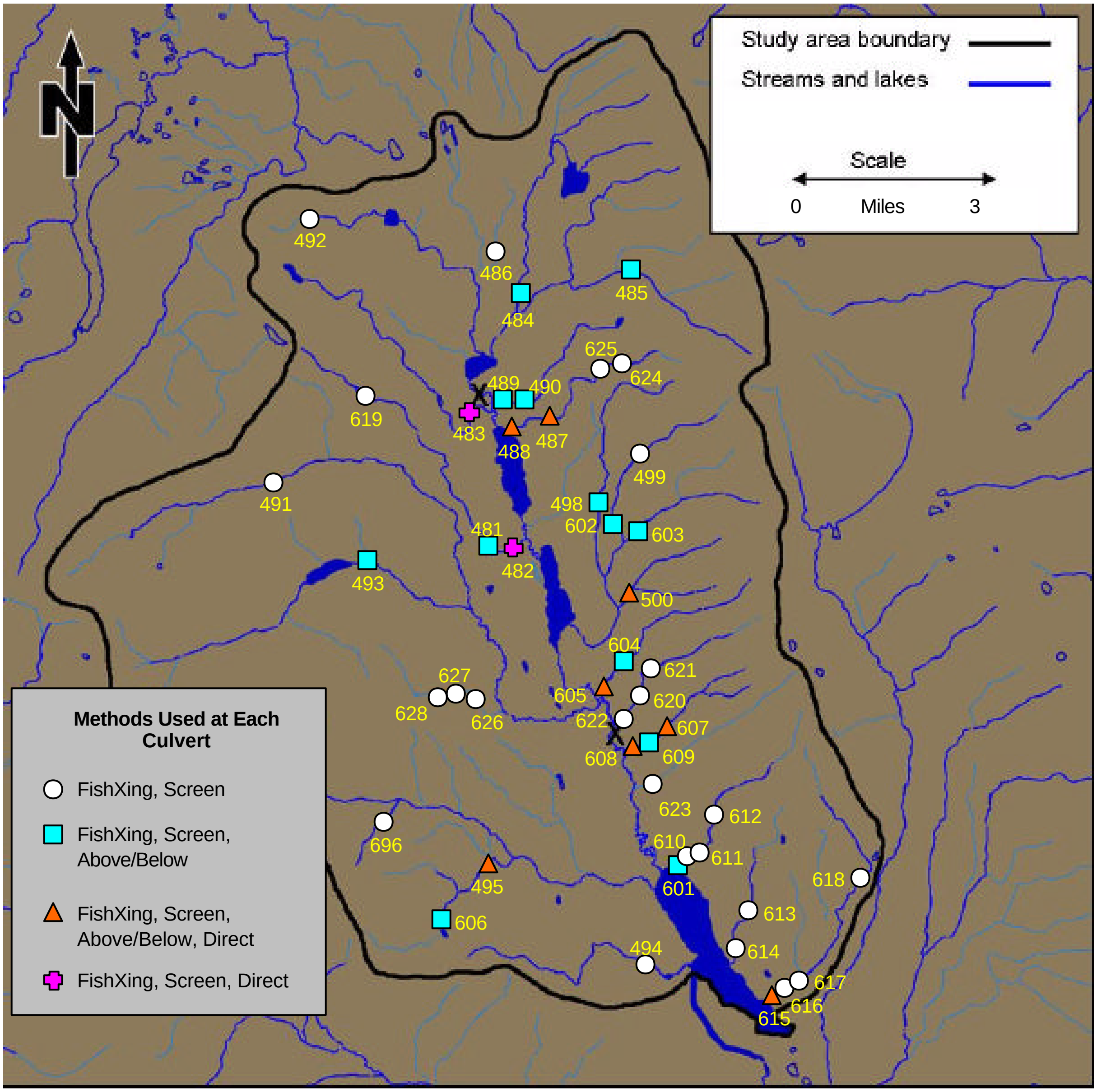

Figure 2. Fish passage assessment sites in the upper Clearwater River basin.

Methods

A tiered approach was used to assess fish passage through culverts throughout the entire upper Clearwater River basin. The FishXing software and a composite of several similar flowchart-based models (the *Composite Screen*) were used to assess juvenile and adult fish passage at 47 culverts (all culverts shown with all symbols in Figure 2) in the study area across a wide range of stream discharges. At a subset of 21 culverts (all culverts with square or triangle symbols in Figure 2), abundance sampling upstream and downstream of each culvert at low flow was used to determine the degree to which culverts are influencing relative abundance, size structure, and species presence. At a further subset of 10 sites (all culverts having triangle or cross symbols in Figure 2), passage was directly measured at low flow by monitoring the movement of marked fish through culverts having differing physical characteristics.

FishXing and the Composite Screen

The FishXing software and the Composite Screen were used to maximize the number of culverts for passage assessment, to evaluate the passage status for both juveniles and adults, and to assess the passage status over a wide range of stream discharge. All culverts in the study area were surveyed and assessed for passage except those on streams that were judged to have little or no fisheries value because they had any combination of the following:

- no flow or intermittent flow as observed at the site,
- a discharge of less than 0.035 cfs,
- a sustained stream slope greater than 15% as measured on a 1:24,000 scale USGS topographic map, or
- no fish presence as determined by electrofishing.

Field data collection was conducted at 27 sites from June through October 2002 and at 20 sites from July to October 2003 for a total of 47 sites (Figure 2) following a protocol developed for passage assessment using the FishXing model (*27*). Each site was assigned a unique stream crossing identification number and its location was recorded using a hand-held global positioning unit. For each culvert, the shape, dimensions, material, corrugation size, and inlet and outlet configuration were recorded. Substrate particle size upstream, downstream, and within the culvert was visually observed and ranked according to the first three substrate sizes that occupy the greatest area (1 = highest, 3 = lowest) to estimate channel roughness. Bankfull channel widths were measured at 5 locations both upstream and downstream of each culvert. A total station survey instrument was used to determine culvert slope and length, channel gradient upstream and downstream, outlet drop height and plunge pool depth, and the tail water cross-section dimensions. A Gurley flow meter was used to measure stream discharge at a cross-section located upstream of the influence of the culvert, and to measure water depth and velocity at the culvert inlet and outlet.

Field measurements of stream discharge taken during the summer low flow period were input into FishXing as the low passage flow. The 10% May exceedence flow was estimated for each site using the USGS regional regression equations for estimating monthly stream flow characteristics at un-gaged sites (*28*) and was subsequently input into FishXing as the high passage flow. A 5.9 inch long cutthroat trout was selected in FishXing as the adult "analysis fish". Due to the lack of swimming ability information in FishXing regarding juvenile cutthroat trout, a 2.4 inch long rainbow trout was selected as the juvenile "analysis fish". A minimum required water depth of 0.3 feet for adults and 0.1 feet for juveniles was used to predict depth-related barriers.

A composite screening instrument was developed specifically for the setting of this study. The composite screen is similar to that used by regulatory and conservation agencies in other locations. The composite screen used in this study uses an approach similar to examples of other flowchart based screening instruments that have been developed for specific fish and settings (*29, 30 and 31*). First, barrier status is assessed for juvenile and adult fish. Then there are three main physical attributes of a culvert that identify the barrier designation; the presence or absence of a natural streambed in the culvert, the degree of the outlet drop if one exists, and the slope of the culvert. The composite screen is intended to be a quick and easy to use method for identifying potential barriers to fish passage. US Forest Service personnel were involved in the development of the composite screen used here, and as of this writing continue to work on a draft of such an instrument for use in the region where this study took place.

Population Assessment (Above/Below Sampling)

Electrofishing was used to sample upstream and downstream of a subset of 21 culverts (Figure 2) to determine the degree to which culverts influence relative abundance, size structure, and species presence. Because low conductivities (less than 100 µmho/cm^3 or 1639 µmho/in^3) in some streams prohibited the ability to sample efficiently, the subset of culverts was not randomly selected, however they were carefully selected to be a representative sample of all the culverts in the study. The 21 selected sites incorporated the wide range of culvert characteristics (slope, length, outlet drop height, culvert material type, etc.) observed throughout the study area. Sampling was conducted from July to August 2002 and in August 2003 during the summer low flow period.

Single pass electrofishing was used to accomplish the objective of comparing several fish population characteristics at a large number of sites over a broad geographic area (multiple pass electrofishing was used to precisely determine abundance at a few locations). It has been concluded that when sampling to estimate the number of species in stream fish assemblages, that it is more efficient to sample a large area with one pass than to sample a smaller area with multiple passes (*32*). At each site, sampling was conducted over 295 ft reaches immediately downstream and upstream of the culvert.

Care was taken to electrofish slowly and thoroughly through all areas in each reach during an upstream pass. A two or three-person crew used a Smith-Root model 15-D generator powered backpack electrofishing unit operated at a DC pulse frequency of 30-40 Hz, and 400 – 700 V depending on water conductivity. For consistency at a site, the same settings were always used downstream and upstream of the culvert. All captured fish were anesthetized with clove oil, identified by species, and fork length was measured.

To avoid bias associated with small sample sizes that result from low densities, comparisons were restricted to sites where the larger relative abundance was at least 5 fish per reach. Relative abundance was considered to be substantially different at a site if there were at least 2 times as many fish in one reach relative to the other. Tests for differences in relative abundance for each species in all downstream versus all upstream reaches were performed by using a two-tailed Wilcoxson paired-sample test. Species presence was compared in the downstream versus upstream reach at each of the 21 culvert sites that were sampled.

Size differences between each downstream and upstream reach were compared using a two-tailed Mann-Whitney test. To compare the overall size structure at all 21 culvert sites combined, a two-tailed Wilcoxon paired-sample test was used to determine if there is a difference between the lengths of each species, and for all fish combined, in all of the downstream versus upstream reaches.

To account for the possible influence of habitat differences below and above culverts, habitat features were measured throughout each 295 ft reach where fish were sampled. Each reach was divided into habitat units (*33*) according to their main physical features. The habitat unit length was recorded and wetted width, average depth, and maximum depth was measured. Mann-Whitney tests were used to compare upstream versus downstream habitat variables. For all tests, differences were considered significant if the p-value was = 0.05.

Direct Passage Assessment

Direct passage was measured at 10 culvert sites (Figure 2) where marked fish were released downstream of the culvert and recaptured in traps upstream. The sites were selected to be representative of all the culverts in the study. The 10 selected sites incorporated the wide range of culvert characteristics (slope, length, outlet drop height, culvert material type) observed throughout the study area. Direct passage assessment was conducted during July to September 2003 during summer low flow.

At each site, a control and treatment reach of equal stream area were designated, with the control reach located immediately downstream of the treatment (Figure 3). The control reach was a section of contiguous natural stream channel whereas the treatment reach was 2 sections of natural stream channel with the culvert located in between. Each reach was blocked at the downstream and upstream ends with wire mesh that was supported by rebar stakes driven into the substrate. At the upstream ends, a trap box was positioned to capture fish that moved upstream. Trap boxes were constructed of ½ inch plywood and wire mesh. To minimize the escape of trapped fish, pyramid shaped entrances were constructed that forced fish to swim slightly upward into the box and thus kept the entrances away from the bottom of the trap. Additionally, baffles were constructed to provide cover and refuge from currents away from the entrances. To enhance attraction to the trap boxes, internal baffles were used to direct water through the entrance, creating an “attraction flow” area. As well, the wire mesh leads at the upstream end of each reach were positioned diagonally to direct fish towards the trap boxes.

Once the traps were installed, existing fish in each reach were removed by electrofishing and placed downstream of the study section. Electrofishing was then used to collect 50 fish (except site number 500 where only 40 fish were collected) upstream of the study section. Fish were anesthetized with clove oil, identified by species, fork length was measured, and the fish were divided into two similar groups of 20-25 based on species and size. Groups were than randomly assigned to either the treatment or control reach by flipping a coin. Pelvic fin clips were used to mark the fish according to their respective group: treatment fish received a right fin clip and control fish received a left fin clip. Upon recovery, fish were released into the lower end of their designated reach. Fish were then recaptured in the traps as they moved upstream toward their original capture location.

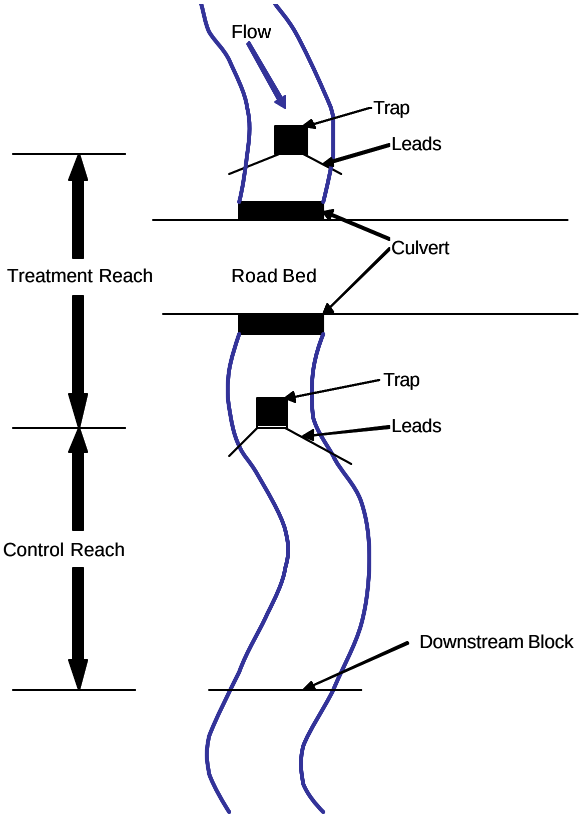

Figure 3. Diagram of the direct passage assessment study.

The number of fish that moved upstream into the respective traps was monitored for three days after being released. Recaptured fish were anesthetized, identified by species, fork length was measured, fish were checked for fin clips, and then released upstream of the study section.

The hydraulic conditions at the site were monitored each day over the 3 day study period. A Gurley flow meter was used to measure discharge at an upstream cross-section and water depths and velocities were measured at the inlet and outlet of the culvert. Discharge, water depths, and velocities were averaged to determine the overall hydraulic conditions during the study period.

Two measures of the degree of passage success were calculated. The *relative passage efficiency* is the ratio of the number of marked fish that pass through the treatment (culvert) section to the number that pass through the control section, expressed as a percentage, or 100 x T/C, where C is the number of fish recaptured in the control reach and T is the number of fish recaptured in the treatment reach. A relative pass efficiency of greater than 100 is possible if more fish navigate the culvert than do the control. A relative passage efficiently of infinity occurs if no fish pass through the control, but some do pass through the culvert. The relative passage efficiency was used for qualitative comments concerning the direct assessment results. The fish passage *impedance ratio* was also calculated to compare the proportions of fish moving upstream through the treatment (culvert) and control reaches. The ratio was calculated as (C-T)/C. The two terms are directly related, except that negative impedance ratios were converted to zeros to indicate that the number of recaptures in the treatment (culvert) reach was greater than or equal to that of the control (indicating no restriction of passage through the culvert). A passage impedance ratio of 1 specifies that no fish moved upstream through the treatment (culvert), while infinity results if no fish pass through the control reach. Simple linear regression was used to examine the relationship between the physical conditions of the culvert and the fish passage impedance ratio. Relationships were considered significant if the p-value was = 0.05. The fish passage impedance ratio was also compared to the passage status as determined from FishXing at the low flow conditions that were measured during the direct passage study.

Results and Discussion

Primary results are shown in Table 3. Each culvert is listed with columns that indicate whether or not there were fish passage concerns for each of the assessment methods used. Cells in Table 3 labeled "B" (for *Barrier*) indicate that an assessment method (FishXing, for example) infers that there are fish passage concerns for that culvert. That is not to say that the assessment method predicts that no fish will pass, only that there are passage concerns. Cells labeled "I" (for *Inconclusive*) indicate that the culvert should be further studied (a result only possible for the Composite Screen). Cells labeled "P" (for *Passable*) indicate *no fish passage concerns*. A blank cell indicates that the assessment method for that column was not used at that site.

The Composite Screen

The Composite Screen was used at all 47 sites. The Screen indicated that 38 of 47 culverts had low-flow adult-fish passage concerns while 9 of 47 culverts had no concerns for adult fish passage at low flow. Seven of the nine culverts that did not have passage concerns were culverts having continuous substrate beds - the culvert floor was similar to the natural stream bed nearby (these have an asterisk next to the site number in Table 3). All culverts except these seven continuous substrate culverts either had concerns of excessive pipe slope or were found to merit further study with respect to pipe slope. A culvert slope of 2% or greater indicates passage concerns in the Screen. A maximum allowable slope of 2% is typical of that used in comparable flowchart-based screening tools (29, 30 and 31). The outlet drop height was only a concern in 8 of 47 culverts for adult fish and in 16 of 47 culverts for juvenile fish. Overall, only the seven natural substrate culverts had no fish passage concerns at all using the Composite Screen, while 2 culverts merit further study and 37 culverts had passage concerns. The Screen does not differentiate by fish species.

FishXing

The FishXing software was used to detect fish passage concerns at all 47 culverts. The software superimposes the swimming and leaping capabilities of an *analysis fish* on the results of a hydraulic assessment of the culvert. The results of the FishXing model are shown in Table 3.

Table 3. Summary of the outcome of each assessment method with all species included.

		Composite Screen								FishXing				Above & Below		Direct Assessment	
Stream Name	Culvert ID	Juvenile Fish, Depth at Low Flow	Adult Fish, Depth at Low Flow	Juvenile Fish, Culvert Slope	Adult Fish, Culvert Slope	Juvenile Fish, Outlet Drop	Adult Fish, Outlet Drop	Juvenile Fish, Overall	Adult Fish, Overall	Juvenile Fish, Depth at Low Flow	Juvenile Fish, May 10% Flow	Adult Fish, Depth at Low Flow	Adult Fish, May 10% Flow	Significant Size Difference, All Species Combined?	Two-Fold Abundance Difference, All Species Combined?	Relative Passage Efficiency	Impedance Ratio
Uhler Creek	481	P	B	B	I	P	P	B	B	P	B_{eb}	P	B_{eb}	No	No		
Uhler Creek	482	B	B	I	I	I	P	B	B	P	$B_{l,v}$	P	B_{l}			210%	0.00
Colt Creek	483	B	B	B	B	B	P	B	B	$B_{l,v}$	$B_{l,v}$	$B_{l,d,eb}$	$B_{l,v}$			0%	1.00
Clearwater Main Stem	484	B	B	B	B	B	I	B	B	$B_{l,v}$	B_{v}	B_{l}	B_{eb}	No	No		
E. Fork Clearwater	485*	P	P	P	P	P	P	P	P	P	P	P	P	No	No		
Unnamed Trib. to Bertha Creek	486*	P	P	P	P	P	P	P	P	P	P	P	P				
Richmond Creek	487	B	B	B	B	P	P	B	B	$B^{l,v}$	B_{v}	B_{d}	$B_{d,eb}$	No	No	106%	0.00
Richmond Creek	488	B	B	B	B	P	P	B	B	B_{d}	B_{v}	B_{d}	$B_{d,eb}$	No	No	129%	0.00
Unnamed Cr. 1/4 N. of Richmond Cr.	489	B	B	B	I	P	P	B	B	B_{d}	B_{v}	B_{d}	B_{eb}	No	No		
Unnamed Cr. 1/4 N. of Richmond Cr.	490	B	B	B	B	P	P	B	B	P	B_{v}	P	B_{eb}	No	No		
Unnamed Trib. West Fork Clearwater	491	B	B	B	B	B	B	B	B	$B^{l,v}$	$B_{l,v}$	B^{l}	$B_{l,eb}$				
Bertha Creek	492	B	B	B	B	B	B	B	B	$B^{l,eb}$	$B_{l,v}$	B^{l}	$B_{l,eb}$				
Unnamed Trib. to Marshall Creek	493	B	B	B	B	I	P	B	B	$B_{l,d}$	B_{v}	B_{d}	P	No	No		
Archibald Cr.	494	B	B	B	I	B	P	B	B	B^{l}	$B_{l,v}$	$B_{l,d}$	B_{l}				
Fawn Creek	495	B	B	B	B	I	P	B	B	B^{l}	$B_{l,v}$	B_{d}	$B_{l,eb}$	Yes	No	47%	0.53
Sheep Creek	496	B	B	B	B	I	P	B	B	B_{dry}	B_{v}	B_{dry}	B_{eb}				
Unnamed Trib. to Inez Cr. (4)	498*	P	P	P	P	P	P	P	P	P	P	P	P	No	No		
Inez Creek (5)	499	B	B	B	B	I	P	B	B	$B_{d,v}$	B_{v}	B_{d}	B_{eb}				
Unnamed Trib. to Camp Creek	500	B	B	B	B	B	I	B	B	B^{l}	$B_{l,v}$	$B_{l,d}$	$B_{l,eb}$	No	No	69%	0.31
Rice Creek (3)	601*	P	P	P	P	P	P	P	P	P	P	P	P	No	No		
Inez Creek	602	B	B	B	B	P	P	B	B	B_{d}	B_{v}	B_{d}	B_{eb}	No	No		
Camp Creek	603	B	B	B	B	I	P	B	B	B^{v}	B_{v}	B_{d}	B_{eb}	No	Yes		
Findell Creek	604	B	B	B	B	B	B	B	B	$B_{l,d}$	$B_{l,v}$	$B_{l,d}$	$B_{l,eb}$	No	No		
Findell Creek	605	B	B	B	B	P	P	B	B	B_{d}	$B_{d,v}$	B_{d}	$B_{d,eb}$	No	No	30%	0.70
Fawn Creek	606	P	P	I	I	P	P	I	I	P	B_{eb}	P	P	No	No		
Benedict Creek	607	B	B	B	B	B	I	B	B	$B^{l,v}$	$B_{l,v}$	B^{l}	$B_{l,eb}$	No	No	18%	0.82
Benedict Creek	608	B	B	B	B	B	B	B	B	$B_{l,d,v}$	$B_{l,v}$	$B_{l,d}$	$B_{l,d,v}$	Yes	No	8%	0.92
Benedict Creek (6)	609*	P	P	P	P	P	P	P	P	P	P	P	P	No	No		
Rice Creek	610*	P	P	P	P	P	P	P	P	P	P	P	P				
Rice Creek	611*	P	P	P	P	P	P	P	P	P	P	P	P				
Rice Creek	612	B	B	B	B	I	P	B	B	$B_{l,d,v}$	$B_{l,v}$	$B_{l,d}$	$B_{l,v}$				
Auggie Creek	613	B	B	B	B	I	P	B	B	B^{l}	B_{v}	B_{d}	$B_{d,eb}$				
Auggie Creek	614	B	B	B	B	P	P	B	B	$B_{l,d,eb}$	B_{v}	B_{d}	$B_{d,eb}$				
Seeley Creek	615	B	B	I	I	I	P	B	B	$B_{l,d,eb}$	$B_{l,v}$	B_{d}	$B_{l,eb}$	No	No	53%	0.47
Seeley Creek	616	B	B	B	B	I	P	B	B	B^{l}	B_{v}	P	B_{eb}				
Seeley Creek	617	B	B	B	I	P	P	B	B	B^{v}	B_{v}	B_{d}	P				
Seeley Creek	618	P	P	I	I	P	P	I	I	P	B_{v}	P	P				
Uhler Creek	619	B	B	B	B	B	B	B	B	$B_{l,d}$	$B_{l,v}$	$B_{l,d}$	$B_{l,eb}$				
Murphy Creek	620	B	B	B	B	B	B	B	B	$B_{l,d}$	B_{v}	$B_{l,d}$	$B_{l,eb}$				
Murphy Creek	621	B	B	B	B	B	B	B	B	$B_{l,d,v}$	$B_{l,v}$	$B_{l,d}$	$B_{l,v}$				
Murphy Creek	622	B	B	B	I	B	I	B	B	$B_{l,d}$	$B_{l,v}$	B_{d}	$B_{l,d,eb}$				
Sawyer Creek	623	B	B	B	B	P	P	B	B								
Richmond Creek	624	B	B	B	B	I	P	B	B	$B^{l,v}$	$B_{l,v}$	$B_{l,d}$	$B_{l,d,eb}$				
Richmond Creek	625	B	B	B	I	B	I	B	B	B^{l}	$B_{l,v}$	B^{l}	B_{l}				
Southern Trib. West Fork Clearwater	626	B	B	B	B	B	B	B	B	B^{l}	$B_{l,v}$	$B_{l,d}$	$B_{l,eb}$				
Southern Trib. West Fork Clearwater	627	B	B	B	B	I	P	B	B	$B_{d,v}$	B_{v}	B_{d}	B_{v}				
Southern Trib. West Fork Clearwater	628	B	B	B	B	B	P	B	B	$B_{l,d,v}$	$B_{l,v}$	$B_{l,d}$	$B_{l,v}$				

B - indicates passage concerns (barrier)
P - indicates no concern (passable)
I - inconclusive
l - culvert length was a concern
v - excessive water velocity was a concern
d - inadequate flow depth was a concern
eb - the required fish burst speed was excessive
dry - the culvert was physically dry during a field visit

superscript - passage not limited by depth after lowering the minimum depth criteria

subscript - either depth was not limiting with larger criteria, or depth remained limiting after lowering the minimum depth criteria

In Table 3, "B" indicates passage concerns (barrier), where "P" indicates no concern (passable). The sub- or super-scripted letters in the cells indicate the limiting factor when passage concerns occurred: culvert length (l), excessive water velocity (v), inadequate flow depth (d), the required fish burst speed was excessive (eb), or the culvert was physically dry during a field visit (dry).

The minimum flow depth criterion in FishXing is a required input for a given analysis fish. During the course of field activities it was observed that many culverts and natural stream riffles had flow depths of as shallow as 0.1 ft. As a result, the one parameter customization applied to FishXing was to set the minimum depth criterion from the default of 0.5 ft to values of 0.1 ft for juvenile fish and to 0.3 ft for adult fish. In cells with "B" and superscripted letters in Table 3, the minimum depth was no longer a limiting factor after the minimum depth criterion was lowered from 0.5 ft to 0.1 ft or 0.3 ft for juvenile or adult fish, respectively. However, in all of these cases the culvert still had other factors that indicated passage concerns overall. Cells with "B" and subscripted letters indicate that either depth was not a limiting factor to begin with, or depth remained a limiting factor after the reduction in the minimum depth criterion.

FishXing indicated low-flow adult-fish passage concerns in 34 of the 47 culverts studied when the minimum allowable flow depth was set at 0.3 ft. Again, the seven culverts having continuous substrate showed no fish passage restrictions at all.

The flow rate used in the high flow FishXing assessments was the flow rate that would be exceeded during the month of May in 1 day out of 10. This flow would be below the 2 year annual return interval flow - the defining flow for a "bank full" event. In 40 of 47 culverts, FishXing indicated passage concerns for juvenile fish at high flow, and similarly in 38 of 47 culverts for adult fish.

Population Assessment

The above/below sampling showed that in only 2 of 21 culverts were there significant differences (95% confidence level using a Mann-Whitney test) in the size of fish captured above and below the culvert when all species were pooled at each individual culvert. In only 1 of 21 culverts was there a two-fold or greater difference in the abundance of fish captured below the culvert as compared to above the culvert when all species were pooled at each individual culvert. An example of a site where fish size and abundance with all species pooled are not different above and below a culvert is shown in Figure 4a. An example of a culvert where differences in fish size exist is shown in Figure 4b, and one where only fish abundance differences exist is shown in Figure 4c.

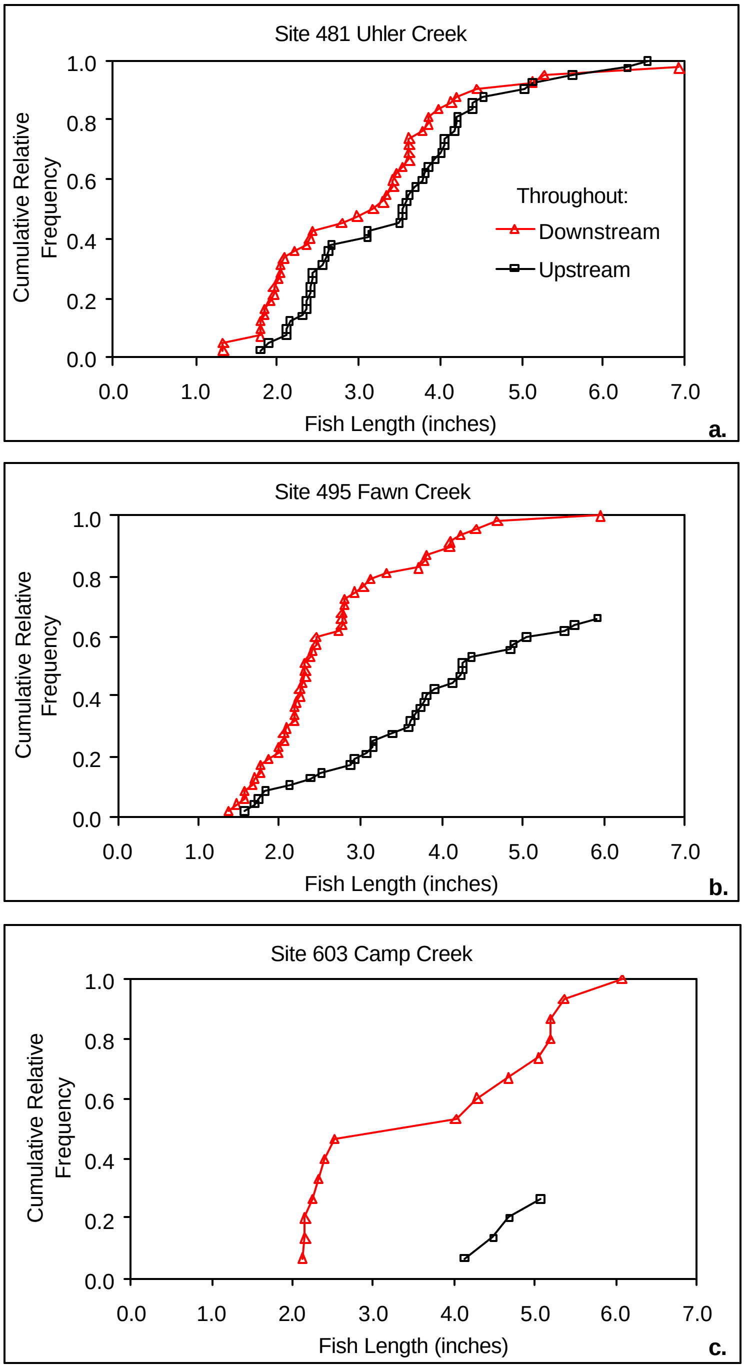

Figure 4. Examples of a) similar size and abundance above and below a culvert, b) differences in fish size but not abundance, c) differences in fish abundance but with too small of sample to compare mean fish size.

When all fish in like species were pooled across all sites, no significant difference in mean fish size above and below the culvert was detected for any species, and no substantial difference in fish abundance was measured for any species. Both these results held true when all fish were pooled at all sites.

The fish sampled above and below the culverts were further cataloged by size and species. Figure 5 shows the abundance and size of fish caught above and below the culverts where less frequently found species were evident. Bull trout were found at 4 sites. Site 485 was the only site that had enough bull trout to compare abundance, and there was no difference in size or abundance from upstream to downstream. Brown trout were found at two sites, but only on one side of the culvert in each case (downstream at site 608 and upstream at site 609). Sculpin were found at two sites, but with no significant size difference upstream to downstream at either site. Site 495 had more than twice as many sculpin below the culvert as above. Brook stickleback were found at two sites but in insufficient numbers to facilitate comparisons, although at both these sites very few Brook Stickleback were found upstream of the culvert.

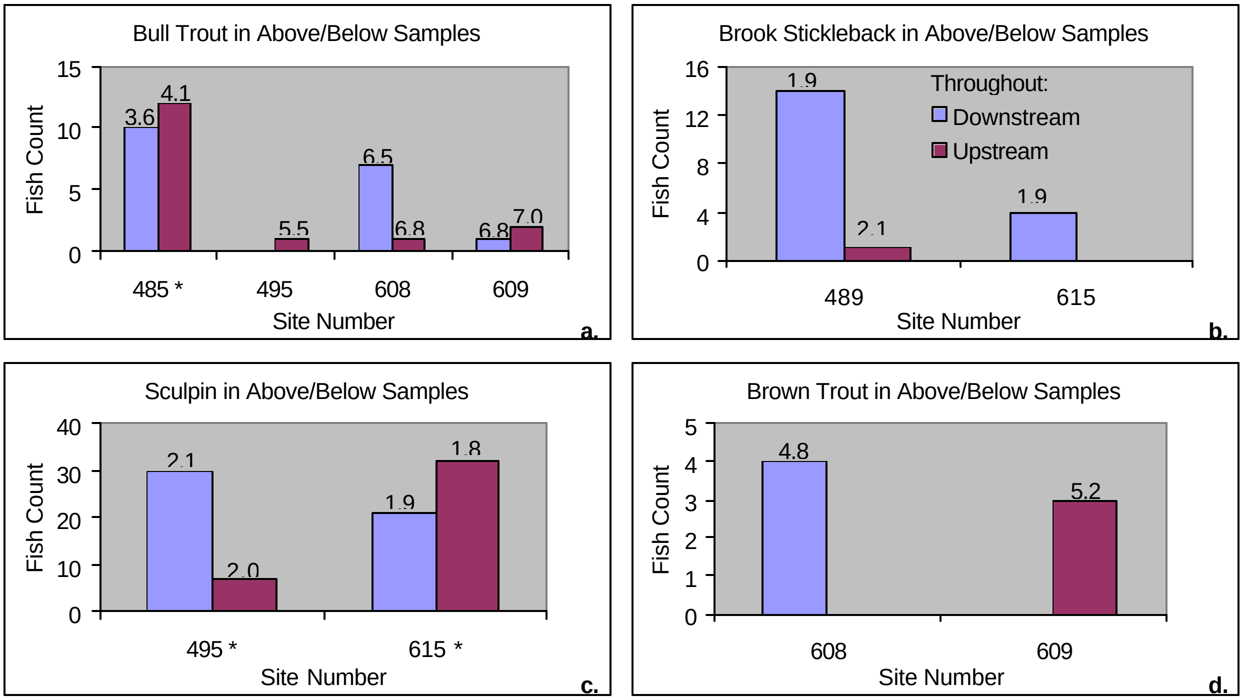

Figure 5. Less abundant species detected in the above/below study. Number above bars are mean fish lengths (in). Asterisks indicate no significant difference in mean fish length. All sites without asterisks had insufficient quantities of fish to contrast fish sizes.

The species most abundant in the study area were brook and cutthroat trout. The relative abundance and mean fish size upstream and downstream of the culverts by species for brook and cutthroat trout are shown in Table 4.

Table 4. Size and relative abundance of fish sampled above and below the culvert for brook and cutthroat trout.

	Relative Abundance				Mean Fish Length (inches)			
	Cutthroat		Brook		Cutthroat		Brook	
Site Number	Downstream	Upstream	Downstream	Upstream	Downstream	Upstream	Downstream	Upstream
481	5	4	36	38	2.06	2.98	3.18	3.56
484	17	11	0	0	1.92	2.45		
485	1	2	10	12	4.06	4.39	3.64	4.06
487	27	31	0	1	2.87	2.96		2.95
488	27	26	0	4	3.09	3.30		2.03
489	13	14	12	10	3.20	3.35	3.98 **	2.57
490	26	20	12 *	5	3.51	3.09	3.94	3.68
493	1	0	19	21	2.91		3.08	3.49
495	17	21	0	2	3.55	3.87		5.47
498	3 *	0	32	32	3.60		3.58	3.49
500	26	18	6	4	3.57	3.62	4.19	4.83
601	4	7	0	0	4.99	4.63		
602	20	12	0	0	3.89	3.71		
603	15 *	4	0	0	3.72	4.60		
604	8	6	0	0	4.39	4.27		
605	9	9	10 *	2	3.58	3.57	3.09	2.46
606	6	9	0	0	3.50	4.56		
607	26	14	11 *	5	3.43	3.23	3.85	4.67
608	13	13	6 #	25	4.12 **	2.86	3.62	2.70
609	13	13	25 *	9	2.86	2.50	2.70	2.94
615	0	1	12	17		5.83	3.03	3.87
Totals	277	235	191	187				
Averages					3.36	3.38	3.37	3.44

** Significant difference in size for that species (95% confidence interval).

* More than two times the population downstream than upstream.

More than two times the population upstream than downstream.

There were 4 instances in 4 culverts (sites 493, 498, 608, and 615) where a species present below the culvert was not present at all in samples taken above the culvert. However, in all 4 instances, the relative abundance of the species present below the culvert was very low (less than 5 fish in the sample reach). As a result, the "not present" status above the culvert may likely be due to a low detection probability associated with the low density, as opposed to an actual lack of species presence due to a culvert barrier. Furthermore, sampling at a culvert upstream of site #608 confirmed the presence of brown trout above this culvert, supporting the notion that the "not present" status above the culvert may likely be due to a low detection probability associated with the low density. An additional 6 instances at 5 culvert sites (sites

487, 488, 495, 609, and 615) had a species present above the culvert that was not present below. Again, in all 6 instances, the relative abundance of the species present above the culvert was very low (less than 5 fish in the reach). This further supports the notion that the “not present” status may likely be due to a low detection probability associated with the low relative abundance, as opposed to an actual lack of species presence due to a culvert barrier.

Three of the 21 above/below sites had significant differences in habitat variables on each side of the culvert (sites 481, 608 and 609). At these sites, habitat differences must be considered in addition to the barrier potential of the culvert when looking at differences in fish abundance or size. Of these three sites, site 609 had a difference in relative abundance for brook trout and site 608 had differences in relative abundance for both bull trout (more below than above) and brook trout (more above than below).

Direct Assessment

At the 10 selected culvert sites, a total of 490 fish were captured, marked, and released for the direct passage assessment. Of these, 284 (60.9%) were cutthroat trout, 180 (38.6%) were brook trout, 2 (0.4%) were bull trout, and 24 (5.2%) were slimy sculpin. Table 5 has a summary of the results, with the sculpin included (Table 3 has sculpin included also), although slimy sculpin were excluded from further analysis due to a very low recapture rate (3 of 12) in the control reaches, indicating that the methodology used here may not be effective for this species. This resulted in a total of 466 fish for the analysis. The average length of fish released in the control reaches was 3.78 inches and ranged from 1.14 inches to 7.83 inches. The average length of fish released in the treatment reaches was 3.82 inches and ranged from 1.38 inches to 7.20 inches. The lengths of marked fish were similar between each treatment group and control group at all 10 sites (Mann-Whitney tests, $p > 0.05$).

Overall, 156 of 233 (67.0%) fish were recaptured after moving upstream through the control reaches, averaging 4.05 inches in length. In the treatment reaches, 94 of 233 (40.3%) fish were recaptured and averaged 4.21 inches. At each of the 10 sites, the lengths of recaptured fish were similar to those marked for both the treatment and control groups (Mann-Whitney tests, $p > 0.05$).

Table 5. All results of the direct assessment studies.

	Cutthroat Trout								Relative	Relative
	Number of Fish				Mean Fish Length (inches)				Passage	Impedance
Site	Control		Treatment		Control		Treatment		Efficiency	Ratio
Number	Marked	Passed	Marked	Passed	Marked	Passed	Marked	Passed	(percent)	
482	2	0	2	1	3.05		3.31	4.29	8	8
483	2	2	2	0	3.74	3.74	3.70		0	1.00
487	24	16	24	16	3.19	3.54	3.11	3.39	100	0.00
488	23	14	22	15	3.54	3.35	3.23	3.54	112	0.00
495	23	17	23	8	3.94	4.09	3.86	4.57	47	0.53
500	19	16	19	11	4.76	4.92	4.92	5.43	69	0.31
605	25	20	25	6	3.78	3.94	3.82	4.02	30	0.70
607	14	6	15	1	3.07	4.02	2.80	4.69	16	0.83
608	10	10	10	0	3.35	3.35	3.35		0	1.00
615										
Average	16	11	16	6	3.60	3.87	3.57	4.27	57	0.43

	Brook Trout								Relative	Relative
	Number of Fish				Mean Fish Length (inches)				Passage	Impedance
Site	Control		Treatment		Control		Treatment		Efficiency	Ratio
Number	Marked	Passed	Marked	Passed	Marked	Passed	Marked	Passed	(percent)	
482	23	10	23	20	4.25	4.54	4.43	4.37	200	0
483	23	12	23	0	4.17	4.57	4.09		0	1.00
487	1	0	1	1	4.41		4.25	4.25	8	8
488	2	0	3	3	4.02		4.45	4.45	8	8
495										
500	1	0	1	0	1.93		3.98		8	8
605										
607	11	5	10	1	3.15	3.82	3.15	2.40	22	0.80
608	14	13	14	2	4.06	4.09	4.13	5.04	15	0.85
615	15	14	15	9	4.29	4.49	4.21	4.80	64	
Average	11	7	11	5	3.78	4.30	4.09	4.22	67	0.33

	Bull Trout								Relative	Relative
	Number of Fish				Mean Fish Length (inches)				Passage	Impedance
Site	Control		Treatment		Control		Treatment		Efficiency	Ratio
Number	Marked	Passed	Marked	Passed	Marked	Passed	Marked	Passed	(percent)	
482										
483										
487										
488										
495										
500										
605										
607										
608	1	1	1	0	3.74	3.74	4.02		0	1.00
615										
Average	1	1	1	0	3.74	3.74	4.02		0	1.00

	Sculpin								Relative	Relative
	Number of Fish				Mean Fish Length (inches)				Passage	Impedance
Site	Control		Treatment		Control		Treatment		Efficiency	Ratio
Number	Marked	Passed	Marked	Passed	Marked	Passed	Marked	Passed	(percent)	
482										
483										
487										
488										
495	2	0	2	0	2.68		2.56		8	8
500										
605										
607										
608										
615	10	3	10	0	2.13	2.36	2.17		0	1.00
Average	6	2	6	0	2.40	2.36	2.36		0	1.00

Results from simple linear regression analyses indicate that there was a significant positive relationship ($p = 0.047$) between passage impedance and the culvert outlet height, but the strength of the relationship was only moderate ($r^2 = 0.408$). No significant relationships were found between relative passage impedance and culvert slope ($p = 0.432$, $r^2 = 0.079$), water depth ($p = 0.757$, $r^2 = 0.013$), length ($p = 0.167$, $r^2 = 0.224$), or constriction ratio ($p = 0.541$, $r^2 = 0.048$). Pipe material was not tested against impedance due to insufficient sample size for some materials.

In the direct passage study, at least one fish passed successfully through 9 of the 10 culverts. Three culverts had no passage impedance, two culverts had less than 50% passage impedance, four culverts had greater than 50% passage impedance, and one culvert had 100% passage impedance. Two of the three culverts that had no passage impedance had no outlet drop, while the third had a 7.08 inch outlet drop. The two culverts with less than 50% passage impedance had outlet drops of 3.54 and 13.39 inches. Three of the four culverts with over 50% passage impedance had an outlet drop (3.54, 8.27, and 24.02 inches), and the culvert that had 100% passage impedance had an outlet drop of 18.11 inches.

A summary of the FishXing results at the 10 sites where direct assessment was performed shows that at all 10 sites FishXing predicted low flow barriers for both juveniles and adults (Table 6). For juveniles, the factors that led to the barrier designation were an excessive leap at the outlet (7 sites), excessive water velocity (6 sites), and insufficient water depth (4 sites). For adults, insufficient water depth was identified as a factor at all 10 sites, and an excessive leap at the outlet (4 sites), and excessive water velocity (1 site) were also factors.

Table 6. FishXing results versus observed passage impedance. Barriers (B) were indicated due to culvert length (l), excessive velocity (v), inadequate flow depth (d), or the required fish burst speed was excessive (eb).

Site	Passage Impedance	FishXing Juvenile Passage Status	FishXing Adult Passage Status
482	0.00	B(l,v)	B(d)
483	1.00	B(l,v)	B(l,d,eb)
487	0.00	B(v)	B(d)
488	0.00	B(d)	B(d)
495	0.53	B(l)	B(d)
500	0.31	B(l)	B(l,d)
605	0.70	B(d)	B(d)
607	0.82	B(l,v)	B(l,d)
608	0.92	B(l,d,v)	B(l,d)
615	0.36	B(l,d,eb)	B(d)

Summary

The results suggest that both the Composite Screen and the FishXing software may be conservative in predicting low flow fish passage barriers. The above/below sampling indicated little overall difference in fish abundance or size distribution upstream and downstream of most culverts studied, but there were many cases where some species exhibited differences in either size or abundance between each side of the culvert. The direct assessment procedure indicated that the size classes and species in the upper Clearwater River basin tended to be more mobile across culverts than would be predicted by the FishXing software and the Composite Screen for adult fish during low flow.

No evidence was found to suggest that the swimming or leaping capabilities of bull trout differ from the other trout species. This is due, to a large part, to the lack of bull trout available for study. Of the approximately 1400 fish cataloged in the study, only 36 were bull trout.

Sculpin and brook stickleback - both reputed to be weak swimming species - either tend to be immobile in natural reaches and in culverts, or are difficult to include in a study using the field techniques used here. In general these species were more abundant downstream of the culverts where they were detected.

It is important to consider that the direct assessment and above/below studies in this project took place during low flow. Good comparisons are between the results of FishXing at low flow and the field methods, and between the results of Composite Screen low flow factors and the field methods. Another issue is that FishXing uses the average velocity in the culvert to assign velocity barrier status. Detailed measurements of velocity diversity inside the culvert were not recorded at the Seeley sites - these culverts were largely scrutinized at low flow when velocity was less of a concern. Additional comments concerning velocity barriers are discussed in Appendix A.

Fish in the Seeley basin were observed to navigate fairly shallow water in the stream and in culverts, indicating that the low flow depth used in FishXing for this setting should be set at 0.1 ft or 0.3 ft for juvenile and adult fish, respectively.

The direct passage assessment indicated that more fish passage occurred during low flow than may have been expected, and the abundance sampling results gave little evidence to indicate that many of the culverts were functioning as barriers to fish passage. However, there was ample evidence indicating that passage was *restricted*, not *prohibited*, at many of the culverts at low flow. Furthermore, high flow was not examined in detail at the field sites in this study. The authors look forward to studies ongoing at the time of this writing where high flow barriers and the extent to which fish passage is adequate are continued topics of interest.

Recommendations and Implementation

Recommendations for implementation stem from three important observations. First, if FishXing or a contemporary screening instrument indicates that a culvert is passable for fish in the setting studied here, it probably is. Implementation of this observation would be to set culverts that are otherwise functional and classify as passable using FishXing on low priority for repair or replacement. Secondly, culverts with natural substrate, such as open arch or partially filled culverts, tended to grade well with respect to fish passibility using FishXing, the composite screen and field observations. Implementation of this observation would be to construct new culverts in this manner when economically feasible and when appropriate from other traditional standpoints, such as water and debris conveyance and traffic load capacity. Lastly, culverts that graded as barriers using FishXing or the composite screen in this setting were not always found to be barriers when assessed using field observations - some were and some were not. Implementation of this observation would be to consider FishXing or contemporary screening tools as a first cut when prioritizing culverts for rehabilitation or replacement. Culverts that from standpoints other than fish passage are prioritized equally for replacement and have been indicated to be potential barriers based on FishXing or contemporary screens should then be subjected to at least some level of field observations for final ranking.

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Appendix A

Comments on Mean Velocity as Passage Barrier Indicator

There is mounting evidence that the velocities in culverts are very diverse spatially, and that fish can locate pathways of low velocity in a culvert that demonstrates a high average velocity. An example is shown in Figure A-1, where a plan view of a concrete box culvert on Mulherin Creek in the Yellowstone basin is shown. Velocities were measured at a depth of 0.2 ft above the culvert floor. The average velocity at the culvert inlet was 5.74 ft/sec and the average velocity at the outlet was 10.38 ft/sec. Fish were observed to pass through this culvert, perhaps by following the pathway indicated where the average velocity along the path was only 4.76 ft/sec.

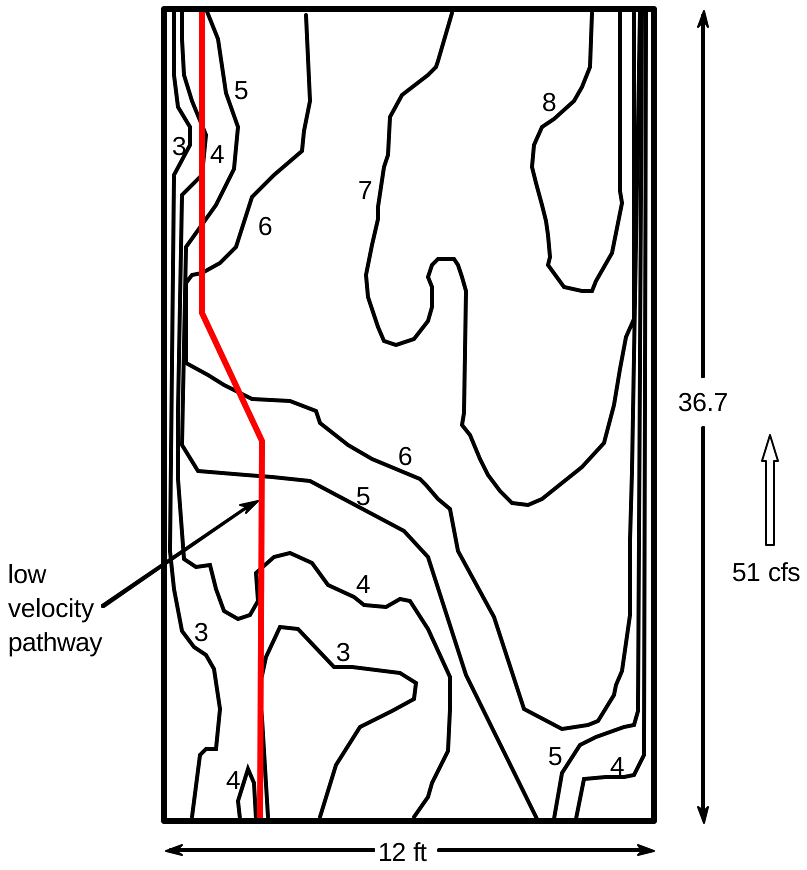

Figure A-1. Plan view of velocity (ft/sec) contours in a box culvert in the Yellowstone drainage, Mulherin Creek, culvert #1, July 13, 2004. Velocities measured on a plane 0.2 ft above the floor of the concrete box culvert

Although a culvert may be passable even with a high average velocity because of low velocity pathways, it is interesting to note that such a culvert can still be a barrier to fish passage for many fish. In the time period from June 16, 2004 to July 8, 2004 when the mean velocity at the site shown in Figure A-1 was very high, visual observation of fish passage attempts were made. During that time period, 91 attempts were made by fish trying to jump into the culvert, 34 successfully made the leap into the culvert, and 18 successfully leapt into the culvert and continued on their way (were not washed back out). This could indicate that when the mean velocity in the culvert is high, fish are less successful in finding a pathway that leads through the culvert than when the mean velocity is low, even if a relatively low velocity pathway exists.