HYDRAULIC STREAM-SIMULATION DESIGN OPTION FOR CULVERT CONSTRUCTION IN EASTERN WASHINGTON TO MEET FISH PASSAGE CRITERIA: HOW BIG IS BIG ENOUGH?

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To the Faculty of Washington State University:

The members of the Committee appointed to examine the thesis of Kathryn Michelle Mozes find it satisfactory and recommend that it be accepted.

Chair

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Abstract

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In the Pacific Northwest, the survival and restoration of anadromous salmon and other Endangered Species Act listed species have been a concern with access to habitat being identified as one of the critical issues. Inadequately designed culverts can prohibit fish from accessing vital habitat. State agencies in Washington found 1,676 impassable culverts just at state road crossings. The preferred method these organizations are using to size replacement culverts for fish passage is the stream-simulation design method. In this method, the width of the culvert bed must be equal to 1.2 times the bankfull width of the channel plus two feet. As a result, culverts are much wider than the stream channel and very expensive to implement. The objective of this research was to evaluate the trade-offs between culvert replacement cost and the percent of time passable for fish. Using the program FishXing, average barrel velocities and water depths as a function of discharge were calculated for fifteen circular culverts in Eastern Washington deemed impassable in the fish passage barrier removal program. Based on estimated daily average stream flows for an entire year, the amount of time each culvert was passable for fish was compared to the construction costs for a series of culvert diameters so that

culvert costs versus the number of days that fish were not able to pass through the culvert over the course of a typical annual hydrograph could be examined. Additionally, the days that fish were not able to pass through the culvert were compared to migratory periods for different fish species. As culvert diameter increased so did construction costs for all fifteen culverts. For eight of the culverts the weakest swimming fish increased passability as the culvert diameter increased while the strongest swimming fish were able to pass during all flows. For the other seven culverts the strongest swimming fish's passablity decreased as culvert diameter increased while the weakest swimming fish's passablity increased. This research will allow decision makers to examine the trade-offs between the cost and the percent of time passable for fish to more effectively prioritize how restoration dollars are being spent.

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DEDICATION

This thesis is dedicated to my parents, husband and friends
who have continuously encouraged and supported me
throughout this entire process

1.0 INTRODUCTION

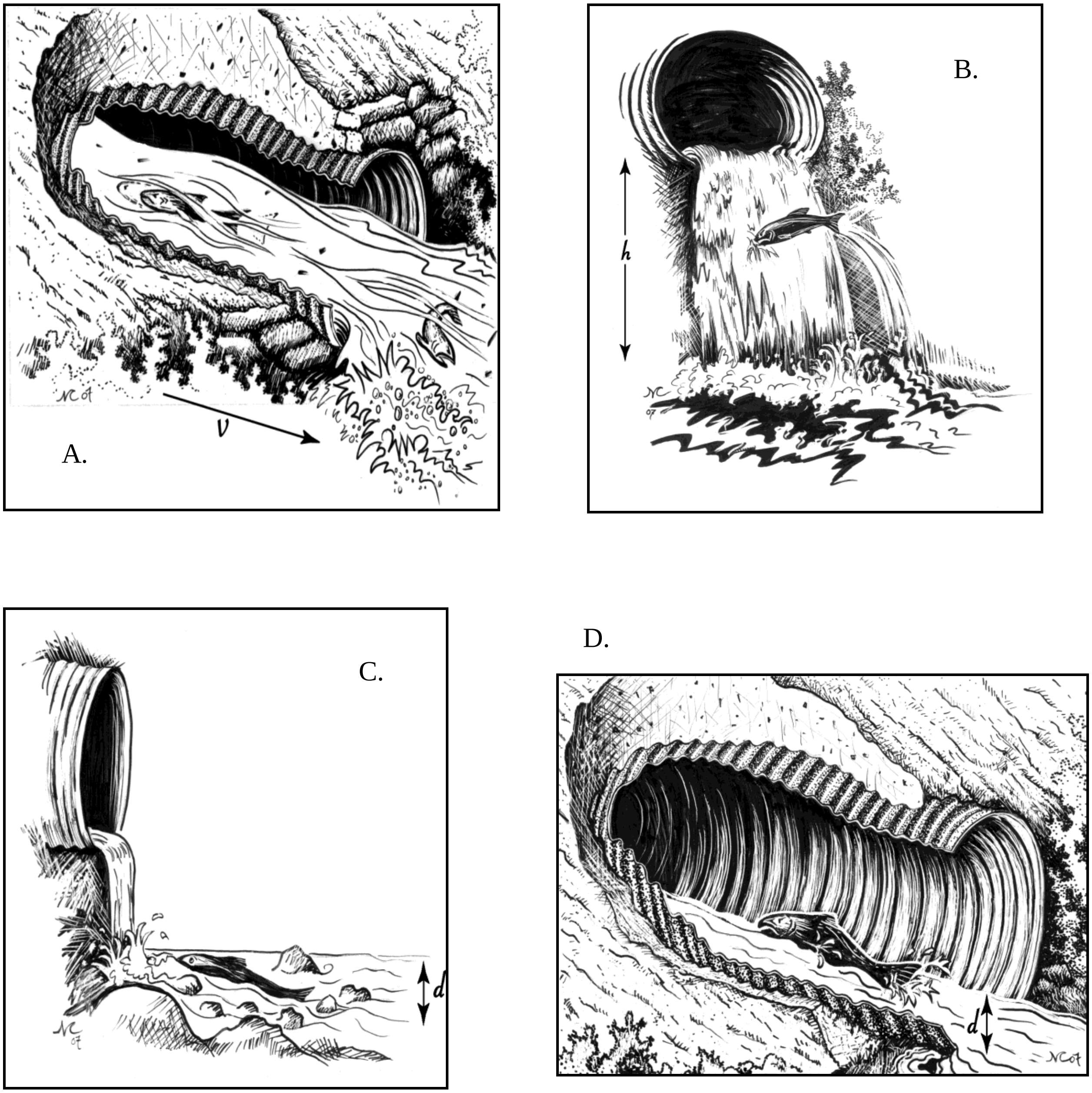
Around the world's oceans, fish populations have been declining at an alarming rate with many species on the verge of collapse due to various factors (Hendrey, 1987; Baker and Votapka, 1990; De Lafontaine et al., 2002; Diamond et al., 2002; Rieman et al., 2003; Cucherousset et al., 2007; Gutberlet et al., 2007; and Kapitzke, 2007). For example, a study conducted in the Swedish Mountain Range concluded that there was a direct correlation between increased acidification and the degradation of habitat and fish species throughout the mountain range (Olofsson et al., 1995). Soto-Galera et al. (1999) examined changes in the long-term distribution of fish in relation to water quality and quantity in the Rio Grande de Morelia-Lago de Cuitzeo basin in Mexico and found that 16 species of the 19 native fish species had declined in distribution. In addition, 5 of the species had been extirpated and 2 species were presumed extinct. These declines were attributed to increases in pollution as a result of the rapidly growing human population. A 2003 study concerning the declining fish populations in Korea concluded that global regulations, technological advances in fishing, national economic development policies, land reclamation projects and pollution have all contributed to the declining populations (Cheong, 2003). Also, the declining population of Atlantic salmon prompted a study to determine if stream crossings met Canadian government regulations on a new section of the Trans Labrador Highway in the province of Newfoundland and Labrador. This study found that 53 percent of culverts were barriers for fish passage. As a result, many of the stream crossings were redesigned based upon state regulations, and careful monitoring is being administered during the final phases of the Highway construction to insure that there is minimal disturbance of habitat during construction (Gibson et al., 2005). To assess the decline of brown trout (*Salmo trutta*) in Swiss rivers, a study was conducted utilizing a Bayesian probability network which found that the suboptimal habitat conditions were most likely a major cause in the declining Brown Trout populations (Borsuk et al., 2006). In another study conducted by Kimirei et al. (2008), the decline of two fish species (*Stolothrissa tanganicae* and *Limnothrissa miodon*) in Lake Tanganyika in Tanzania was attributed to local overfishing and climate change.

In North America, there are concerns over dwindling populations of salmon species (Waddle and Sandelin, 1994; Ligon, 1997; Flosi et al., 1998; Newman, 2000; Wang et al., 2000; National Oceanic and Atmospheric Administration Fisheries Southwest Region, 2001; Lackey, 2003; Lackey, 2004; Botsford et al., 2005; and Krkosek et al, 2007). According to Haines and Baker (1985), some 200 to 400 lakes throughout the Adirondack Mountain region of New York have lost fish populations from acidification. Additionally, Kareiva et al. (2000) attribute the construction of four dams along the lower Snake River to the decline of the River's salmon populations. Declines of some native species have become so severe that they are now listed as threatened or endangered under the US Endangered Species Act (ESA) (Endangered Species Act of 1973). Challenges to managing salmon populations involve habitat, harvest, hydropower, and hatcheries (Mathur et al., 1997; Davis, 1998; Bates et al., 1999; Northwest Power Planning Council, 2000; and Ford and Myers, 2008).

In terms of habitat, access to valuable upstream tributary habitat is essential to the survival of many anadromous salmon and resident fish species (Frissell, 1998; Love, 2001; and FishXing, 2006). Many fish species migrate upstream and downstream during their life cycle seeking a variety of habitat. For some species, this migration is vital for survival (United States Department of Agriculture, 1990). The smaller streams located in the upper reaches of rivers often consist of the best spawning and rearing habitat for salmonids and resident trout (Flosi, 1998; Love, 2001). These streams usually contain steeper channel gradients than larger rivers which can create a pool and riffle sequence. In addition, smaller tributaries produce cooler water than the main rivers because of the inflow from cold springs and the dense canopy covering the small channel (Love, 2001). This creates valuable summer habitat for rearing juveniles as well as spawning grounds for adults.

Inadequately designed culverts can prohibit fish from accessing vital habitat. Fisheries, biologists and engineers have long recognized the need to incorporate fish passage at culverts into their designs (Shoemaker, 1956; Ziemer, 1961; Slatick, 1970; Evans and Johnson, 1972; Engle 1974; and Evans and Johnston, 1980). Recent evidence, however, suggests that earlier criteria may not have been adequate or fully implemented at a scale that would ensure upstream access in many instances (Kay and Lewis, 1970; Metsker, 1970; Lowman, 1974; Dane, 1978; Derksen, 1980; Kane and Wellen, 1985; Powers and Orsborn, 1985; Laird, 1988; Baker and Votapka, 1990; Fitch, 1995; Belford and Gould, 1996; Kahler and Quinn, 1998; Taylor and Love, 2001; Barnard, 2003; and Hotchkiss, 2007). An improved understanding of fish behavior coupled with increased concerns over the survival and the sustainability of fish populations around the world has caused resource managers to begin to initiate action by re-examining barriers to voluntary migration.

There are various factors which create problems for fish migration through culverts. For example, some culverts are beginning to rust or collapse as a result of age and/or lack of maintenance. However, the majority of the barrier problems come from hydraulic issues such as increased velocities, shallow depths, excessive plunge pools and perched culverts (Figure 1). These factors become barriers in relation to the swimming speeds of fish. The swimming speeds of fish are divided into three categories: 1) cruising speed, 2) sustained (or prolonged) speed, 3) and burst speed (Bell, 1973; Dane, 1978; United States Department of Agriculture, 1990; Peake et al., 1997; and FishXing, 2006). The cruising speed is the speed that a fish species can maintain for a long period of time without tiring. The sustained speed of a fish species is the speed the fish can maintain for a long period of time (typically minutes or hours) but ends in fatigue. Burst speed is the highest attainable speed by a fish species and can only be maintained for a short period of time (usually only seconds) (Beamish, 1978 and United States Department of Agriculture, 1990). If the velocities are too high in a culvert a fish may have to swim at burst speed and will become exhausted before it completely passes through, resulting in the culvert becoming impassable. If a culvert is very long and the excessive velocities cause a fish to swim in prolonged mode, then they may not reach the end of the culvert before they become exhausted. In addition, if the plunge pool is too shallow and/or a culvert is perched too high, then the fish may not have enough room to gain speed to jump into the culvert, also resulting in the culvert becoming impassable.



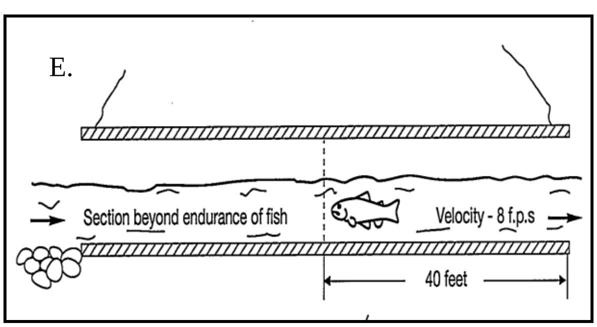


Figure 1: Culverts can be barriers to fish in a variety of ways A) excessive velocities, B) jump too high into culvert, C) no resting pool below culvert, D) insufficient depth inside culvert (Furniss, 2007), and E) length beyond endurance of fish (Gebhards and Fischer, 1972)

To address concerns regarding culvert blockage of habitat in the state of Washington and in response to an assessment that found 1,676 impassable culverts just at state road crossings, the Washington State Department of Fish and Wildlife (WDFW) partnered with the Washington State Department of Transportation (WSDOT) to establish a fish passage barrier removal program. Thus far, WSDOT has only replaced approximately 12% of these culverts so considerable more work needs to be done (Barber et al., 2007). Moreover, because numerous impassable culverts exist at locations other than at state highway crossings, additional partnerships have been developed periodically throughout the implementation of this fish passage barrier removal program such as with the Washington State Department of Natural Resources (WDNR) and the Salmon Recovery Funding Board (SRFB) (WDFW, 2005 and WDFW, 2007). The preferred design methodology these organizations are using to replace culverts that prohibit fish passage is called the stream-simulation design method (SSDM). The SSDM always results in culverts that are much wider than the channel bankfull width and are thus very expensive to implement. Furthermore, the scientific justification for using the bankfull width has not been well documented in the literature. The objective of this research was to develop a procedure for determining culvert replacement costs versus the percent of time the culvert is fish passable in so that regulators can evaluate the trade-offs.

To help answer this objective, fifteen circular culverts in Eastern Washington deemed impassable in the fish passage barrier removal program were analyzed using the program FishXing (FishXing, 2008). Field data from existing culverts such as elevations, diameter, length, and slopes were collected at each location. Based on stream flows and field measurements of existing culvert characteristics, the amount of time each culvert would be passable for the strongest and weakest swimming adult fish species for each culvert was determined for various culvert diameters. Corresponding construction costs were also determined for each culvert bed width. The trade-off between culvert costs based on size and the number of days that the fish were not able to pass through was examined. Additionally, the days that fish were not able to pass through over a typically average annual hydrograph were compared to the migratory periods for different fish species. This research will allow decision makers to examine the trade-offs between the cost and the percent of time passable for fish to more effectively prioritize how restoration dollars are being spent.

2.0 BACKGROUND

2.1 Review of Previous Work

Restoration of declining salmon and trout populations is extremely important in the development of management plans for water bodies across the nation. However, one of the major problems that these fish populations face is an inability to utilize their historic rearing and spawning grounds because of the fish passage barriers that block their access to the upstream habitat. One of these barriers has been identified as culverts (Thompson, 1998; WDFW, 2000; GAO, 2001; Cahoon et al., 2005; Gibson et al., 2005; Wheeler et al., 2005; Barber et al., 2006; and MacDonald and Davis, 2007). A culvert is a hydraulically short conduit placed under a road embankment or some other type of flow obstruction to pass streamflow under the obstruction (Crowe et al., 2005; Mays, 2005; and WDOT, 2006). Many small streams in the Pacific Northwest flow under roads through culverts, where the very presence of a culvert has an impact on stream habitat.

The work done to rectify the problem of culverts as a passage barrier includes efforts to better understand the impacts of road development, different culvert design methods, various model development, and culvert design alterations such as the addition of baffles. For example, Hotchkiss and Frei (2007) created a design reference for the classification, assessment, design and/or retrofit of a roadway-stream crossing to facilitate fish passage. In addition, the American Fisheries Society published a book detailing the many interactions between forest management practices, freshwater aquatic habitats, and the fishes that need them (Meehan, 1991). In 1997, Warren and Pardew examined the effects of four types of road crossings (culvert, slab, open-box, and ford crossings) on fish movement and concluded that overall fish movement was an order of magnitude lower through culverts than through the other crossings or natural reaches (Warren and Pardew, 1997). Latterell et al. (2003) examined the physical constraints on trout (*Oncorhynchus spp.*) distributions in the Cascade Mountains on logged and unlogged streams. During the study it was found that the upstream extent of trout distributions appeared to be resilient to the combined impacts of both historic and current forest management activities, with the exception of impassable road culverts. Another study was done to better understand the impacts of new highways and subsequent landscape urbanization on stream habitat and biota. Wheeler et al. (2005) stated that impacts were often assessed initially during construction phases but were then ignored over the long-term. They added that a much more detailed understanding of how culverts affect fish population movement and how highway networks alter natural regimes was needed (Wheeler et al., 2005).

Different culvert design methods are being implemented by various organizations. For example, the British Columbia Ministry of Transportation and Highways produced a document that outlines various design parameters such as culvert length and grade, inlet and outlet controls, culvert alignment, scheduling, site clearing, and control of sediment and debris (British Columbia Ministry of Transportation and Highways, 2000). According to the document, a culvert's grade may not exceed 0.5% if the culvert is greater than 24 meters in length, 1.0% if a culvert is less than 24 meters in length, or 5.0% at any time (British Columbia Ministry of Transportation and Highways, 2000). The National Marine Fisheries Service-Southwest Region (NMFS-SWR) and the California Department of Fish and Game (CDFG) recommend three different designs: 1) the active channel design method, 2) the stream-simulation design method, and 3) the hydraulic design method (National Oceanic and Atmospheric Administration Fisheries Southwest Region, 2001 and CDFG, 2002). The active channel design method is a simplified method which does not require determination of high and low fish passage design flows, water velocity, and water depth. The intent of this method is to size culverts sufficiently large and embed them deep enough into the channel to allow the natural movement of bedload and formation of a stable streambed inside the culvert (CDFG, 2002). Both the stream-simulation design and hydraulic design methods are utilized in Washington State and will be discussed in more detail later.

The Maine Department of Transportation states that in order to pass fish effectively through a culvert, the culvert must satisfy four objectives: 1) pass the design peak flow event (typically 50-year for culverts < 10 ft in diameter and 100-yr for larger structures), 2) not exceed a specified flow velocity representing conditions during periods of upstream movement, 3) maintain a minimum depth for fish movement at a specified flow representing low flow conditions when fish may be moving, and 4) maintain channel elevation between stream bed and pipe at inlet and outlet through which fish can easily pass (no excessive drops) (Maine Department of Transportation, 2004).

Various models have been developed and tested which simulate the effects of stream crossing construction on fish populations. Swimming performances of six migratory fish species were examined against controlled water velocities in a large, open-channel flume to develop models of the maximum distance traveled of each species during their burst phase by Haro et al. (2004). House et al. (2005) developed a model which estimated the percent of a cross section that was within the swimming abilities of juvenile fish developed from velocity measurements on first-generation stream simulation culverts. O'Hanley and Tomberlin (2005) developed a decision-making approach based on integer programming techniques to optimize the priority decision making for culvert barrier repair and removal. Another model, FishXing, is a software tool designed to help engineers, fish biologists, and hydrologists in the assessment and design of culverts for fish passage (FishXing, 2008). This program is widely used all over the United States and Canada (British Columbia Ministry of Forests, 2002; Bates, 2003; Lang et al., 2004; Cahoon, 2005; and Clarkin et al., 2006). Although there are other hydraulic evaluation models (such as CulvertMaster, 2000; HEC-RAS, 2004; and FHWA, 2007), they do not incorporate the swim performance information that FishXing offers. Therefore, additional calculations comparing fish swimming performance to the hydraulic properties in the culvert are required for these other models (Clarkin et al., 2005).

Adding baffles to culverts is often considered to dissipate stream flows for high slope design or for remedial work on existing culvert stream crossings. Zrinji and Bender (1995) conducted an experimental risk evaluation for baffled culvert fishway design. They used a form of sensitivity analysis of interdependent variables to evaluate a field-tested baffled culvert design for freshwater fish. They state that the design approach moves fish passage evaluation from post-design adaptations to pre-design alternatives. MacDonald and Davies (2007) studied the impacts that baffles had on jollytail (*Galaxias maculates*) and spotted galaxias (*Galaxias truttaceus*) passage through a culvert. They found that both species had the most successful passage with a complex baffle arrangement. However, they also showed that passage was much improved with smaller baffles in a non-complex arrangement and suggested using those as a more cost-effective option (MacDonald and Davies, 2007). Additionally, Thurman et al. (2006) conducted a study on juvenile salmon passage in sloped-baffle culverts to establish hydraulic guidance to help biologists and engineers to improve baffle design to aid juvenile salmon migration. They built a culvert test bed facility at Washington Department of Fish and Wildlife Skookumchuck Rearing Facility to test fish passage success and study the hydrodynamic regimes induced by the baffles.

2.2 Overview of Problem in the Pacific Northwest

Numerous studies have been conducted to understand and remedy the fish passage problem as shown above. In the Pacific Northwest, barrier culverts have become a main concern particularly due to their impact on ESA listed species such as salmon and Bull Trout. Bowler (1984) conducted a study on the effects of roadways on fish in Idaho and found that there was a correlation between road building used to access trees for harvesting and declining fish populations in Northern Idaho and Eastern Washington. Many roads were built over streams, resulting in constructed road crossings that became barriers. In addition, Bowler found that logging caused hydrograph modifications and produced warmer stream temperatures because of less vegetation cover over the streams.

There are many negative impacts a culvert may have on a dynamic stream environment. Five common conditions at culverts which create migration barriers for fish are: excess drop at the culvert outlet, high velocity within the culvert barrel, inadequate depth within the culvert barrel, turbulence within the culvert, and debris and sediment accumulation at the culvert inlet or internally (Bates et al., 2003). This has become such a problem in Washington and Oregon that the United States General Accounting Office (GAO) submitted a report recommending action be taken to mitigate the problems in current culvert conditions on federal property in these states (GAO, 2001). The GAO report details the Bureau of Land Management (BLM) and the United States Forest Service's (USFS) concerns with the condition of culverts on fish bearing streams on the over 41 million acres of federal lands in Oregon and Washington (GAO, 2001).

Recognizing the problem of culverts as fish passage barriers, the WSDOT and the WDFW have collaborated to record and, over time, fix all the fish passage barriers at state highway crossings in Washington. In 1991, WSDOT allocated funding from the Highway Construction Program to contract the Washington Department of Fisheries (since then the Department of Fisheries has merged with the Department of Wildlife to become WDFW) to conduct a study of prioritizing state route barriers that needed to be corrected. The Washington Department of Fisheries found about 1,700 fish passage barriers just at state highway crossings and has recorded 205 barriers fixed as of 2007 (Table 1). Over the course of the inventory, WSDOT spent over $45.5 million to conduct habitat studies, prioritize, and correct fish passage (Barber et al., 2007) and will need to spend much more to complete the effort. In addition, the BLM's and the USFS's ongoing investigation identified nearly 2,200 barrier culverts on federal forest lands in Oregon and Washington, as of August 2001. They estimate that once the investigation is done, around 4,800 culverts will have been identified as barriers (GAO, 2001). According to BLM officials, the estimated total cost to eliminate their backlog of around 700 barrier culverts is $46 million, while Forest Service officials estimate a total cost of about $331 million to eliminate its backlog of approximately 4,800 barrier culverts. In addition, at the current rate of replacement, BLM officials estimate that it will take 25 years to restore fish passage through all barrier culverts and USFS officials estimate that they will need more than 100 years to eliminate all barrier culverts (GAO, 2002). Although a comprehensive assessment of private timber company lands has not be conducted, research and evaluation efforts by timber companies like Plum Creek Timber suggest that barrier culverts are a potentially bigger problem than presently understood (Sugden, 2007).

In 2004, the cost-share program, the Family Forest Fish Passage Program, was established to assist family forest landowners in correcting fish barriers associated with forest roads. The DNR, WDFW, and SRFB work together to implement the program funding 75-100 percent of the cost of correcting small forest landowners' fish barriers. As of 2007, the program has funded 152 barrier removal projects, spending a total of $9.73 million, reopening about 351 miles of upstream habitat for fish. They currently have approved over 300 additional projects and receive new applications for projects daily (WDFW, 2007).

Table 1: Estimated number of fish bearing crossings and barrier crossings requiring fish passage repair based on the WSDOT expanded fish passage inventory (Barber et al., 2007)

Source	Fish-Bearing Stream Crossings	Fish Passage Barriers	Barriers with Significant Habitat Gain	Barriers with Limited Habitat Gain[1]	Barriers with Habitat Threshold Gain Not Determined	Barriers Fixed[2]
WDFW 2006 Fish Passage and Diversion Screening Inventory Database	3,142	1,676	1,266	363	47	205
Extrapolated[3] data Total	3,238	1,758	1,328	382	48	

[1] Barriers that do not meet current WDFW threshold habitat gain criteria to justify correction using dedicated funding until higher priority barriers are corrected.
[2] Two hundred and five WSDOT fish passage barriers have been reported as replaced or retrofitted for fish passage; however, 45 of those require additional work to meet current fish passage criteria.
[3] Estimated statewide numbers based upon inventories conducted through March 2007.

The culvert design guidelines that are depicted in the Washington State Administrative Code (WAC) are included under WAC 220-110-070. The WAC outlines the design limitations for satisfying adult fish passage requirements of water crossing structures where fish are present (Table 2). Two options to meet fish passage criteria are described in the WAC: (1) the no-slope design option and (2) the hydraulic design option. A third option, preferred by the WDFW and used extensively by the WSDOT (although not currently outlined in the WAC) is the stream simulation design method (SSDM). A flow chart of the design process is presented in Appendix A-1. Additional details on the no-slope design and the hydraulic design options are presented in Appendix A-2 and Appendix A-3, respectively. Since the major focus of this research is on the applicability of the SSDM, that procedure is described in detail in the next section.

Table 2: Fish Passage Design Criteria for Culvert Installation (WAC 220-110-070)

Criteria[1]	Adult Trout > 6 inches (150 mm)	Adult Pink, Chum Salmon	Adult Chinook, Coho, Sockeye, Steelhead
1. Culvert Length (ft)	Maximum Velocity (ft/sec)		
a) 10 – 60	4.0	5.0	6.0
b) 60 – 100	4.0	4.0	5.0
c) 100 – 200	3.0	3.0	4.0
d) greater than 200	2.0	2.0	3.0
2. Flow Depth Minimum (ft)	0.8	0.8	1.0
3. Hydraulic Drop, Maximum (ft)	0.8	0.8	1.0

[1]Table adapted from WAC 220-110-070 (WAC, 2000)

2.3 Stream Simulation Design Method (SSDM)

The SSDM is used to create and/or maintain natural stream processes in a culvert. This design is becoming the preferred method in the WSDOT fish passage barrier removal program. According to WDFW and WSDOT, with the SSDM option, fewer calculations are required (Bates et al, 2003). These agencies explain that by using this design option, it eliminates the need to consider certain parameters like target species, timing of migration, and fish-passage hydrology. In addition, they argue that the criterion such as velocity and depth that is required in the hydraulic design option does not have to be calculated (Bates et al., 2003). In this design method, the equation used to determine the culvert bed width is:

$$W_{culvertbed} = 1.2W_{ch} + C \qquad (1)$$

where $W_{culvertbed}$ is the width of the bed of the culvert, W_{ch} is the width of the bankfull channel, and C is a safety factor equal to 2 feet (English) or 0.61 meters (metric).

Bankfull width of a channel is defined as the stage when water just begins to overflow into the active floodplain, with a flow recurrence interval of about 1 to 2 years. It is usually associated with a change in vegetation, topography, or sediment texture (Bates et al., 2003 and Hotchkiss, 2007). Utilizing this equation results in culverts that are much wider than the channel width (often resulting in bridges) and very expensive to implement. While relatively simple to design, the scientific rationale for such size requirements is not well documented and will likely be scrutinized in the future due to the high cost to taxpayers. Moreover, this policy may not be palatable for private landowners without sufficient and well documented justification. This design has led to restoration projects such as in Skobob Creek (Figure 2) and Taylor Creek (Figure 3). The Skobob Creek box culvert (1.83 meters wide) was replaced with a 37 meter wide single span bridge. The total cost of the project was $1.8 million, creating 18,210.9 meter^2 (4.5 acres) of rearing habitat to salmonids and resident trout. The Taylor Creek culvert was changed from a 1.52 meter wide concrete culvert to a full-span bridge. The total cost of the project was $2.14 million, creating 3,300 meters of potential habitat for salmonids and resident trout.

Figure 2: Skobob Creek (crossing SR 106), 1.83 m wide concrete box culvert replaced with a 37 m wide single span bridge (Barber et al., 2006)

Figure 3: Taylor Creek (crossing SR 18), 1.52 m wide concrete round culvert replaced with a full span bridge for $2.14 million (Barber et al., 2006)

3.0 RESEARCH METHODS

3.1 Data Collection

WSDOT has compiled a state-wide Fish Passage Inventory List of inadequately designed culverts. There are currently about 300 identified fish passage blockages at WSDOT crossings in eastern Washington (Barber et al., 2007). Culverts were chosen from the inventory list based on four factors: 1) location, 2) size, 3) water surface drop, and 4) culvert shape in order to minimize the number of variables that would need to be evaluated during this research. The locations were selected to guarantee spatial variability and a wider variety of fish species and timing requirements. Larger culverts were chosen over smaller culverts. For consistency, only round culverts with little or no water surface drops were selected for analyses. Additionally, culverts that were dry certain times of the year were not evaluated. The focus was on Eastern Washington, so culverts were chosen from only the North Central, Eastern, South Central, and Southwest (Klickitat county only) WSDOT regions (Figure 4). Fifteen culverts in Eastern

Washington deemed impassable in the WSDOT fish passage barrier removal program were analyzed as part of this research. The locations of the study sites are shown in Figure 5 and correspond to the # column in Table 3. The culverts are pictured in Appendix C.

Each culvert was surveyed and gaged to determine culvert dimensions, streambed and culvert slopes, elevations, water-surface levels, and water discharge. The equipment used to survey and gage each culvert included a Leica TPS400-3 total station, a Pygmy velocity meter, and a Price AA velocity meter. Table 3 summarizes the data that was collected.

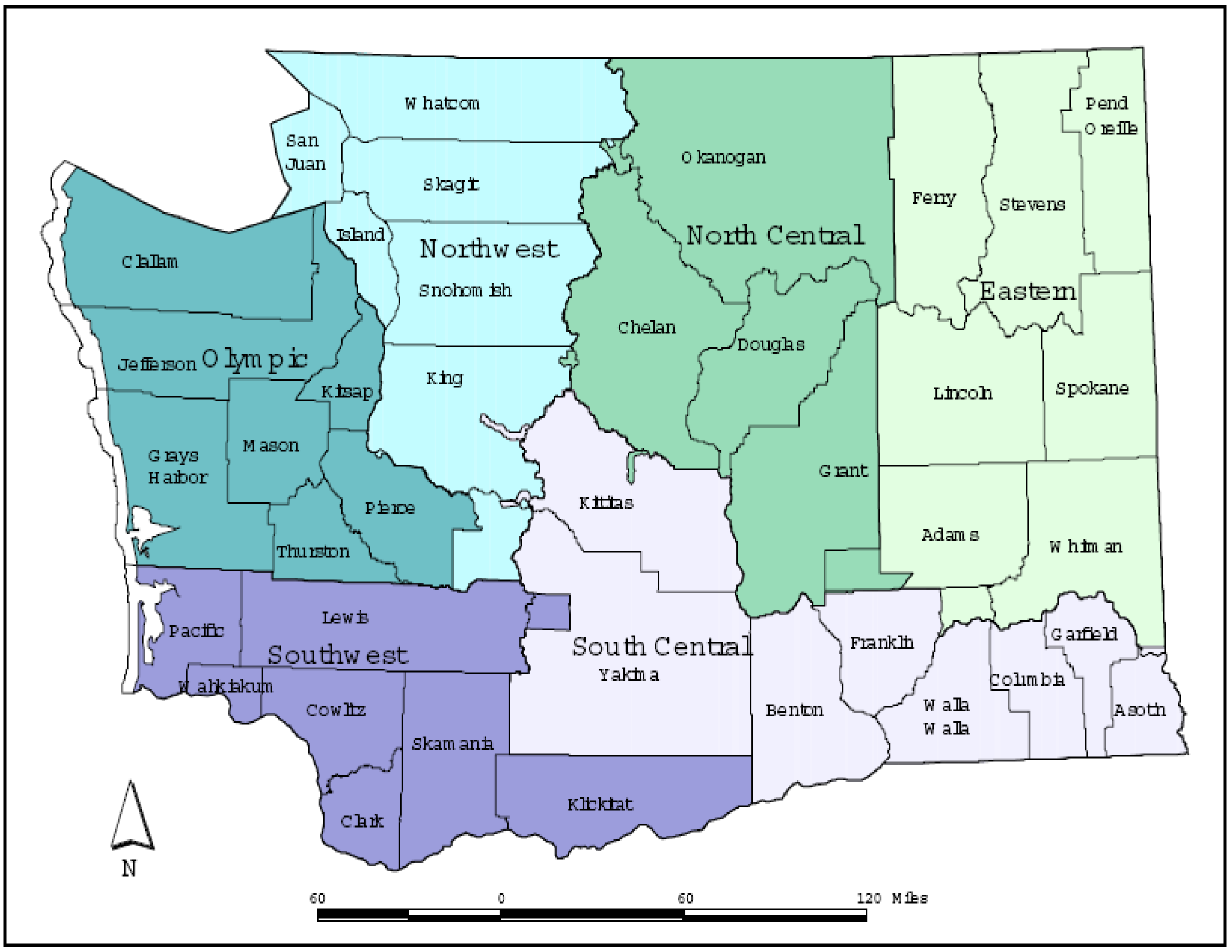


Figure 4: Washington Department of Transportation's defined regions for the WSDOT Fish Passage Inventory done by Washington State Department of Fish and Wildlife

Table 3: Data collected during survey work for each culvert

#	Stream	Road	Mile Post	Material	Diameter (ft)	Length (ft)	Slope (%)	Embedded	Outlet Bottom Elevation[1]	Inlet Bottom Elevation[1]	Discharge (cfs)[2]
1	Beebe Creek	US 97	235.30	Corrugated Steel	4.50	142.76	2.13	No	990.60	993.64	14.19
2	Byrd Canyon Creek	97 AR	220.76	Precast Concrete	3.00	158.63	3.26	Yes	990.96	996.14	0.18
3	Crab Creek Wasteway	SR 26	29.87	Corrugated Aluminum	6.50	67.36	0.82	No	992.01	992.56	No Data[4]
4	Crab Creek Wasteway	SR 26	29.95	Corrugated Steel	3.00	87.99	9.00	No	984.08	992.00	No Data[3]
5	Curlew Creek	SR 21	174.35	Corrugated Steel	6.00	44.95	0.87	No	989.45	989.84	6.04
6	Matsen Creek	US 395	249.90	Precast Concrete	4.00	100	5.00	Yes	993.37	998.37	0.28
7	Mill Creek	SR 142	25.32	Corrugated Steel	6.50	47.9	1.50	No	988.15	988.87	3.40
8	Summit Creek	SR 20	215.96	Corrugated Steel	3.00	374.67	6.80	Yes	990.91	1016.39	0.38
9	Tallant Creek	SR 20	225.60	Precast Concrete	5.00	85.04	1.70	No	992.73	994.18	7.66
10	Tallant Creek	SR 20	224.40	Precast Concrete	3.50	73.17	5.40	No	989.09	993.04	No Data[4]
11	Thorton Creek	I-90	88.42	Precast Concrete	3.00	463.34	10.30	No	994.25	1041.97	0.31
12	Unnamed	I-82	68.32	Precast Concrete	8.75	255.26	0.80	No	983.69	985.73	8.89
13	Unnamed	I-82	72.38	Corrugated Steel	4.00	507.9	0.60	Yes	984.26	987.31	7.75
14	Unnamed	SR 20	208.44	Corrugated Steel	1.50	49.11	6.09	No	989.95	992.94	No Data[3]
15	Whistler Canyon Creek	US 97	328.84	Precast Concrete	3.00	115.81	1.40	Yes	981.00	982.62	No Data[3]

[1] A reference number of 1000 feet was used to determine the culvert outlet bottom elevation of each culvert and then inlet elevations were determined based on the calculated outlet elevations.
[2] A onetime discharge for each stream was determined during survey work to use as a reference when determining daily discharges.
[3] The water was not moving fast enough to gage a flow.
[4] The water was moving too fast to gage a flow.

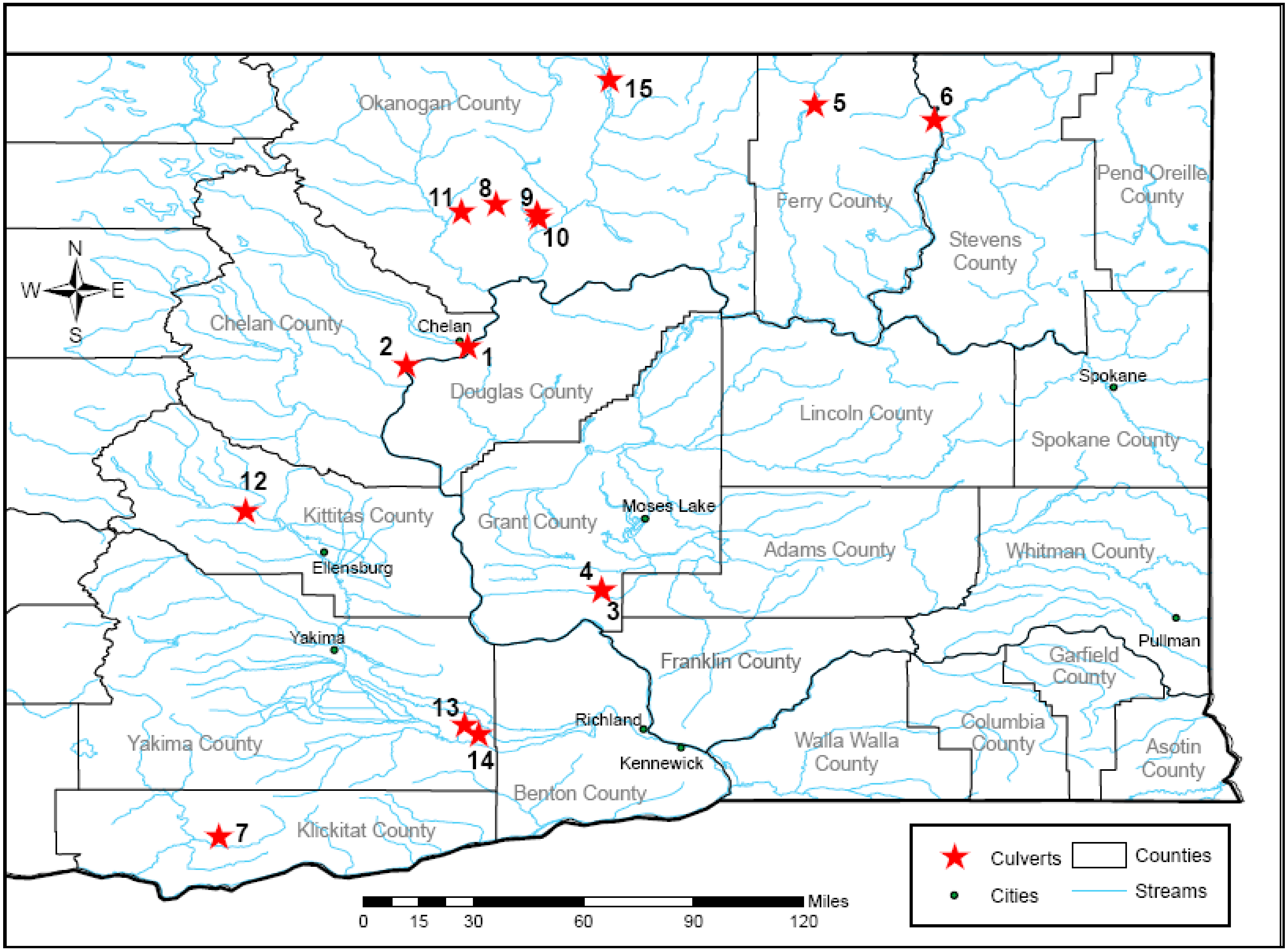


Figure 5: Map of the culverts surveyed throughout Eastern Washington

3.2 FishXing

The field data collected was used in the FishXing program (FishXing, 2008). This program models the complexities of culvert hydraulics and fish performance for a wide variety of species and crossing configurations while also allowing the user to input additional data. As a design tool, FishXing uses the iterative process of designing a new culvert to provide passage for fish. This software models fish capabilities against culvert hydraulics across a range of inputted stream discharges. In addition, water surface profiles can be calculated for a variety of culvert shapes using gradually varied flow equations. The program then compares the flows, velocities and leap conditions with the swimming abilities of the fish species of interest. The output includes tables, graphs, and an animated schematic summarizing the water velocities, water depths, and outlet conditions, then lists the limiting fish passage factors and flows for each culvert design (Pacific Northwest Research Station, 2006). See Figure 6 for the input screen.

In FishXing, the hydraulic calculations from the culvert outlet to the culvert headwater immediately upstream of the inlet are based on the conservation of energy and mass, described by the basic energy balance equation:

$$y_{HW} + \frac{V_{HW}^2}{2g} + \Delta Z = y_{TW} + \frac{V_{TW}^2}{2g} + y_{frictionloss} + y_{exitloss} \qquad (2)$$

where y_{HW} is the head water depth (L), V_{HW} is the headwater velocity (L/T), ΔZ is the change in elevation (L), y_{TW} is the tailwater depth (L), V_{TW} is the tailwater velocity (L/T), and g is the acceleration due to gravity in (L/T^2).

The headwater velocity is low and therefore negligible in most cases. In addition, the tailwater velocity can be neglected if the upstream and downstream channels are similar. FishXing assumes both these parameters and does not include bend losses, junction losses, or grate losses. This reduces the energy equation to:

$$y_{HW} + \Delta Z = y_{TW} + y_{frictionloss} + y_{entranceloss} + y_{exitloss} \tag{3}$$

For determining water depths within the culvert, FishXing solves the appropriate form of the energy equation using a step method. Solutions are then obtained at regular intervals throughout the culvert. The generalized procedure that FishXing utilizes to determine the water surface profile and water velocities within a culvert at the specified flow are (FishXing, 2008):

1) Determine the tailwater elevation at the desired flow
2) Determine boundary conditions for solving the gradually varied flow equations by finding
    a. hydraulic slope
    b. curve type based on hydraulic slope and tailwater depth
    c. if free surface outlet conditions apply, if so:
        i. calculate the location near the outlet that flow switches from gradually varied flow to rapidly varied flow conditions
        ii. determine the water depth at the free surface outlet
    d. determine starting location and depth for the downstream and/or upstream boundary
3) Solve the gradually varied flow or full flow equations to obtain a water surface profile through the culvert
    a. Use backwater calculations for non-steep slopes or backwatered steep slope culverts

b. Use frontwater calculations for steep slopes

c. For steep slopes, check for a hydraulic jump within the culvert

4) Determine headwater depth based on energy losses within the culvert

5) Calculate average cross sectional water velocities within the culvert and the contraction velocity within the inlet zone

6) Calculate outlet plunge characteristics

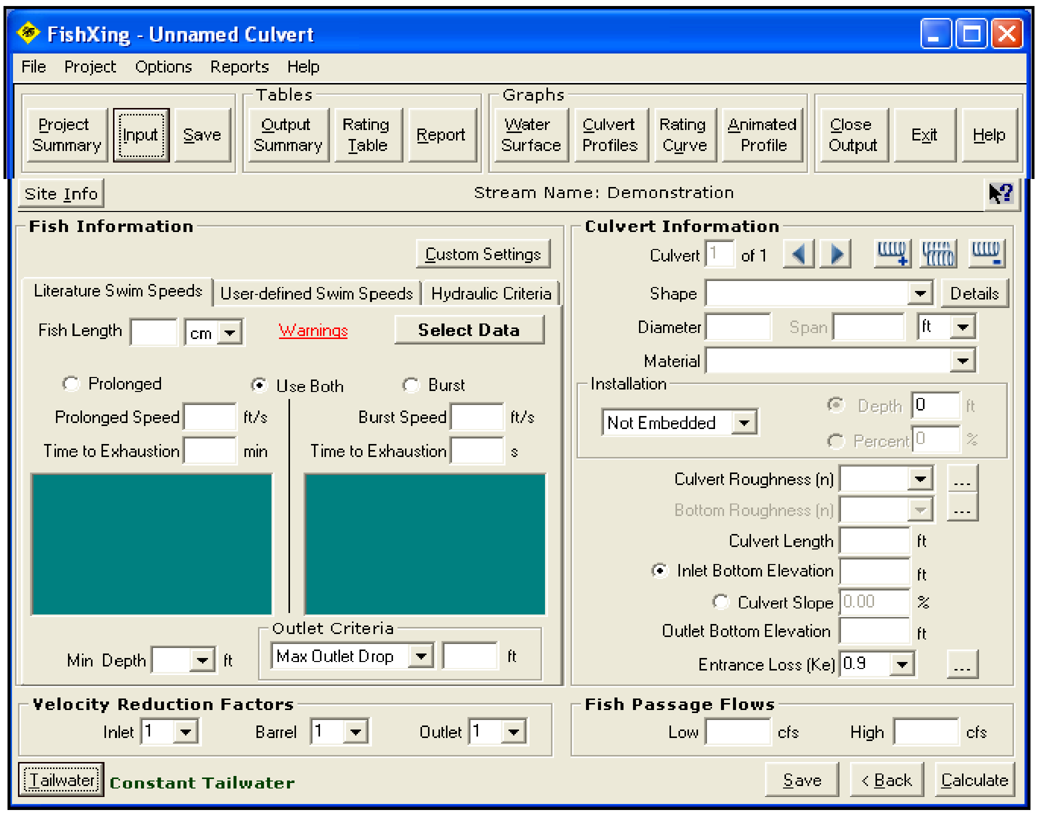


Figure 6: Data input screen for the program FishXing

Initially the user will define the site information under the Site Info tab. This information allows the user to write notes about the culvert, its location, etc. The Culvert Information portion of the input screen window allows the user to specify a culvert's shape, material, size, and placement. The Fish Information portion of the input screen window is used to evaluate fish passage conditions. The user is able to select from three different methods to describe the fish capabilities and fish passage requirements: 1) Literature swim speed, select from a list of swimming abilities that has been compiled from the available literature compiled by FishXing, 2) User-Defined swim speed, the user can specify swim speed data for a specific fish, or 3) Hydraulic criteria, the user can use water velocity, water depth, and outlet drop criteria to assess passage conditions. The Fish Passage Flows portion of the input screen is where the user specifies the Low and High Fish Passage design flows. FishXing generates profiles for each of the flows and examines fish passage conditions at all flows between them (FishXing, 2008).

Two parameters were changed from the current culvert design for calculating the percent of flows passable with new culvert diameters: culvert slope and embeddedness. The culvert slope was changed to simulate the stream's natural slope unless the channel slope was the primary reason for passage failure, in which case it was changed to zero percent for this research. To maintain a zero slope for these channels, upstream and/or downstream controls would have to be implemented (such as a series of weirs at the downstream end of the culvert to back up flow to a higher depth to reach the culvert outlet without a large hydraulic drop). In addition, all culverts were looked at without being embedded into the channel. As a result, the only material inside the simulated new culvert designs was the material of the culvert. If a culvert is embedded within the stream channel material, the velocity changes passing over the material. Depending upon the material used, the water's energy is dissipated and pools and riffles may be created inside the culvert.

3.3 Determining Fish Species

Fish species data was not collected as part of this study during surveying. To determine the fish species in each stream, information from the Pacific States Marine fisheries Commission's StreamNet project (http://www.streamnet.org/) was utilized. StreamNet is a cooperative, multi-agency information management and distribution project focused on fisheries and aquatic related data in the Columbia River basin and the Pacific Northwest. From 2001-2004, the Northwest Power and Conservation Council worked with StreamNet contributors to develop comprehensive subbasin plans throughout the Columbia River basin which included the collection of species distribution data stored in StreamNet. The data is downloadable in shapefile format so that it can be utilized in ArcGIS (ESRI, 2006). To determine which fish species were in the streams of interest for this study, this data was mapped in ArcGIS against stream and culvert placement (Figure 7 and Table 7).

Strongest and weakest fish were determined based on the current research. Watts (1974) compiled maximum speed data of several adult fish species from various research studies (Table 4). In addition, Bell (1986 and 1991) outlines the average swimming speeds of a number of adult fish species (Table 5). The United States Department of Agriculture also compiled fish swimming speed data in their report from 1990 (Table 6). From this information the weakest and strongest fish species were determined for each stream (Table 8).

Once all the data was input in FishXing, the program was run to determine the percentage of design flows that were fish passable for each culvert. The procedure for estimating design flows is explained in the next section.

Table 4: Maximum swimming abilities of various fish species (Watts, 1974)

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

*Hydrotechnical Research Institute of Lenigrad

Table 5: Relative swimming abilities of adult fish (table adapted from Bell, 1991)

Species	Cruising Speed (ft/s)	Sustained Speed (ft/s)	Bursting Speed (ft/s)
Chinook	0 to 4.0	4.0 to 11.0	11.0 to 22
Coho	0 to 3.8	3.8 to 11.0	11.0 to 21.5
Sockeye	0 to 3.8	3.8 to 11.1	11.1 to 21.6
Steelhead	0 to 5.0	5.0 to 14.8	14.8 to 27.0
Cutthroat	0 to 2.7	2.7 to 6.0	6.0 to 13.7
Brown Trout	0 to 2.6	2.6 to 7.2	7.2 to 12.5
Grayling	0 to 2.8	2.8 to 7.3	7.3 to 14.1
Whitefish	0 to 1.8	1.8 to 4.7	4.7 to 9.1
Shad	0 to 3.1	3.1 to 7.9	7.9 to 14.7
Carp	0 to 2.2	2.2 to 4.0	4.0 to 14.3
Lamprey	0 to 1.1	1.1 to 3.2	3.2 to 6.8

Table 6: Swimming capabilities of various fish species (U.S. Dep. Agriculture, 1990)

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

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

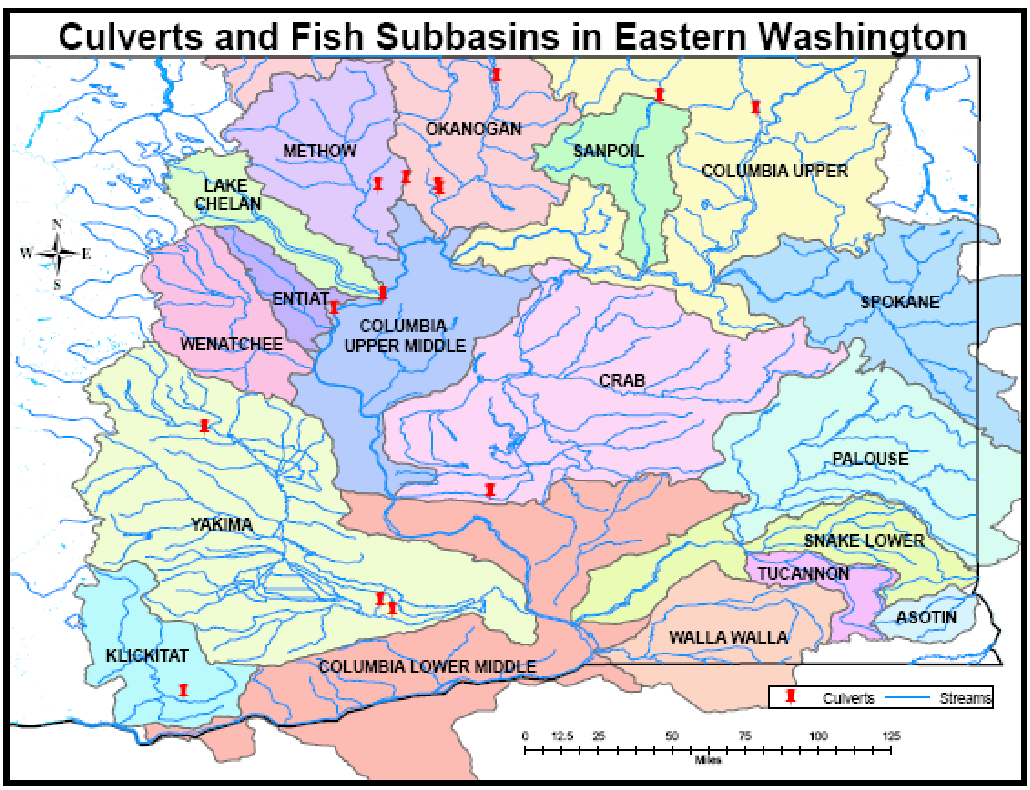


Figure 7: Fish subbasins utilized in the StreamNet Project

Table 7: Fish species recorded during the subbasin plans project through StreamNet

	FISH SPECIES RECORDED IN EACH SUBBASIN																		
Fish Subbasin	Chinook Salmon	Coho Salmon	Landlocked Sockeye Salmon (Kokanee)	Sockeye Salmon	Steelhead	White Sturgeon	Pacific Lamprey	Bull Trout	Rainbow Trout	Redband Trout	Westslope Cutthroat Trout	Largemouth Bass	Smallmouth Bass	Burbot	Walleye	Black Crappie	Mountain Whitefish	Yellow Perch	Bluegill sunfish
Lake Chelan	X		X		X			X			X								
Columbia Upper Middle	X	X	X	X	X	X	X	X	X								X		
Crab	X	X	X		X			X				X	X		X	X		X	X
Columbia Upper	X	X	X	X	X	X	X	X	X	X				X					
Klickitat	X	X		X	X			X	X										
Okanogan	X	X		X	X			X											
Yakima	X	X		X	X		X	X											
Methow	X	X		X	X			X											
Okanogan	X	X	X		X			X											

Table 8: Fish species data utilized in FishXing for each surveyed stream

				Focal Species Used in FishXing		**Used for Weakest Fish**			**Used for Strongest Fish**		
Stream	**Road**	**Mile Post**	**Fish Subbasin**	**Weakest**	**Strongest**	**Small Adult Size (cm)**	**Large Adult Size (cm)**	**Minimum Depth (ft)**	**Small Adult Size (cm)**	**Large Adult Size (cm)**	**Minimum Depth (ft)**
Beebe Creek	US 97	235.30	Lake Chelan	Bull Trout	Steelhead	15	25	0.2	20	75	0.6
Byrd Canyon Creek	97 AR	220.76	Columbia Upper Middle	Bull Trout	Steelhead	15	25	0.2	20	75	0.6
Crab Creek Wasteway	SR 26	29.87	Crab	Sockeye Salmon	Steelhead	15	50	0.2	20	75	0.6
Crab Creek Wasteway	SR 26	29.95	Crab	Sockeye Salmon	Steelhead	15	50	0.2	20	75	0.6
Curlew Creek	SR 21	174.35	Columbia Upper	Sockeye Salmon	Chinook Salmon	15	50	0.2	20	75	0.6
Matsen Creek	US 395	249.90	Columbia Upper	Sockeye Salmon	Chinook Salmon	15	50	0.2	20	75	0.6
Mill Creek	SR 142	25.32	Klickitat	Bull Trout	Steelhead	15	25	0.2	20	75	0.6
Summit Creek	SR 20	215.96	Okanogan	Bull Trout	Steelhead	15	25	0.2	20	75	0.6
Tallant Creek	SR 20	225.60	Okanogan	Bull Trout	Steelhead	15	25	0.2	20	75	0.6
Tallant Creek	SR 20	224.40	Okanogan	Bull Trout	Steelhead	15	25	0.2	20	75	0.6
Thorton Creek	I-90	88.42	Yakima	Bull Trout	Steelhead	15	25	0.2	20	75	0.6
Unnamed	I-82	68.32	Yakima	Bull Trout	Steelhead	15	25	0.2	20	75	0.6
Unnamed	I-82	72.38	Yakima	Sockeye Salmon	Steelhead	15	25	0.2	20	75	0.6
Unnamed	SR 20	208.44	Methow	Bull Trout	Steelhead	15	25	0.2	20	75	0.6
Whistler Canyon Creek	US 97	328.84	Okanogan	Bull Trout	Steelhead	15	25	0.2	20	75	0.6

3.4 Determining Design Flows

Using stream flows and culvert characteristics, the percent of flows that the culvert was passable for the strongest and weakest fish was determined. Since most culverts were located on small streams without long-term gaging stations, the fish passage design stream flows were determined using the predictive method for ungaged streams in "Modeling Hydrology for Design of Fish Passage" by Rowland et al. (2002). This study demonstrates a method to calculate fish passage design stream flows that represents a hydrological interpretation of the high flow design discharge specified in the WAC. According to the WAC, the high flow design discharge is the flow that is not exceeded more than ten percent of the time during the months of adult fish migration (Bates et al., 1999 and WAC 220-110-070-3biiB). The technique modeled by Rowland et al. eliminates the problem of determining the migration month by focusing on the worst possible month occurring in each water year. This design stream flow is defined as the highest flow occurring in each water year that is equaled or exceeded by the previous three days, averaged over a number of years and termed "mean annual fish passage design flow," "4-day fish passage flow," or Q_{FP4} (Rowland et al., 2002).

The four steps to determine the predictive method for ungaged streams in this study are:

1) Locate stream and design site on a 1:250,000 Quadrangle,
2) Calculate the area of the watershed upstream of design site,
3) Locate the 6th field HUC (Hydraulic Unit Code) and stream on the appropriate Fish Passage Flow Design Map (maps are separated by area and can be found in the Rowland et al. (2002) study), and then

4) Multiply the 6th field HUC factor (written inside each 6th field HUC on the maps) with watershed area to determine design flow.

Since successful upstream fish passage through culverts depends on the selection of appropriate design flows, many predictive models have been developed to estimate the flows at ungaged sites by establishing a relationship between watershed attributes and the measured flow at gaged sites (Rowland et al., 2002). In Washington, the WDFW developed regression equations for estimating fish passage design flows in Washington west of the Cascade Mountains, with no correlation to Eastern Washington (Powers and Saunders, 1996). Therefore, the USGS published a design manual for the WDNR that provided regression equations for estimating fish passage design flows in Eastern Washington (Kresch, 1999). Compared to this widely used USGS regression model for determining flow values, Rowland et al.'s model (the WSU model) provides smaller percentages of error than does the USGS regression approach. This is depicted in Table 9. Therefore it was chosen as the method for determining fish passage design flows for this research.

Table 9: Percent standard error of the WSU model versus the USGS regression model (table adapted from Rowland et al., 2003)

		Total	Region 1[a]	Region 2[a]	Region 3[a]	Region 4 & 5[a]	Region 6[a]
WSU	%SE[b]	36	44	39	17	39	27
	(R^2)[c]	0.951	0.966	0.966	0.894	0.878	0.84
USGS	%SE[b]	75	52	80	33	275	32
	(R^2)[c]	0.876	0.881	0.892	0.816	0.0004	0.84

[a] Regions represent those used by the USGS regression model (Kresch, 1999)
[b] Percent standard error
[c] Coefficient of deviation

Watersheds for the culverts used in this research were delineated in ArcGIS using the Hydrology Modeling toolbox application for each of the 15 culvert areas. The basins are shown in Appendix C. Digital elevation, stream, and road data for Washington were all downloaded from the USGS interactive seamless data distribution server (USGS, 2008).

To determine average daily flows for each ungaged stream, the nearest United States Geological Survey (USGS) gaged streams were used to develop ratios between the ungaged stream's fish passage design storm ($Q_{FP4\ ungaged}$) and the gaged stream's fish passage design flow ($Q_{FP4\ gaged}$). Each gaged stream's daily flows ($Q_{daily\ gaged}$) were scaled by its own fish passage design flow ($Q_{FP4\ gaged}$) and then multiplied by the ungaged stream's (the stream of interest) fish passage design flow ($Q_{FP4\ ungaged}$) (both calculated using Rowland et al.'s method). This resulted in an estimated hydrograph of daily flows for the ungaged stream ($Q_{daily\ ungaged}$). Figure 8 displays one USGS gage's daily measured flow while Figure 9 shows the corrected daily flows for the ungaged stream of interest.

$$Q_{daily\ ungaged} = \frac{Q_{daily\ gaged}}{Q_{FP4\ gaged}} * Q_{FP4\ ungaged} \qquad (4)$$

The watershed area, QFP4, USGS gaged stream utilized, and the resulting design flows for all 15 culverts are presented in Table 10.

Table 10: Stream flows utilized in FishXing calculated using Rollin et al.'s method for ungaged streams

Culvert Stream	**Road**	**Mile Post**	**Watershed Area (mi²)**	**Q_{fp4} (cfs/mi²)**	**Design Flow (cfs)**	**Gaged Stream ID Number**	**Gaged Stream**	**High Flow (cfs)**	**Low Flow (cfs)**
Beebe Creek	US 97	235.30	8.51	1.28	10.89	12449950	Methow River	24.180	0.133
Byrd Canyon Creek	97 AR	220.76	3.53	1.28	4.52	12452800	Entiat River	8.383	0.036
Crab Creek Wasteway	SR 26	29.87	21.35	0.53	11.32	12467000	Crab Creek	168.474	0.171
Crab Creek Wasteway	SR 26	29.95	1.67	0.53	0.89	12467000	Crab Creek	13.246	0.013
Curlew Creek	SR 21	174.35	27.53	1.14	31.38	12401500	Kettle River	39.700	0.095
Matsen Creek	US 395	249.90	5.42	1.54	8.35	12404500	Kettle River	11.250	0.037
Mill Creek	SR 142	25.32	8.98	3.57	32.06	14113000	Klickitat River	176.150	1.585
Summit Creek	SR 20	215.96	1.90	1.80	3.42	12447200	Okanogan River	9.623	0.061
Tallant Creek	SR 20	225.60	13.28	1.13	15.01	12447200	Okanogan River	42.233	0.269
Tallant Creek	SR 20	224.40	12.12	1.13	13.70	12447200	Okanogan River	38.547	0.245
Thorton Creek	I 90	88.42	1.14	3.69	4.21	12488500	American River	8.285	0.054
Unnamed	I 82	68.32	29.83	0.53	15.81	12510500	Yakima River	54.976	0.269
Unnamed	I 82	72.38	19.24	0.53	10.20	12510500	Yakima River	35.468	0.174
Unnamed	SR 20	208.44	1.44	1.72	2.48	12447200	Okanogan River	6.978	0.044
Whistler Canyon Creek	US 97	328.84	5.61	0.75	4.21	12442500	Similkameen River	12.090	0.032

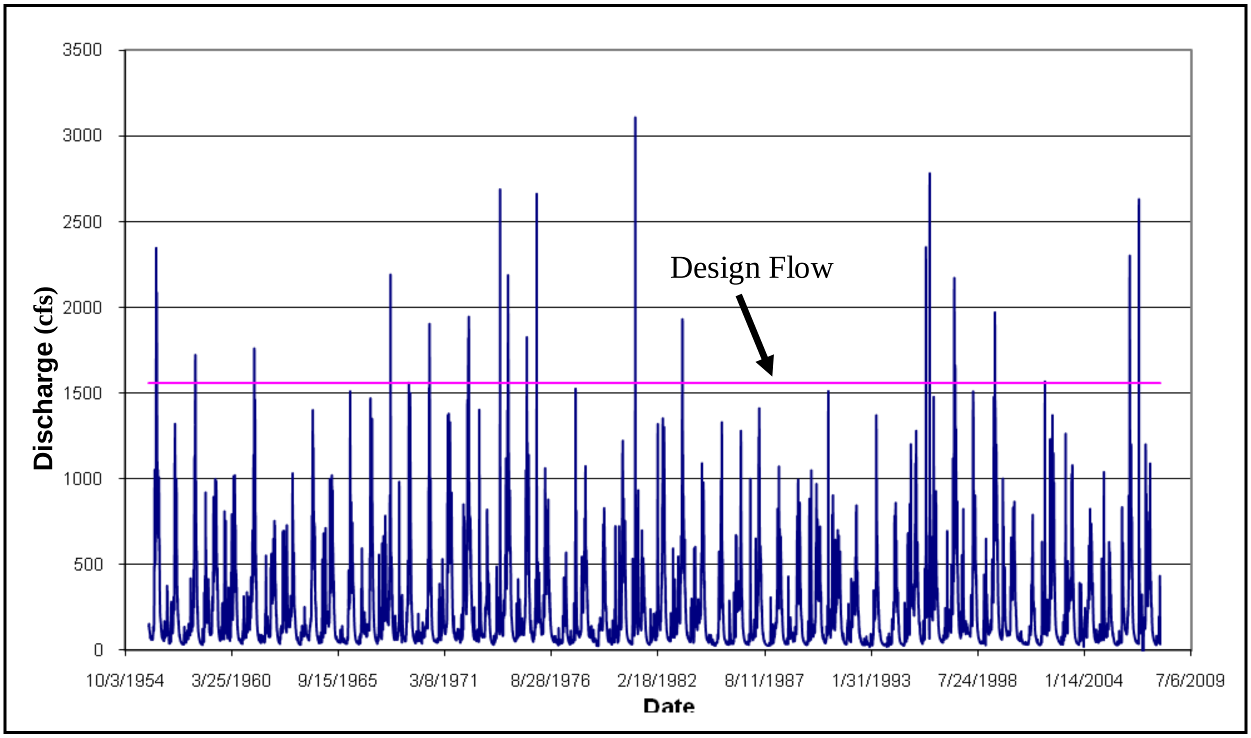


Figure 8: The daily discharge data for the USGS gage on the American River

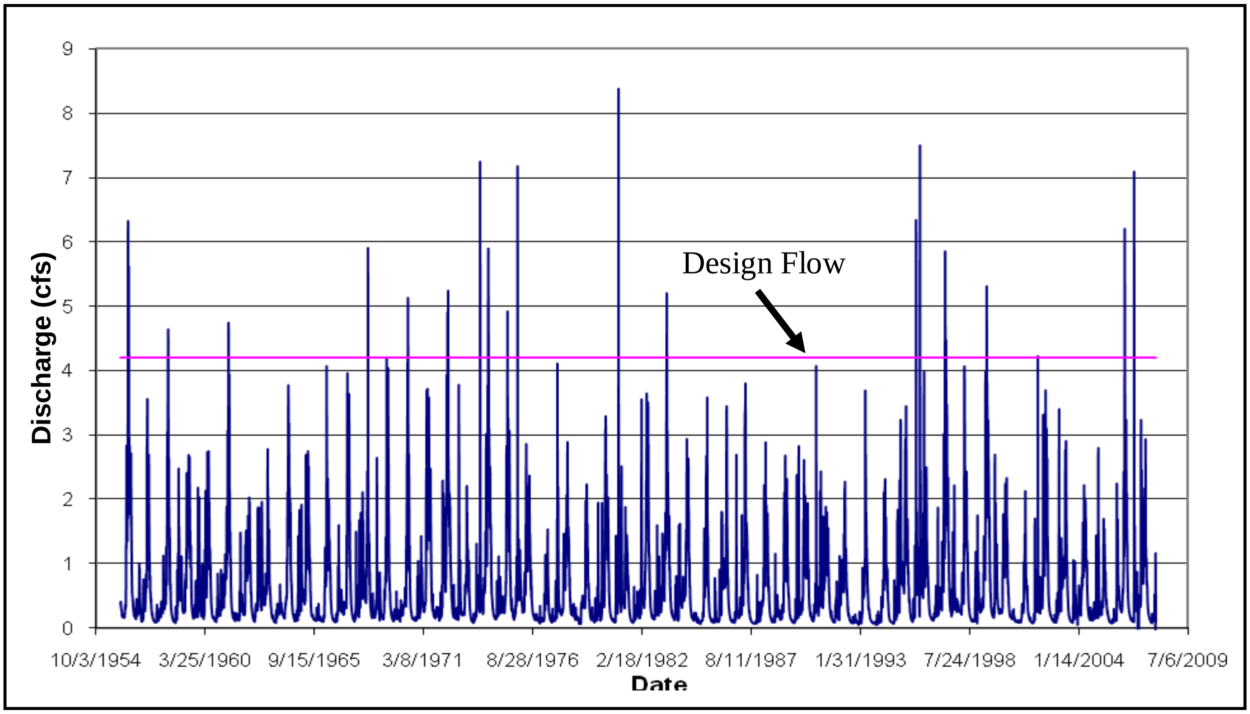


Figure 9: The corrected daily flows for the ungaged stream, Thorton Creek, from the American River's USGS gage's daily discharge data

With the percent of passage determined from FishXing and the average daily discharges estimated, the time of year that is impassable for the weakest and strongest fish species was found and compared to times of migration for each culvert. Fish migration periods correspond to spawning times for adult fish. Some spawning times for fish species in Montana, Idaho, and Eastern Washington are outlined by the United States Department of Agriculture, 1990 (Figure 10). Additional fish migration data for common species in the Western United States can be found in Appendix D.

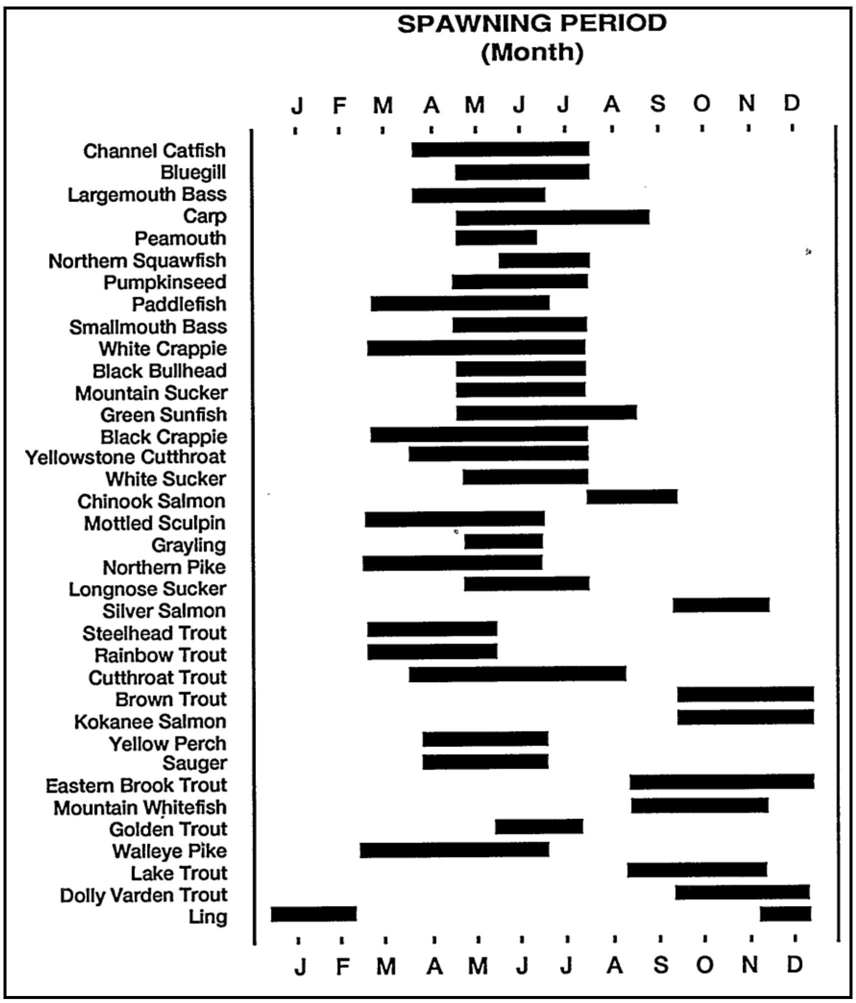


Figure 10: Spawning period for some fish species in Montana, Idaho, and Eastern Washington (U.S. Department of Agriculture, 1990)

3.5 Cost Analysis

Construction costs for each potential culvert diameter were determined for comparison to the percent of time that culvert flow velocities were fish passable. Construction costs are very site specific and represent a number of parameters. The WSDOT 2008 Trends in Highway Materials Costs was utilized to establish specific costs for culvert construction. This report outlines the average costs for various materials such as concrete and asphalt for all of Washington State. Table 11 represents the costs used for this research (WSDOT, 2008).

Table 11: Material prices used for determining culvert construction costs

Material	**Cost**
Roadway excavation	$6.31/cubic yard
Crushed Surfacing	$15.15/ton
Hot Mix Asphalt	$61.36/ton
Portland Cement Concrete Pavement	$140.65/cubic yard
Steel Reinforcing Bar	$1.15/pound
Structural concrete	$567.75/cubic yard
Structural Steel	$1.70/cubic yard

Culvert size costs were determined based on dimensions (length, L; diameter, D; and thickness, Th).

$$CulvertCost = L * D * Th * material \tag{5}$$

The WSDOT produced a standard specifications manual for roads, bridges, and other municipal construction in 2008. This manual outlines in great detail the legal requirements for culvert construction. It states that for pipes over 18 inches in diameter, the trench width must be (1.5 x culvert diameter) + 18-inches. In addition, shoring must be utilized to maintain road stability during construction. Figure 11 and equations 6-10 show how the excavation and shoring areas were determined.

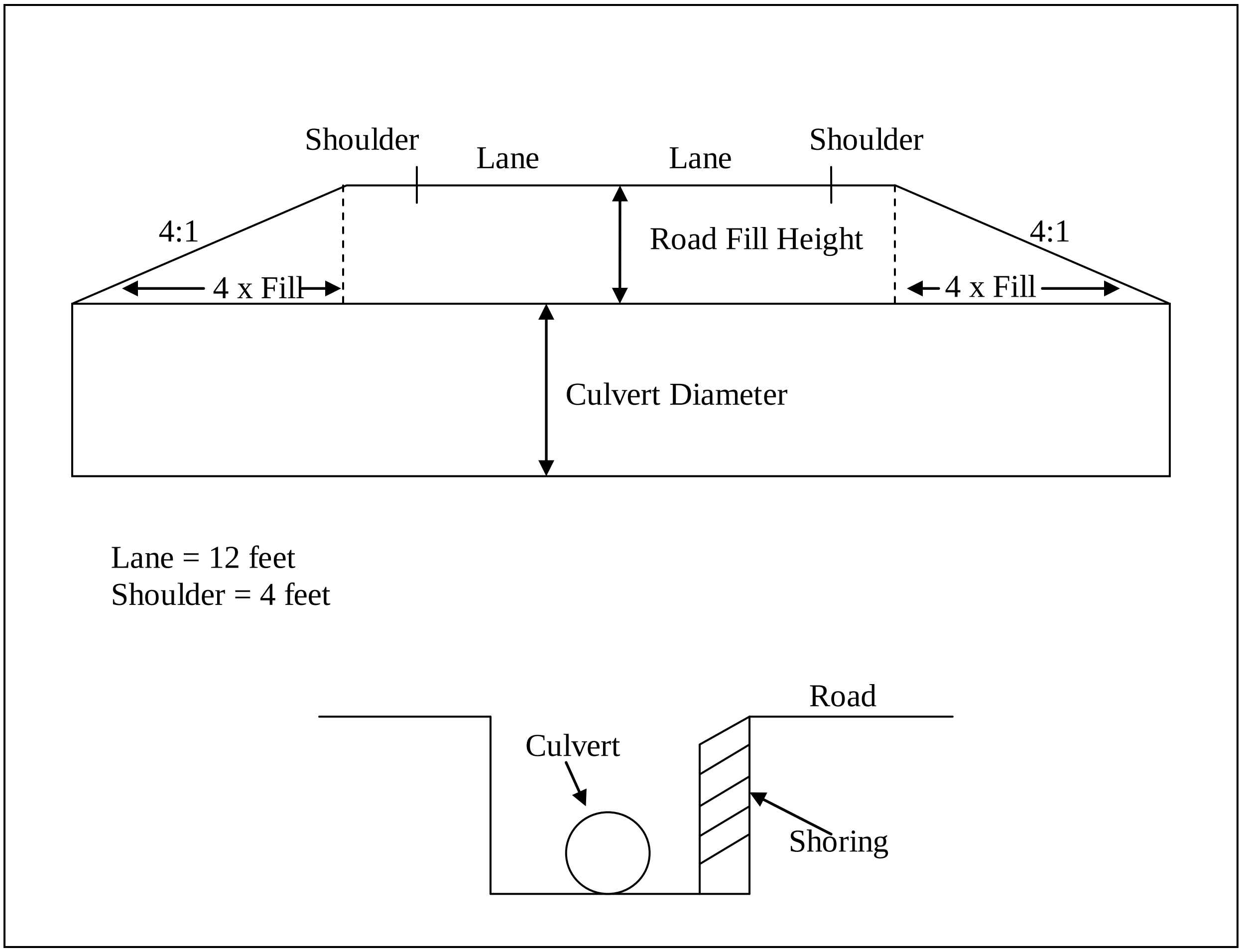


Figure 11: Schematic of culvert excavation parameters

$$L_{culvert} = (2 * W_{Shoulder}) + (\# Lanes * W_{lane}) + 2(4 * H_{Fill}) \quad (6)$$

$$E.W. = 1.5 * D_{culvert} + 1.5\, feet \quad (7)$$

$$L_{road} = (2 * W_{shoulder}) + (2 * W_{lane}) \quad (8)$$

$$Excavation = (L_{road} * E.W. * (D_{culvert} + H_{Fill})) + 2\left((4 * H_{Fill}) * E.W. * \left(\frac{D_{culvert} + D_{culvert} + H_{Fill}}{2}\right)\right) \quad (9)$$

Where $L_{culvert}$ is the length of the culvert, $W_{shoulder}$ is the width of the road shoulder, #Lanes is the number of lanes on the road, W_{lane} is the width of each lane, H_{fill} is the fill height from the top of the culvert to the top of the road, E.W. is the excavation width required, $D_{culvert}$ is the diameter of the culvert, and L_{road} is the total length of the road.

$$Shoring = \left(L_{road} * \left(D_{culvert} + H_{fill}\right)\right) + 2\left(\left(4 * H_{fill}\right) * \left(\frac{2 * D_{culvert} + H_{fill}}{2}\right)\right) \qquad (10)$$

Where shoring is the trench wall area that needs to be supported to keep the current road intact.

Additional construction costs were also needed such as traffic control, structural excavation, backfill, channel excavation and restoration, and road repair. To determine these costs, the WSDOT unit bid analysis was utilized (WSDOT, 2008). This tool enables project planners to see previous bids for project items. For this research, the average statewide low bid for 2007 was utilized as the cost estimate. Table 12 shows these costs used.

Table 12: Prices used for determining construction costs

Removing Guardrail	$5.40/linear foot	Gravel Backfill	$35.56/cubic yard
Compaction	$1.00/cubic yard	Other Traffic Control	41.59/hr
Channel Excavation	$30.37/cubic yard	Construction Signs	$16.16/square foot
Structural Excavation Including Haul	$17.40/cubic yard	Equipment	lump sum
Backfill	$18.16/cubic yard	Channel Reconstruction	lump sum
Shoring	$69.42/linear foot	Clearing-Grubbbing	lump sum
Crushed Surfacing Base	$125.22/cubic yard	Removing Cement Pavement	$21.38/square yard
Asphalt Emulsion	$449.60/ton	Removing Asphalt Pavement	$4.19/square yard
Asphalt Fog Seal	$438.42/ton	Planning	lump sum
Flaggers	$40.96/hr	Pollution Control	lump sum
Temporary Traffic Control	lump sum	Engineering and Administration	20%

4.0 RESULTS AND DISCUSSION

Study results depicting the relationships between culvert construction costs and the percent of fish passable flows for each of the 15 culverts are shown in Figures 12-26. Both the strongest swimming fish species and weakest swimming fish species for each culvert are shown in these figures.

4.1 Beebe Creek Culvert

Initially, the Beebe Creek culvert was only passable for 0.2% of the flows for the weakest fish because of excessive velocities caused by a steep pipe slope. The slope of the Beebe Creek culvert was changed from 2.13% to 1% based on the measured slope of the surrounding stream channel. As a result, the culvert became passable 100% of the flows for the strongest swimming fish and about 58% of the flows for the fish with the weakest swimming abilities based on the calculated design flow of 10.9 cfs (Appendix C). Increasing the diameter of the culvert resulted in an increase in the percent of flows passable for the weakest swimming fish. However, to gain 100% passage for the fish with the weakest swimming abilities, the construction costs would increase to about $700,000 (Figure 12). The weakest swimming species for this culvert are Bull Trout which are a resident fish species and would need passable flows throughout the entire year. The strongest swimming fish are Steelhead which are a migratory fish. Based on average daily flow values, Steelhead can pass every day of the year. When the flows are 58% passable for Bull Trout about three months of the year are impassable.

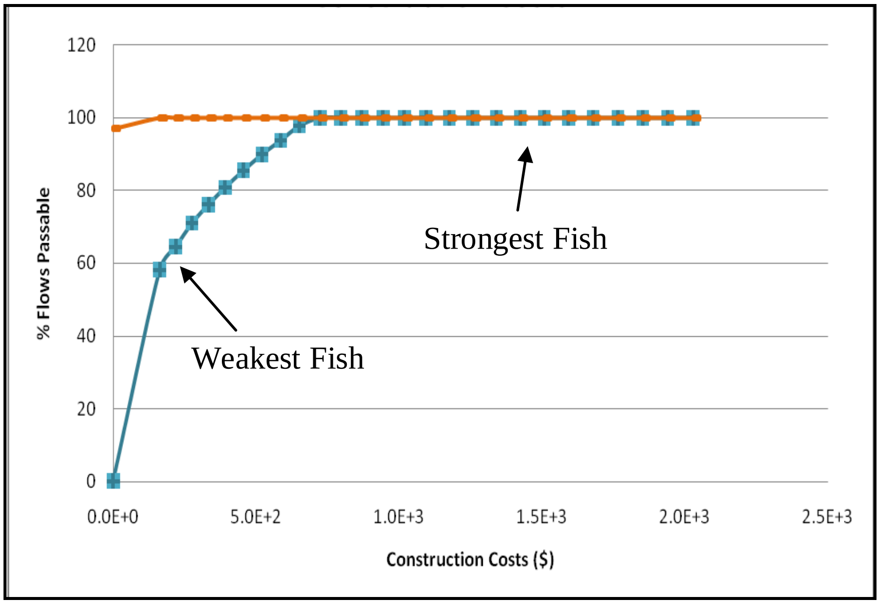


Figure 12: Percent of flows fish passable versus construction costs for the Beebe creek culvert

4.2 Byrd Canyon Creek

The Byrd Canyon Creek culvert was initially not passable for the weakest swimming fish during any flows. The slope was changed from 3.26% to 1% to simulate the surrounding channel slope. In response, the culvert became passable about 22% of the flows for the weakest swimming fish and about 56% of the flows for the strongest swimming fish without changing culvert diameter. As the culvert diameter was increased the percent of flows passable for the weakest swimming fish increased while the percent of flows passable for the strongest swimming fish decreased. The dominating passage problem for the weakest swimming fish was velocity while for the strongest swimming fish it was depth. As the diameter increased, the weakest fish improved passability while the strongest fish eventually could not pass through the culvert during any flows. In addition, based on the Q_{FP4} of 4.52 cfs, the strongest fish were only able to pass through 0.88% of the flows and only at a diameter of 3 feet. A diameter of 4 feet was completely impassable for the strongest swimming fish because the depth was too shallow based on this flow (Appendix C). To maintain a high percent of passability (around 70%) for the weakest swimming fish, the construction costs would increase to about $2 million (Figure 13). The listed species the Bull Trout is also the weakest fish for the Byrd Canyon culvert and would need passage year round. The strongest species are Steelhead which are a migratory species. However, even at the highest percent of flows passable for Steelhead, this species would only be able to pass for a few weeks during the spring high flows.

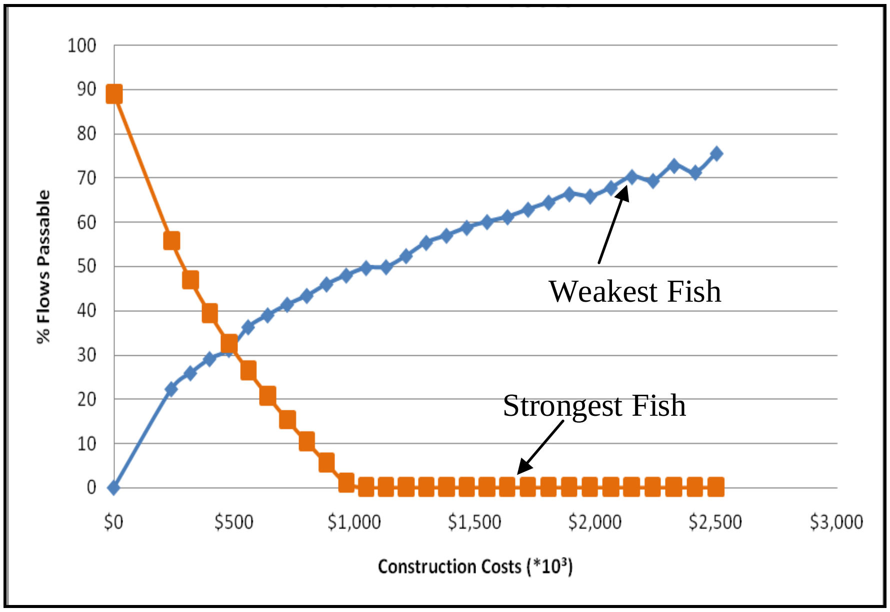


Figure 13: Percent of flows fish passable versus construction costs for the Byrd Canyon creek culvert

4.3 Crab Creek Wasteway at Mile Post 29.87

The Crab Creek Wasteway culvert was only passable initially up to 5.87 cfs. However, the slope was not the dominating problem as it simulated the surrounding stream channel. Therefore, it was kept at 0.82%. Similar to the Byrd Canyon Creek culvert, the percent of flows passable for the weakest swimming fish increased as the diameter increased; while the percent of passable flows for the strongest swimming fish decreased as the culvert diameter increased. Details can be found in Appendix C and Figure 14. The weakest swimming fish species for this culvert was Sockeye Salmon while the strongest swimming fish species was Steelhead. At about 60% passage, the flows were only impassable for about 1 week during the highest flows at the beginning of March for the weakest species and only passable for about 2 months for the strongest species.

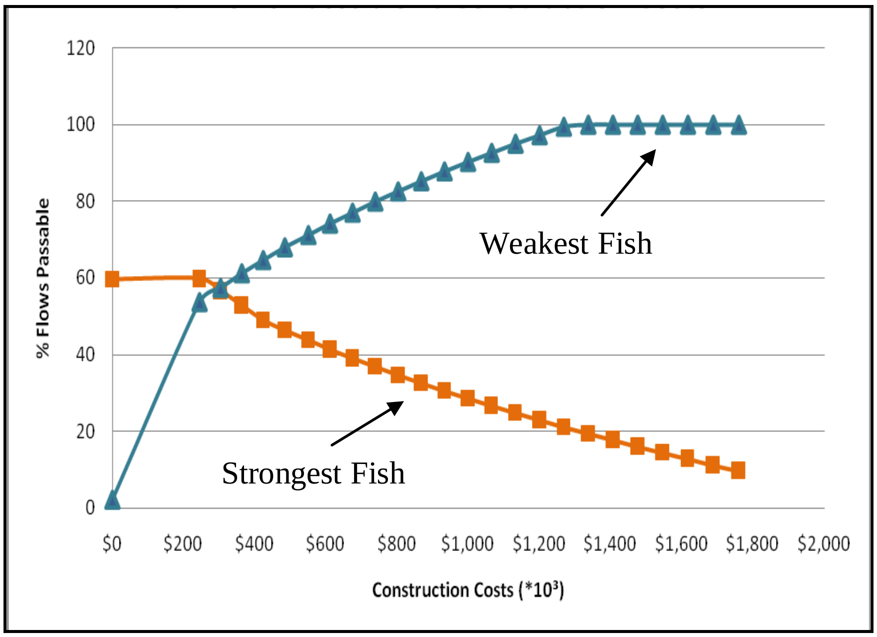


Figure 14: Percent of flows fish passable versus construction costs for the Crab Creek Wasteway culvert at mile post 29.87

4.4 Crab Creek Wasteway at Mile Post 29.95

The initial percentage of flows passable for this Crab Creek Wasteway culvert was 0% for the weakest swimming fish and about 37% for the strongest swimming fish. The current culvert slope is 9%. This is immediately a fish passage issue and would be similar to a small waterfall for a fish to jump up. The long length of the culvert having a continuous steep slope proves impossible for passage. The slope was changed to 3% for this research. Again, similar to Byrd Canyon Creek and the other Crab Creek Wasteway, the weakest swimming fish were able to increase their percent of flows passable as the diameter increased because their dominating passage problem is velocity. On the other hand, the percent of passage for the strongest swimming fish decreased as culvert diameter increased because their dominating passage problem is depth (Appendix C). The cost for culvert construction costs increased from about $200,000 to almost $700,000 to increase passage by only 30% for the weakest species. To increase passage by another 20% for the weakest species the cost increased to over $1 million (Figure 15). The weakest swimming species for this culvert are Sockeye Salmon while the strongest swimming species are Steelhead. Both of these species are migratory. For the weakest species the flows were impassable for about one month until about 40% passage where the flows were only impassable for about one week. At 80% passage, the flows were only impassable for two days of the entire year. However, for the strongest swimming fish, only about 1 month was passable at 50% passage.

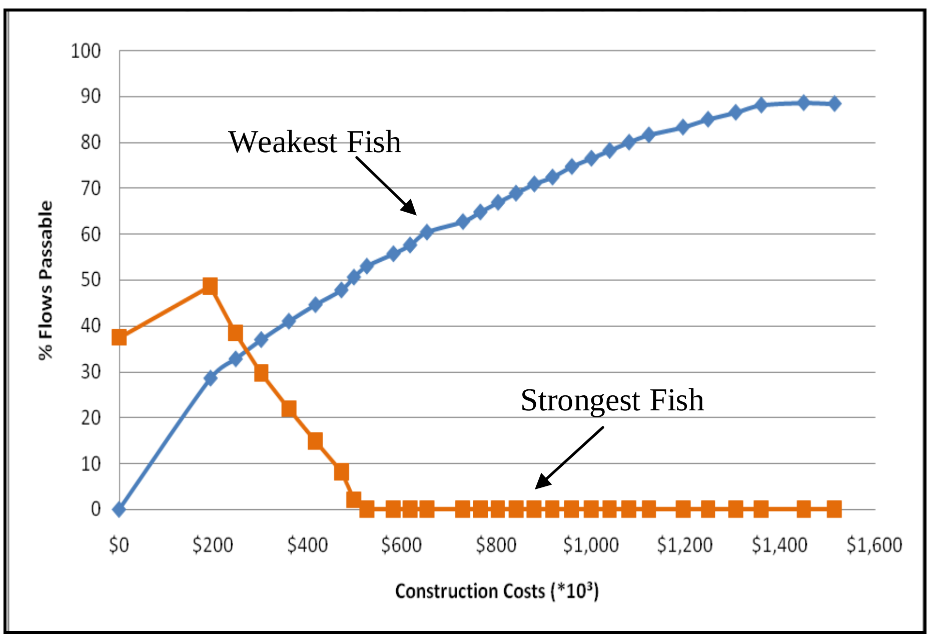


Figure 15: Percent of flows fish passable versus construction costs for the Crab Creek Wasteway culvert at mile post 29.95

4.5 Curlew Creek

The Curlew Creek culvert had an initial percent of flow passage of 34.4% for the weakest swimming fish and 100% for the strongest swimming fish. The passage problem for this culvert is currently velocity. The culvert slope was kept the same at 0.87% because this simulated the surrounding channel slope while the culvert diameter was increased. For this culvert the strongest swimming fish were able to pass through 100% of the time and depth was not a problem. The weakest swimming fish increased their passage percentage as the diameter increased because the velocity decreased. To increase the passage from about 40% to 100% for the weakest swimming fish the culvert construction costs would become almost $1.5 million (Figure 16). Both the strongest swimming species and weakest swimming species for this culvert are migratory (Sockeye and Chinook Salmon). However, at minimum percent passage, the months impassable for Sockeye Salmon are between migration periods, end of May to the beginning of June and therefore may not be important to design for (Appendix C).

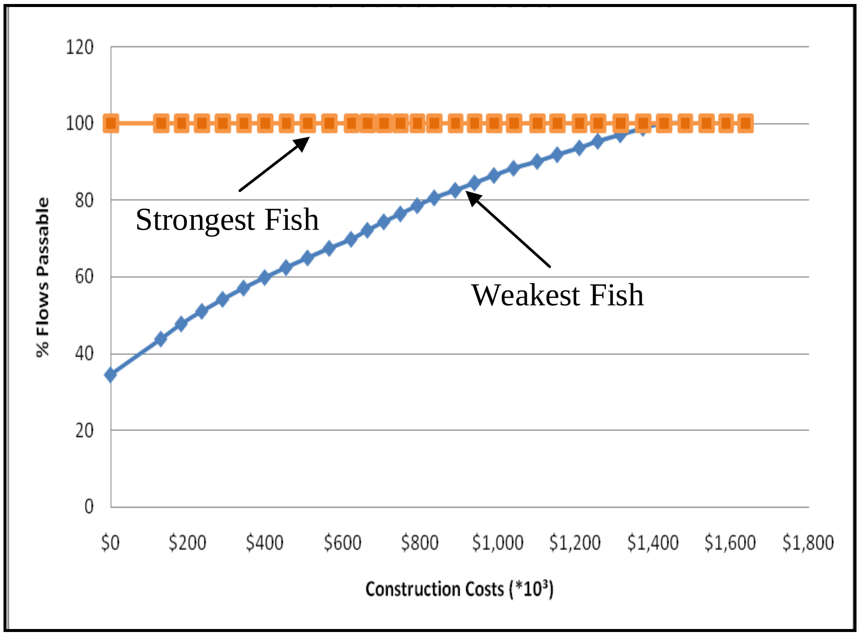


Figure 16: Percent of flows fish passable versus construction costs for the Curlew Creek culvert

4.6 Matsen Creek

The Matsen Creek culvert has an initial slope of 5% which was the passage problem for fish. Initially no flows were passable for the weakest swimming species. Therefore, for the purpose of this research the culvert slope was changed to 0% to estimate culvert costs although that did not match the surround channel slope. To maintain fish passage while mimicking the surrounding channel slope additional methods will need to be used (for example baffles or step weirs to raise the water level downstream of the culvert). At a zero percent slope the Matsen Creek culvert percent of passage for the weakest swimming fish increased to about 50% without changing diameter, and the strongest swimming fish were able to pass 100% of the time (Appendix C). To double the percent of passage to 100% for the weakest swimming fish the construction costs would increase to about $900,000 (Figure 17). The weakest swimming fish for this culvert are the migratory Sockeye Salmon and the strongest swimming fish are Chinook Salmon. However, similar to the Curlew Creek culvert the days the flows were impassable for Sockeye Salmon were not during their migratory period (end of May to beginning of June).

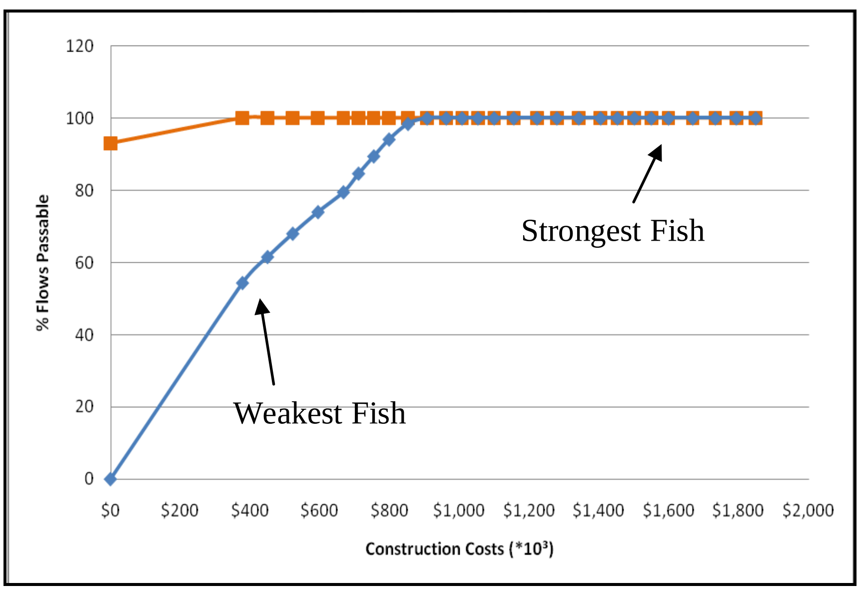


Figure 17: Percent of flows fish passable versus construction costs for the Matsen Creek culvert

4.7 Mill Creek

For the Mill Creek culvert, only 6% of flows were initially passable for the weakest swimming fish species based on a high 100 year flow of 150 cfs. The original culvert slope is 1.5% which was changed to 1.0% to simulate the surrounding channel. Based on the fish passage design flow (Q_{FP4}) of 32.1 cfs the percent of passage for the strongest swimming fish becomes 100% while the percent of passage increases with culvert diameter for the weakest swimming fish (Appendix C and Figure 18). The list species, Bull Trout are the weakest swimming fish for this culvert and they are a resident species who would need passage all year long. The strongest swimming fish species for this culvert are the migratory species Steelhead and are able to pass through during all flows of the year.

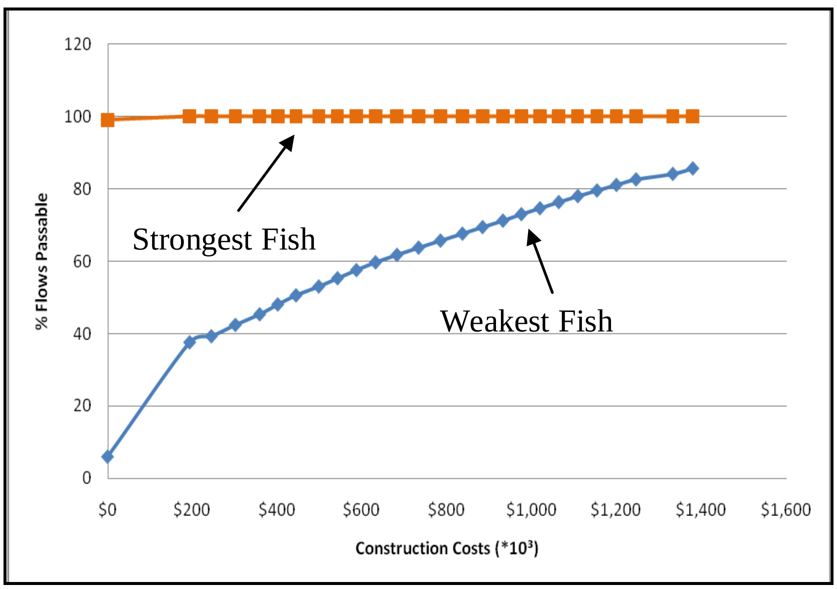


Figure 18: Percent of flows fish passable versus construction costs for the Mill Creek culvert

4.8 Summit Creek

Parallel to the Crab Creek Wasteway and Matsen Creek culverts, the Summit Creek culvert has a high slope of 6.8%. As a result the slope was the primary passage problem, creating velocity and depth barriers. Additional methods as mentioned earlier will need to be used to maintain fish passage while mimicking the surrounding channel slope. Therefore, for the purpose of this research, the slope was changed to 0%. Like the Curlew Creek culvert, the strongest fish had 100% passability with the new slope and the percent of passage for the weakest swimming fish increased with culvert diameter (Appendix C). To maintain 100% passage for this culvert, the culvert costs would increase from about $200,000 to $1.5 million (Figure 19). The weakest swimming fish for this culvert was Bull Trout who would need passage all year round. The strongest swimming fish for this culvert was the migratory species Steelhead who were able to pass during all flows of the year.

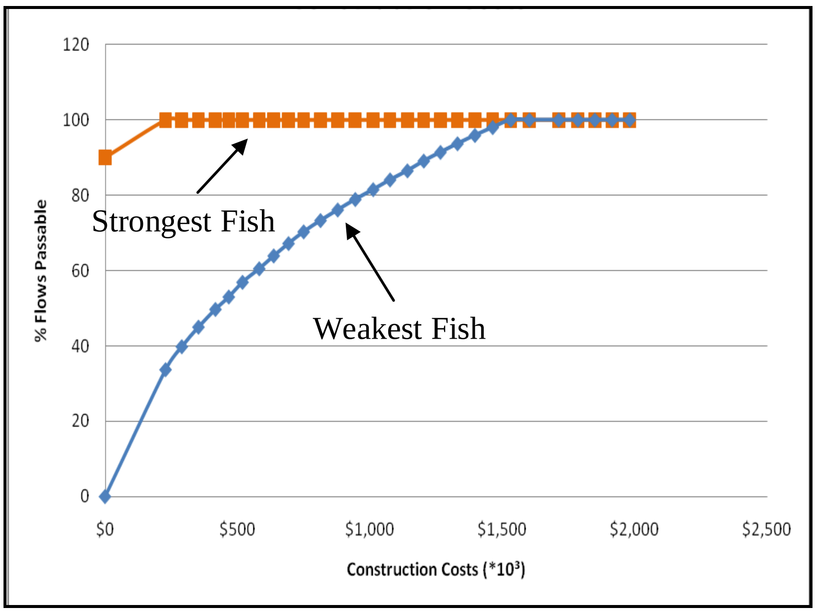


Figure 19: Percent of flows fish passable versus construction costs for the Summit Creek culvert

4.9 Tallant Creek at Mile Post 224.4

Initially, the Tallant Creek culvert is not passable during any flows for both the strongest and weakest swimming fish species. The slope is currently at 5.4% grade and is the primary passage barrier. As a result, the slope was changed to 0% to determine construction costs. For this culvert, the strongest swimming fish were able to pass through 50% of the flows without changing culvert diameter. However, as the diameter increased, their passage decreased because of the decreasing depth. The weakest swimming fish increased passage percentage as culvert diameter increased, but to maintain a passage of about 33% (an increase of only 20% from no culvert diameter increase) the cost would increase to about $1.2 million. However, there would also be 0% passage for the strongest swimming fish because of the depth barrier (Appendix C and Figure 20). The weakest swimming fish for this culvert was Bull Trout who would need passage all year round. In addition, with 33% of flows passable over two months of the year would be impassable for this species. For the strongest species, Steelhead, based on average daily flows at the most only about 1.5 months would be passable.

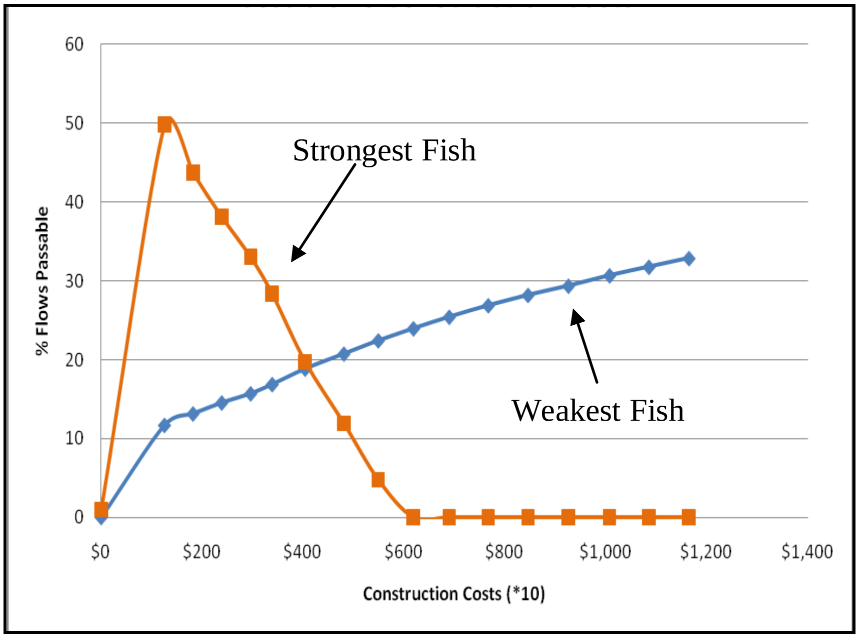


Figure 20: Percent of flows fish passable versus construction costs for the Tallant Creek culvert at mile post 224.4

4.10 Tallant Creek at Mile Post 225.6

The Tallant Creek culvert was initially passable up to about 5.7 cfs for the weakest swimming fish before a velocity barrier developed. The slope for this culvert was kept at a 1.7% grade. The weakest swimming fish's passable barrier is velocity; therefore as the culvert diameter increased so did passability. The strongest swimming fish on the other hand have barriers of both depth and velocity. As a result, there is an initial increase in passage for the strongest fish as diameter increases and velocity decreases; but, once velocity is no longer a barrier the percent of passage begins to decrease with diameter increase as the depth gets smaller (Appendix C). The culvert construction costs would increase from about $200,000 to almost $800,000 to increase passage for the weakest swimming fish by 30%. However, at about 65% passage for the weakest swimming fish there would be 0% passage for the strongest swimming fish (Figure 21). The weakest swimming fish for this culvert are the resident species Bull Trout and the strongest swimming fish are the migratory species Steelhead. For Bull Trout only about one week during the year is impassable at 75% passage while for Steelhead at 30% passage only about one month is passable.

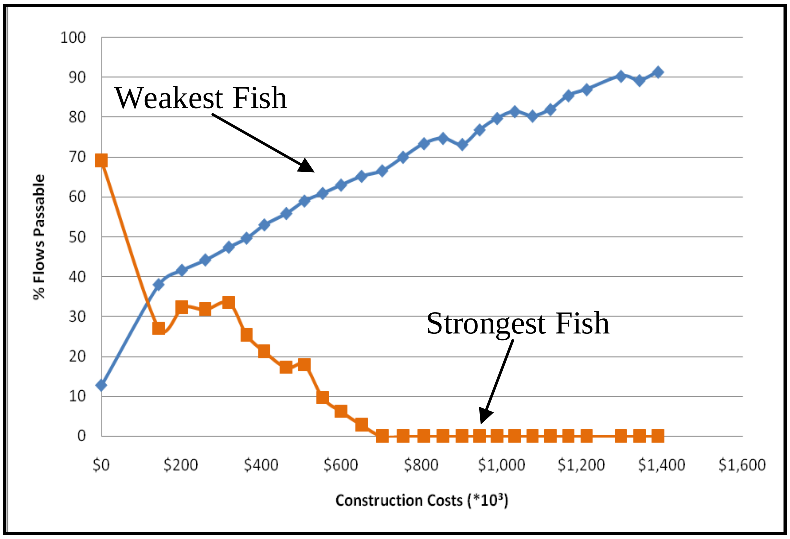


Figure 21: Percent of flows fish passable versus construction costs for the Tallant Creek culvert at mile post 225.6

4.11 Thorton Creek

The Thorton Creek culvert also has an initial problem with slope. Currently the slope of the culvert is 10.3% resulting in 0% percent of passage. Most likely fish are not trying to swim up this culvert because similar to the Crab Creek Wasteway culvert it probably replaced a small waterfall. The slope was changed to 0% for the purpose of the research and like the Tallant Creek, Matsen Creek, and Summit Creek culverts, to maintain fish passage while simulating the surrounding channel slope additional passage aides will need to be utilized. For this culvert, the weakest swimming fish (Bull Trout) had a velocity barrier while the strongest swimming fish (Steelhead) had a depth barrier. This resulted in an increased percent of passage for the weakest fish with increased culvert diameter and a decreased percent of passage for the strongest fish with increased diameter (Appendix C). The Thorton Creek culvert has a very large fill depth of about 66 feet and would require massive amounts of excavation to replace this barrier problem. This results in huge costs for a culvert that fish may not be trying to swim through (Figure 22).

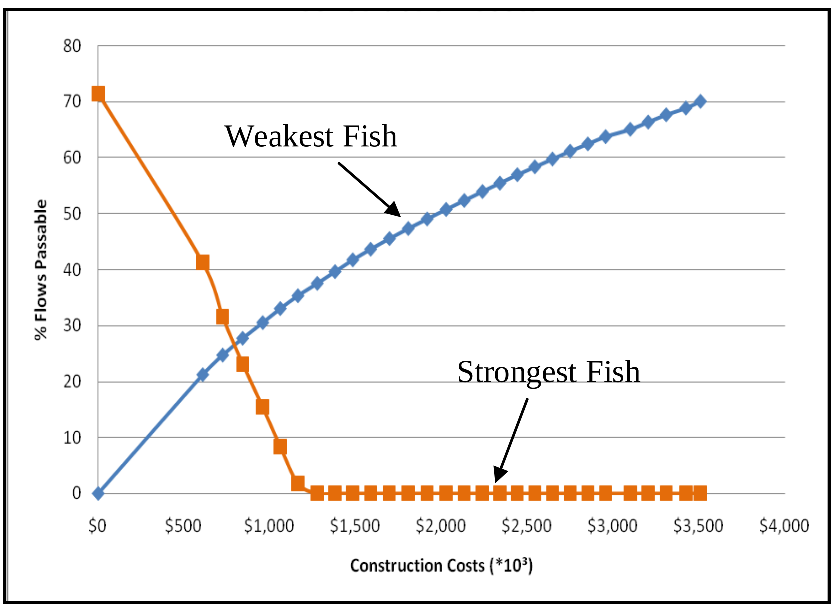


Figure 22: Percent of flows fish passable versus construction costs for the Thorton Creek culvert

4.12 Unnamed Creek on SR20

The Unnamed Creek culvert on SR20 is a very small culvert with a current barrier slope of 6.09%. The initial percent of passage is 0% as a result. The slope was changed to 0.51% and passage was increased to 100% for the strongest swimming fish without changing diameter. The percent of flows passable for the weakest swimming fish increased as the culvert diameter increased. However, to maintain 100% passage for the weakest fish, the construction costs would increase by about $1 million (Appendix C and Figure 23). The weakest swimming fish (resident Bull Trout) had barriers of both depth and velocity for this culvert. However, velocity was only a barrier until about 55% passable flows based on average daily flow values and initially it was only a barrier about 2 months of the year. Depth on the other hand prevented this fish species from passing through about half of the year at minimum passage. The strongest swimming species, migratory Steelhead, were able to pass through the culvert during all flows throughout the year.

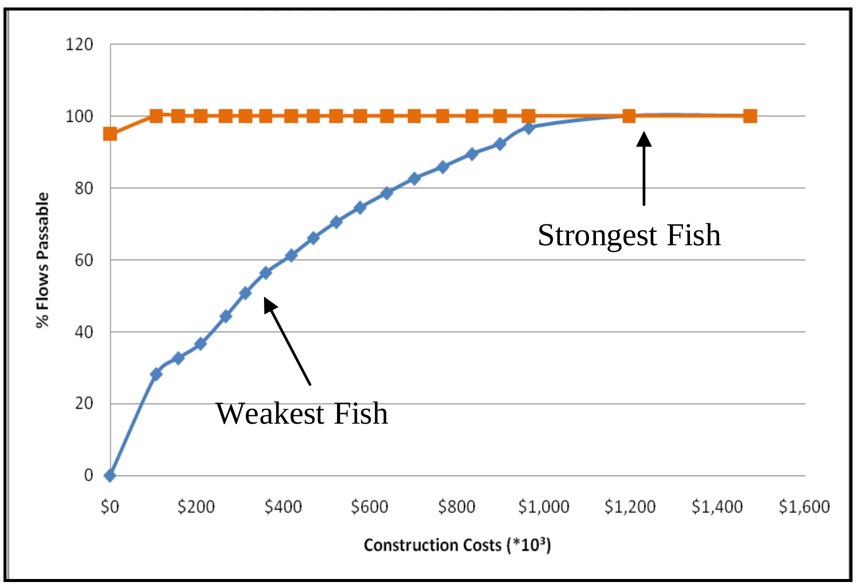


Figure 23: Percent of flows fish passable versus construction costs for the Unnamed Creek culvert on SR20

4.13 Unnamed Creek on I-82 at Mile Post 68.32

Only 1.3% of the flows were initially passable for the weakest fish at the Unnamed Creek culvert on I-82 at mile post 68.32. In addition, both velocity and depth were passage barriers initially. The slope was changed from 0.80% to 0%. Like the Unnamed Creek on SR20, the strongest swimming fish were able to pass 100% of the flows without changing culvert diameter. Velocity was the barrier for the weakest swimming fish and therefore the percent of passage for the weakest species increased as the culvert diameter increased (Appendix C). The costs for construction would increase by about $1.4 million to gain about 85% passage for the weakest species. The weakest swimming fish for this culvert are Bull Trout, a resident fish who would need passage all year long. The strongest swimming fish for this culvert are Steelhead and are able to pass through during all flows of the year. Based on average daily flows, Bull Trout are unable to pass only about one week of the year from the end of May to the beginning of June at about 60% passage.

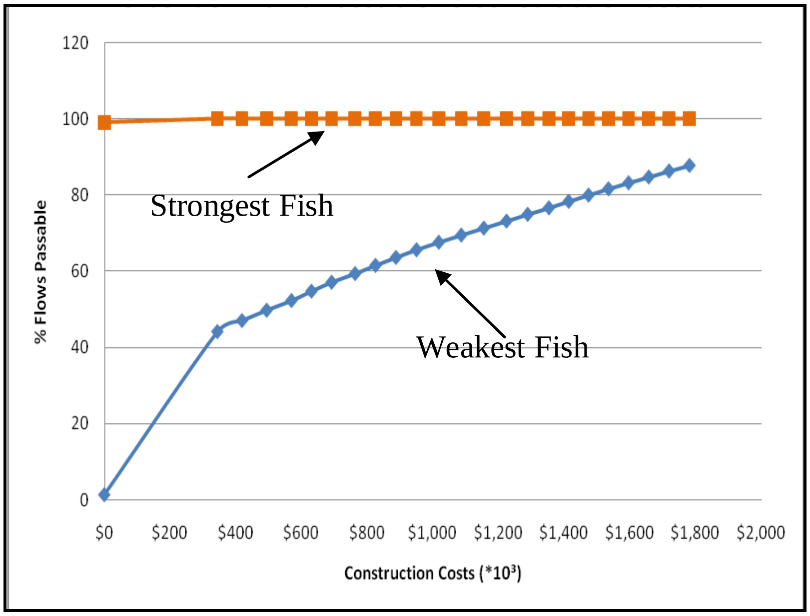


Figure 24: Percent of flows fish passable versus construction costs for the Unnamed Creek culvert on I-82 at mile post 68.32

4.14 Unnamed Creek on I-82 at Mile Post 72.38

Initially, this Unnamed Creek culvert has a 4.4% passage for the weakest swimming fish with depth and velocity as barriers. The culvert slope was changed from 0.6% to 0.4% to simulate the surrounding channel slope. The weakest swimming fish have both depth and velocity barriers, but still increase the percent of passage as the culvert diameter increases. The passage still increases because although depth is a barrier, velocity is the dominating passage barrier and the increased passability from velocity is greater than the decreased passablity from depth. In contrast, for the strongest swimming fish depth is the only barrier and as the culvert diameter increases the percent of passage for these fish decreases. To gain approximately 70% passability for the weakest swimming fish, the strongest swimming fish would have only about 10% passability (Appendix C and Figure 25). The weakest swimming fish for this culvert are migratory Sockeye Salmon and the strongest swimming fish are migratory Steelhead. At 25% passage only about one month of flows are passable for the weakest swimming fish. Additionally, at about 50% passage, there is only approximately one week where the high impassable flows exist for this fish species. However, this week is in the middle of their downstream migratory period in April and would be a barrier issue. For the strongest swimming species, about four months are passable at about 70% passage. However, at about 50% passage less than one month of the flows are passable from the end of May to the middle of June.

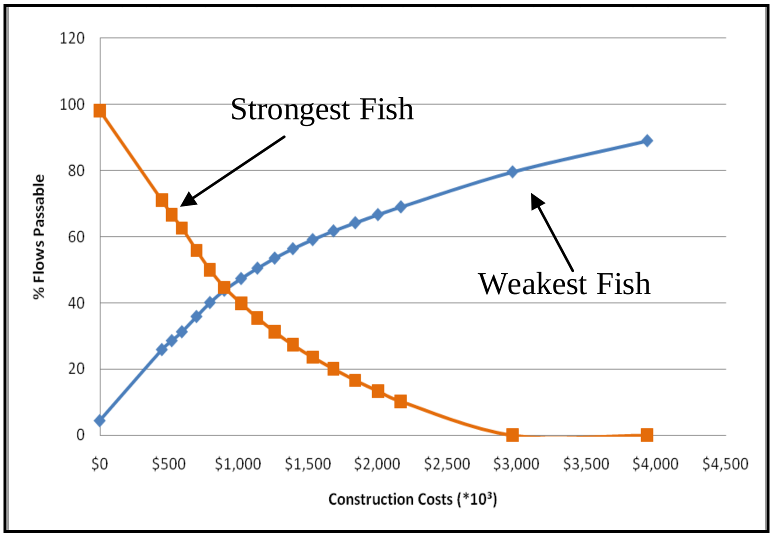


Figure 25: Percent of flows fish passable versus construction costs for the Unnamed Creek culvert on I-82 at mile post 72.38

4.15 Whistler Canyon Creek

The Whistler Canyon Creek culvert had an initial passage of 39.1% for the weakest swimming species and 100% passage for the strongest swimming species. The culvert slope is currently 1.4% and it was not changed because it simulated the surrounding channel slope. At an increased diameter of 6 feet with a high flow of 15 cfs, there would be 100% passage for both the weakest and strongest swimming fish (Appendix C). This would increase construction costs by approximately $200,000 (Figure 26). The weakest swimming fish for this culvert are Bull Trout, a resident fish who would need passage all year long. The strongest swimming fish for this culvert are migratory Steelhead and are able to pass through during all flows of the year.

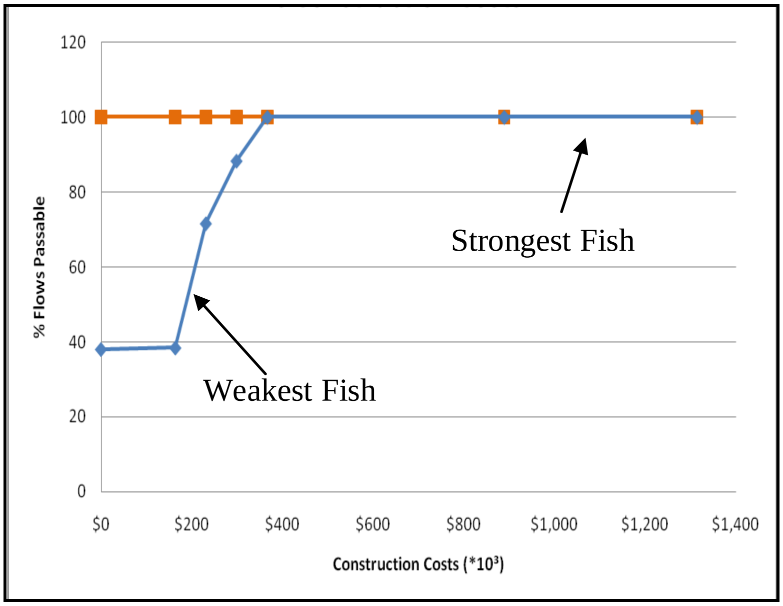


Figure 26: Percent of flows fish passable versus construction costs for the Whistler Canyon Creek culvert

In spite of the individual differences of each culvert, some trends were found. Not surprisingly, as the culvert diameter increased so did the cost (Figure 27). An equation for estimating culvert replacement cost is equation 11 where y represents construction costs and x represents the diameter.

$$y = 60357x + 48367 \tag{11}$$

In addition, two distinct trends were identified. For the seven culverts located on Byrd Canyon, both Crab Creek Wasteways, both Tallant Creeks, Thorton, and one Unnamed Creek on I-82 (Figure 13, 14, 15, 20, 21, 22, and 25), the percent of flows passable for the weakest swimming fish steadily increased with diameter size while the percent of flows passable for the strongest fish decreased as the diameter size increased. In general, velocity is the greatest problem for the weaker swimming fish species and as diameter increases, the velocity decreases. For stronger swimming species, depth is the determining factor in non-embedded culverts. Consequently, as the culvert diameter increases, the depth of flow decreases and the fish have a more difficult time passing through the culvert. In some cases, this resulted in zero percent of passable flows. However, it should be pointed out that if the culvert was embedded, a natural low-flow channel might help this situation for some flow rates.

For the other eight culverts (Figure 12, 16, 17, 18, 19, 23, 24 and 26) the percent of flows passable for the weakest swimming fish species increased with larger diameters while all the flows were passable for the strongest swimming fish. The culverts with steeper slopes, such as Crab Creek Wasteway at mile post 29.95 (9.0% slope) and Thorton Creek (10.3% slope), probably do not have fish trying to swim up them and likely would not have fish passage naturally. The stream gradients around these culverts are large and therefore another type of energy dissipater would be needed for fish passage to be feasible. Figures 28 and 29 demonstrate the basic trends of the percent of passable flows versus culvert diameter for the weakest and strongest swimming fish species.

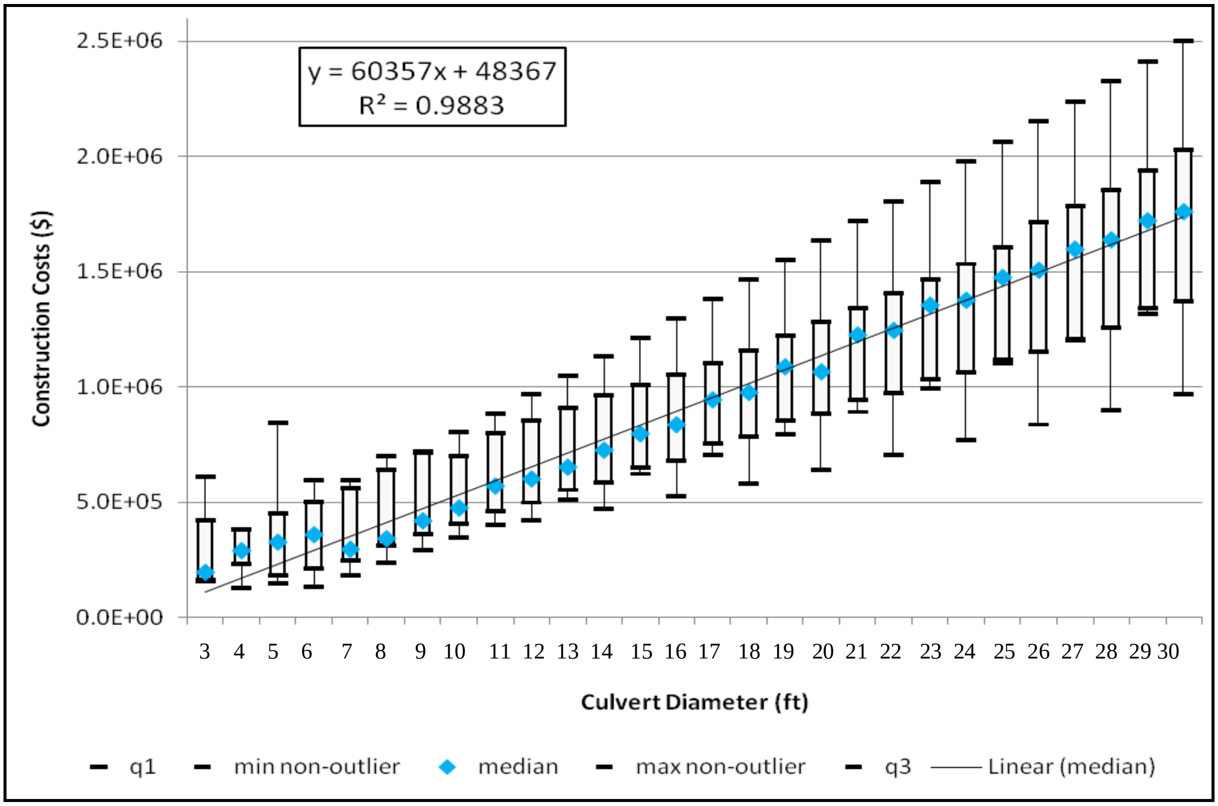


Figure 27: Box plot representing the distribution of culvert diameter versus construction costs for all fifteen culverts

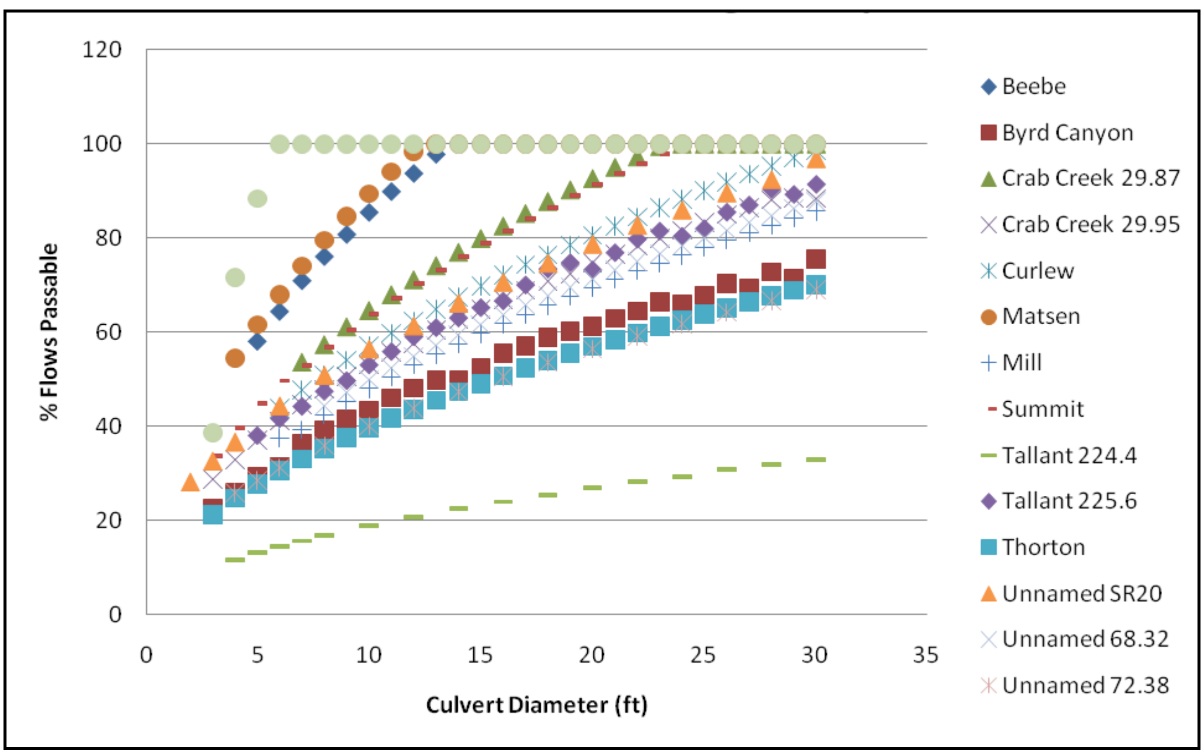


Figure 28: Percent of passable flows versus culvert diameter for the weakest swimming fish species

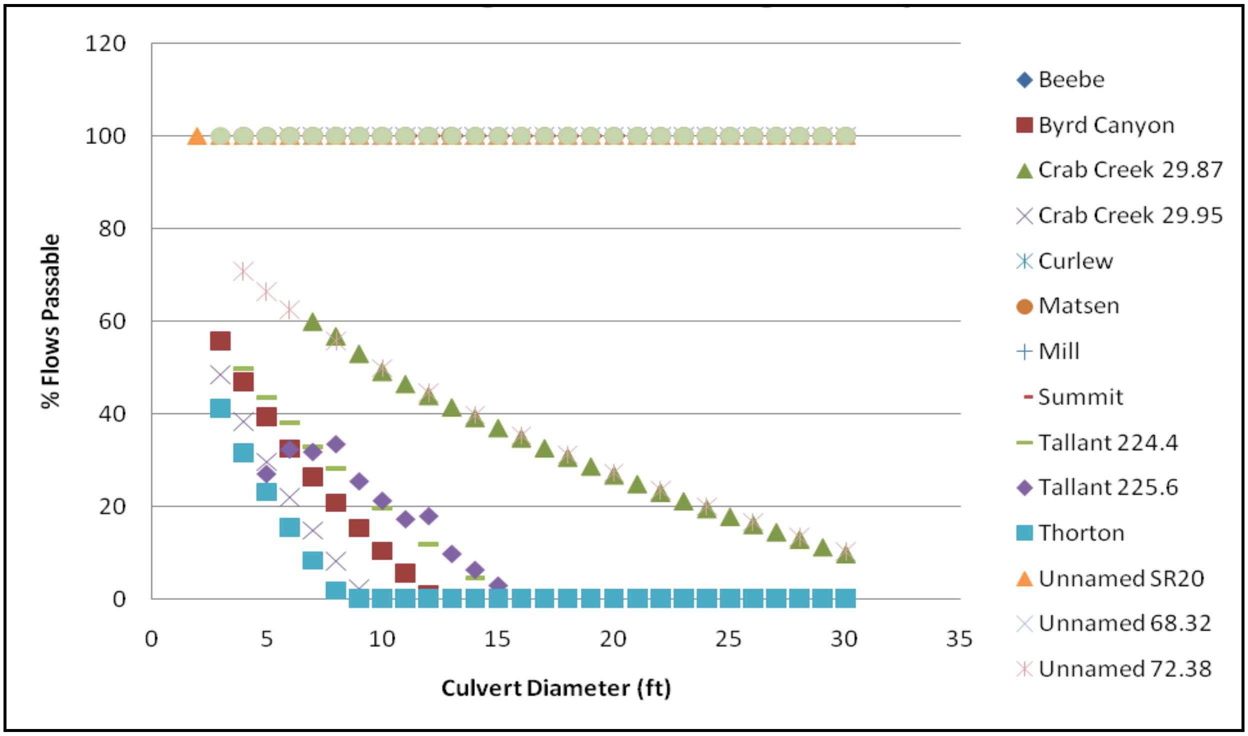


Figure 29: Percent of passable flows versus culvert diameter for the strongest swimming fish species

5.0 CONCLUSIONS and RECOMMENDATIONS

Declining fish populations have become a growing concern around the world as we begin to better understand the concept of ecosystem sustainability. In North America, the survival and restoration of the declining anadromous salmon and resident trout populations are extremely important in the development of water resources management plans. Many small streams in the Pacific Northwest flow under roads through culverts where the very presence of a culvert impacts stream habitat and can create barriers for fish passage. In Washington State, the WSDOT and the WDFW have collaborated to record and, over time, fix all of the fish passage barriers at state highway crossings. However, the SSDM preferred by WDFW produces culverts that are typically much wider than the channel width and very expensive to implement. This research evaluated the trade-offs between culvert replacement cost and the percent of flows passable for adult fish. It was found that culvert design is site specific and in order to most efficiently redesign a cost effective culvert, understanding the hydraulic data is vital to determine whether fish passage is even feasible or needed. If current culvert conditions have slopes comparable to small waterfalls, then 100% fish passage might not be necessary. In addition, if the flows that are impassable are not during fish migration periods or are for very short durations during the year then again, 100% fish passage might not be necessary. Also, utilizing the weakest swimming species as the culvert design target species may result in depth barriers for the strongest swimming fish trying to pass through the culvert.

After conducting this research, it is recommended that multiple options be explored when implementing a new culvert design. The SSDM may not be the most cost effective. Additional research should be conducted using different culvert parameters and fish species to better understand the tradeoffs between percent of passage and cost. This research will allow decision makers to more effectively prioritize how restoration dollars are being spent. Also, by using the methodology developed in this research, policy makers can quickly evaluate the trade-offs between percent passage and cost to decide if 100% passage is necessary at all fish/road crossings.

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Appendix A

CULVERT DESIGN REQUIREMENTS

A-1. Overview of Washington State Design Alternatives

The culvert design guidelines that are depicted in the Washington State Administrative Code (WAC) are under WAC 220-110-070. This outlines the design limitations for satisfying fish passage requirements of water crossing structures where fish are present. Two options to meet fish passage criteria are described in the WAC: (1) the no-slope design option and (2) the hydraulic design option. A third option, used by the WDFW and the WSDOT, which is not currently outlined in the WAC, is the stream simulation design method. Figure A1 shows a flow chart of the culvert design process for fish passage.

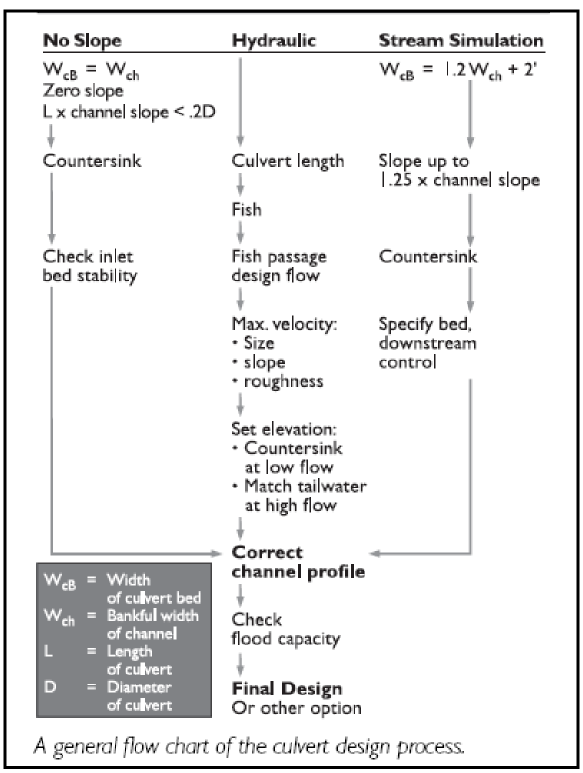

Figure A1: Culvert Design for Fish Passage Flow Chart (Bates et al, 2003)

A-2. No-Slope Design

The purpose of the no-slope design is to simulate a natural channel inside a culvert. This design option for culvert construction is usually applicable for new and replacement culvert installations, simple installations, low to moderate natural channel gradients or culvert lengths (normally less than a 3% slope), or if passage is needed for all species (Bates at el., 2003 and 1999). This option requires minimal calculations, but results in very conservative culvert sizes (Auckland Regional Council). If the culvert is sufficiently large and installed flat, it allows for natural bedload movement which forms a stable bed inside the culvert. As a result, successful fish passage can be expected.

The no-slope option is limited by slope and length and is therefore not applicable to all culverts. Any shape may be used for this design which includes round, pipe-arch, or elliptical. The requirements for the no-slope design are: (1) the culvert bed width must be equal or greater than the average channel bed width, (2) the culvert bed must have a flat gradient, (3) the downstream end of the culvert must be countersunk by a minimum of 20 percent of the culvert's diameter, (4) the upstream end of the culvert can be countersunk only to a maximum of 40 percent of the culvert's diameter, and (5) the design must have adequate flood capacity (WAC, 2000; Bates et al., 2003). A reasonable upper limit for this option for the condition where the natural channel slope (ft/ft) times culvert length (ft) does not exceed 20-percent of the culvert rise (Inter-fluve, 2002). Figure 2 shows a schematic of the no-slope design option.

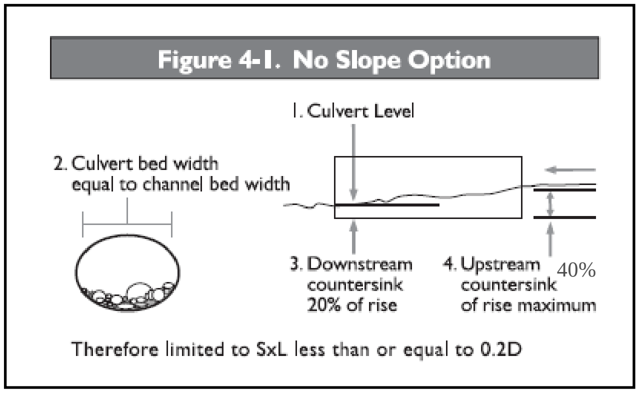

Figure A2: No-slope design option (Bates et al, 2003)

A-3. Hydraulic Design

The Hydraulic Design Option is based on the swimming abilities (velocity, depth, and maximum turbulence requirements) of a specific target fish species and age class associated with a road crossing. Unlike the no-slope design, the hydraulic design option can be applied to retrofits of existing culverts as well as to the design of new or replacement culverts. Historically, this was the preferred method for culvert construction; however this is no longer the case. According to Bates et al. (2003), this design option is not even permitted in some situations.

This design option specifies several design criteria (see Table 2). According to the WAC, the minimum depth of water that is inside the culvert must be met using the two-year seven-day low flow discharge or the ninety-five percent exceedance flow occurring during fish migration months. For the high flow design discharge, velocity requirements must be met. The flow that is not exceeded more than 10 percent of the time during the months of adult fish migration is considered the high flow design discharge. However, the two year peak flood flow may be utilized when stream flow data is unavailable for the stream of interest (WAC, 2000). In addition, the maximum hydraulic drop must be satisfied for all flows between the low and high flow values. Lastly, the bottom of the culvert must be placed below the natural channel grade at a minimum of 20 percent of the culvert diameter (WAC, 2000; Bates et al., 2003).

Appendix B

B-1. EXAMPLE OF CULVERT COST ESTIMATIONS

Anchor Environmental prepared a conceptual design and cost report of three culverts for the city of Olympia, WA and Thurston County (2005). For one culvert the report suggested removing the existing 36 inch culvert and replacing it with a 16 foot diameter steel plate culvert on a 2.4 percent slope. Figure B1.1 outlines the cost estimates determined for this replacement project.

Description	Unit	Quantity	Cost	Amount
1 Mobilization/Demobilization	L.S.	1	$68,442.00	$68,442.00
2 Traffic Control	L.S.	1	$9,900.00	$9,900.00
3 Erosion Control	L.S.	1	$55,550.00	$55,550.00
4 Clear and Grub	acre	2	$5,060.00	$10,120.00
5 Fish Removal	L.S.	1	$550.00	$550.00
6 Dewater	L.S.	1	$11,000.00	$11,000.00
7 Remove Road Fill	C.Y.	26,000	$6.60	$171,600.00
8 Access Road	C.Y.	6,000	$6.60	$39,600.00
9 Access Road Surface	C.Y.	180	$66.00	$11,880.00
10 Disposal	C.Y.	10,000	$4.40	$44,000.00
11 Culvert Bedding	C.Y.	300	$66.00	$19,800.00
12 Culvert 16 foot Structural Plate	feet	165	$1,243.00	$205,095.00
13 Streambed Gravel	C.Y.	600	$88.00	$52,800.00
14 Backfill and Compaction	C.Y.	22,000	$6.60	$145,200.00
15 Removal and Disposal of Culver	L.S.	1	$3,850.00	$3,850.00
16 Road Grading	C.Y.	1,200	$8.80	$10,560.00
17 Guardrail	L.S.	1	$22,000.00	$22,000.00
18 Restore Road Grade	L.S.	1	$31,130.00	$31,130.00
19 Stream Channel Restoration	L.S.	1	$11,000.00	$11,000.00
CONSTRUCTION TOTAL				$924,100.00
Engineering and Administration	20%			$184,800.00
PROJECT TOTAL				$1,108,900.00

Figure B1: Culvert reconstruction costs estimated for Gull Harbor Road (Anchor Environmental, 2005)

Appendix C

CULVERT CALCULATIONS

C-1. Beebe Creek Culvert

Figure C1.1: Downstream end of the Beebe Creek culvert

Figure C1.2: Looking upstream at the downstream end of the Beebe Creek culvert

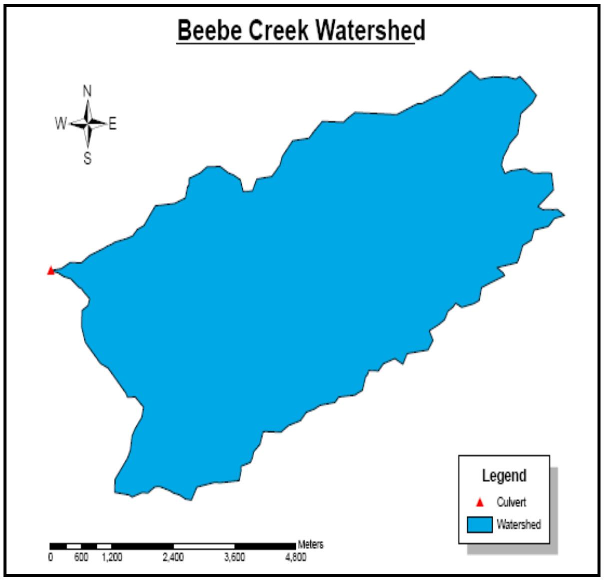

Figure C1.3: Delineated watershed for the Beebe Creek culvert

Comments:

Work has been done on the downstream end of Beebe Creek to create good habitat for spawning adult fish and growing juveniles. A weir is placed directly downstream to create a large pool and a smaller side channel is constructed for better juvenile passage.

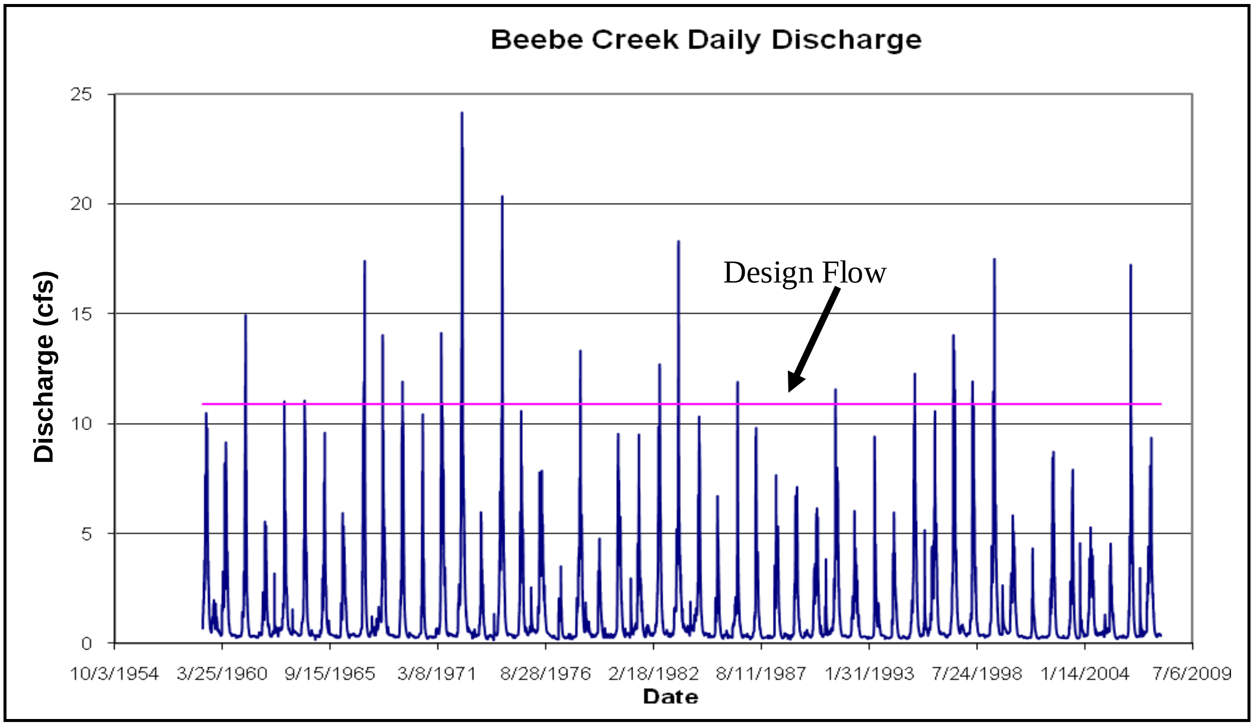

Figure C1.4: Daily stream discharge values for Beebe Creek determined using the USGS Methow River gage

Table C1.1: Beebe Creek culvert's current fish passage summary

BEEBE CREEK INITIAL FISH PASSAGE SUMMARY	
Low Passage Design Flow	0.10 cfs
High Passage Design Flow	25.0 cfs
Percent of Flows Passable	0.20%
Passable Flow Range	0.15 to 0.20 cfs
Depth Barrier	0 to 0.15 cfs
Leap Barriers	None
Velocity Barrier	0.20 cfs and Above
Pool Depth Barrier	None

Table C1.2: Beebe Creek FishXing output for different culvert diameters for the weakest fish

Beebe Creek (Bull Trout, Flows: 0.10 to 25.00)						% Passable Based on Design Flow
Diameter (ft)	% Passable	Flows Passable (cfs)	Barrier	Depth Barrier (cfs)	Velocity Barrier (cfs)	
5	25.40	0.10 to 6.33	Velocity	None	6.34 and above	58.13
6	28.20	0.10 to 7.02	Velocity	None	7.02 and above	64.46
7	31.00	0.10 to 7.73	Velocity	None	7.73 and above	70.98
8	33.30	0.10 to 8.29	Velocity	None	8.29 and above	76.12
9	35.40	0.10 to 8.80	Velocity	None	8.81 and above	80.81
10	37.40	0.10 to 9.31	Velocity	None	9.32 and above	85.49
11	39.30	0.10 to 9.79	Velocity	None	9.79 and above	89.90
12	41.00	0.10 to 10.21	Velocity	None	10.22 and above	93.76
13	42.80	0.10 to 10.65	Velocity	None	10.65 and above	97.80
14	44.50	0.10 to 11.07	Velocity	None	11.07 and above	100.00
15	46.00	0.10 to 11.46	Velocity	None	11.47 and above	100.00
16	47.60	0.10 to 11.86	Velocity	None	11.86 and above	100.00
17	49.00	0.10 to 12.21	Velocity	None	12.21 and above	100.00
18	50.50	0.10 to 12.59	Velocity	None	12.59 and above	100.00
19	51.90	0.10 to 12.93	Velocity	None	12.94 and above	100.00
20	53.30	0.10 to 13.26	Velocity	None	13.27 and above	100.00
21	54.60	0.10 to 13.60	Velocity	None	13.61 and above	100.00
22	55.90	0.10 to 13.92	Velocity	None	13.93 and above	100.00
23	57.20	0.10 to 14.25	Velocity	None	14.26 and above	100.00
24	58.50	0.10 to 14.55	Velocity	None	14.56 and above	100.00
25	59.60	0.10 to 14.85	Velocity	None	14.85 and above	100.00
26	60.90	0.10 to 15.16	Velocity	None	15.16 and above	100.00
27	62.00	0.10 to 15.45	Velocity	None	15.45 and above	100.00
28	63.00	0.10 to 15.70	Velocity	None	15.70 and above	100.00
29	64.30	0.10 to 16.02	Velocity	None	16.02 and above	100.00
30	65.40	0.10 to 16.29	Velocity	None	16.29 and above	100.00

Table C1.3: Beebe Creek FishXing output for different culvert diameters for the strongest fish

Beebe Creek (Steelhead, Flows: 0.1-25.0)						% Passable Based on Design Flow
Depth (ft)	% Passable	Flows Passable (cfs)	Barrier	Depth Barrier (cfs)	Velocity Barrier (cfs)	
5	100.00	0.10 to 25.00	None	None	None	100
30	100.00	0.10 to 25.00	None	None	None	100

C-2. Byrd Canyon Creek

Figure C2.1: Upstream end of the Byrd Canyon Creek culvert

Figure C2.2: Downstream end of the Byrd Canyon Creek culvert

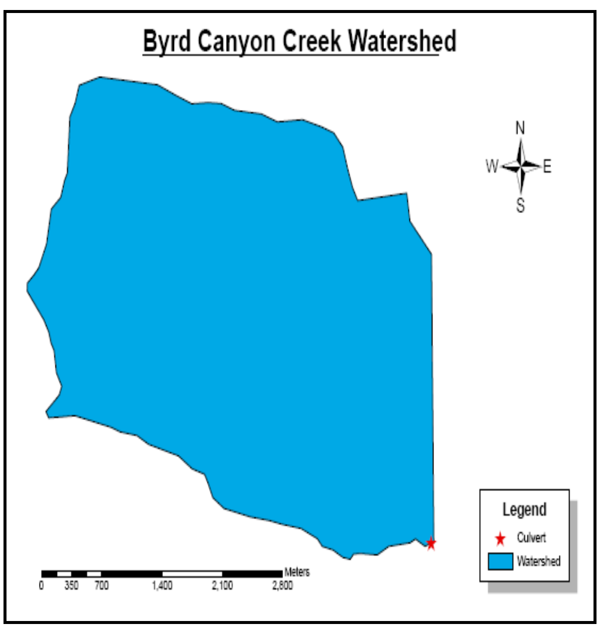

Figure C2.3: Delineated watershed for the Byrd Canyon Creek Watershed

Comments:

Culvert continues under a railroad after Alternative Route 97 before it reaches the outlet into Byrd Canyon Creek.

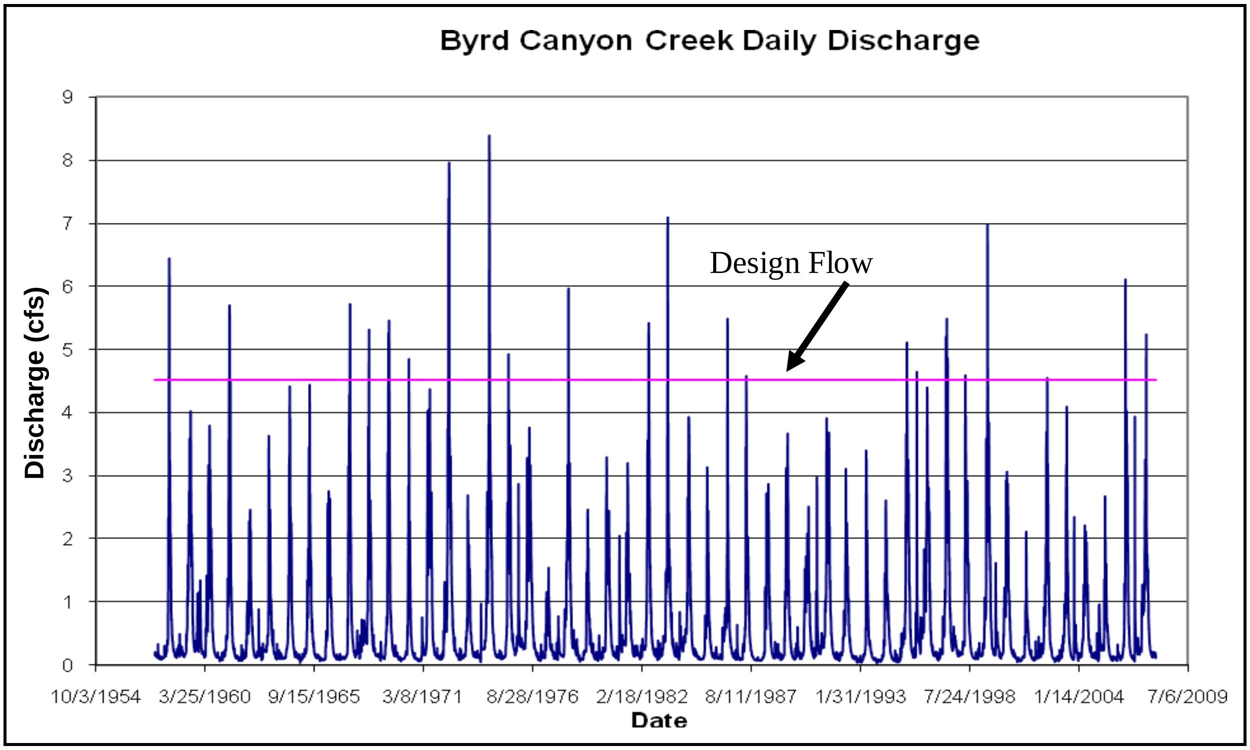

Figure C2.4: Daily stream discharge values for Byrd Canyon Creek determined using the USGS Entiat River gage

Table C2.1: Byrd Canyon Creek culvert's current fish passage summary

BYRD CANYON CREEK INITIAL FISH PASSAGE SUMMARY	
Low Passage Design Flow	0.10 cfs
High Passage Design Flow	10.00 cfs
Percent of Flows Passable	0.00%
Passable Flow Range	None
Depth Barrier	0 to 1.19 cfs
Leap Barriers	None
Velocity Barrier – Long	0.84 cfs and Above
Pool Depth Barrier	None

Table C2.2: Byrd Canyon Creek FishXing output for different culvert diameters for the weakest fish

Byrd Canyon Creek (Bull Trout, 0.10 to 10.0)						% Passable Based on Design Flow
Diameter (ft)	% Passable	Flows Passable (cfs)	Barrier	Depth Barrier (cfs)	Velocity Barrier (cfs)	
3	22.3	0.10 to 2.23	Velocity	None	2.23 and above	49.34
4	25.9	0.10 to 2.59	Velocity	None	2.60 and above	57.30
5	29.1	0.10 to 2.91	Velocity	None	2.92 and above	64.38
6	31.2	0.10 to 3.12	Velocity	None	3.13 and above	69.03
7	36.3	0.10 to 3.63	Velocity	None	3.63 and above	80.31
8	39.0	0.10 to 3.90	Velocity	None	3.90 and above	86.28
9	41.4	0.10 to 4.14	Velocity	None	4.14 and above	91.59
10	43.4	0.10 to 4.34	Velocity	None	4.35 and above	96.02
11	46.0	0.10 to 4.60	Velocity	None	4.60 and above	100.00
12	48.0	0.10 to 4.80	Velocity	None	4.80 and above	100.00
13	49.7	0.10 to 4.97	Velocity	None	4.97 and above	100.00
14	49.9	0.10 to 4.99	Velocity	None	5.00 and above	100.00
15	52.4	0.10 to 5.24	Velocity	None	5.24 and above	100.00
16	55.4	0.10 to 5.54	Velocity	None	5.54 and above	100.00
17	57.0	0.10 to 5.70	Velocity	None	5.70 and above	100.00
18	58.8	0.10 to 5.88	Velocity	None	5.88 and above	100.00
19	60.1	0.10 to 6.01	Velocity	None	6.01 and above	100.00
20	61.2	0.10 to 6.12	Velocity	None	6.13 and above	100.00
21	62.9	0.10 to 6.29	Velocity	None	6.30 and above	100.00
22	64.5	0.10 to 6.45	Velocity	None	6.45 and above	100.00
23	66.4	0.10 to 6.64	Velocity	None	6.64 and above	100.00
24	65.9	0.10 to 6.59	Velocity	None	6.59 and above	100.00
25	67.8	0.10 to 6.78	Velocity	None	6.78 and above	100.00
26	70.3	0.10 to 7.06	Velocity	None	7.06 and above	100.00
27	69.4	0.10 to 6.97	Velocity	None	6.98 and above	100.00
28	72.8	0.10 to 7.31	Velocity	None	7.31 and above	100.00
29	71.3	0.10 to 7.16	Velocity	None	7.16 and above	100.00
30	75.6	0.10 to 7.58	Velocity	None	7.58 and above	100.00

Table C2.3: Byrd Canyon Creek FishXing output for different culvert diameters for the strongest fish

Byrd Canyon Creek (Steelhead, 0.10 to 10.0)						% Passable Based on Design Flow
Depth (ft)	% Passable	Flows Passable (cfs)	Barrier	Depth Barrier (cfs)	Velocity Barrier (cfs)	
3	55.8	4.48 to 10.00	Depth	0 to 4.48	None	0.88
4	46.9	5.35 to 10.00	Depth	0 to 5.35	None	0.00
5	39.3	6.11 to 10.00	Depth	0 to 6.11	None	0.00
6	32.5	6.78 to 10.00	Depth	0 to 6.78	None	0.00
7	26.4	7.39 to 10.00	Depth	0 to 7.39	None	0.00
8	20.7	7.96 to 10.00	Depth	0 to 7.96	None	0.00
9	15.3	8.48 to 10.00	Depth	0 to 8.48	None	0.00
10	10.3	8.98 to 10.00	Depth	0 to 8.98	None	0.00
11	5.5	9.45 to 10.00	Depth	0 to 9.45	None	0.00
12	1.0	9.90 to 10.00	Depth	0 to 9.90	None	0.00
13	0.0	None	Depth	All Flows	None	0.00
14	0.0	None	Depth	All Flows	None	0.00

C-3. Crab Creek Wasteway at Mile Post 29.87

Figure C3.1: Downstream end of the Crab Creek Wasteway culvert at mile post 29.87

Figure C3.2: Downstream of the Crab Creek Wasteway culvert at mile post 29.87

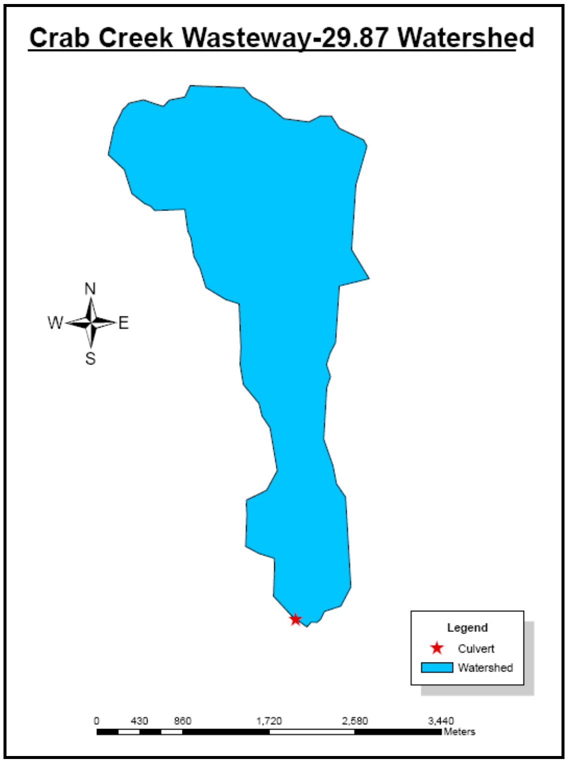

Figure C3.3: Delineated watershed for Crab Creek Wasteway at mile post 29.87

Comments:

A large pool has been scoured out downstream of the culvert. Saw fish in the pool during survey work.

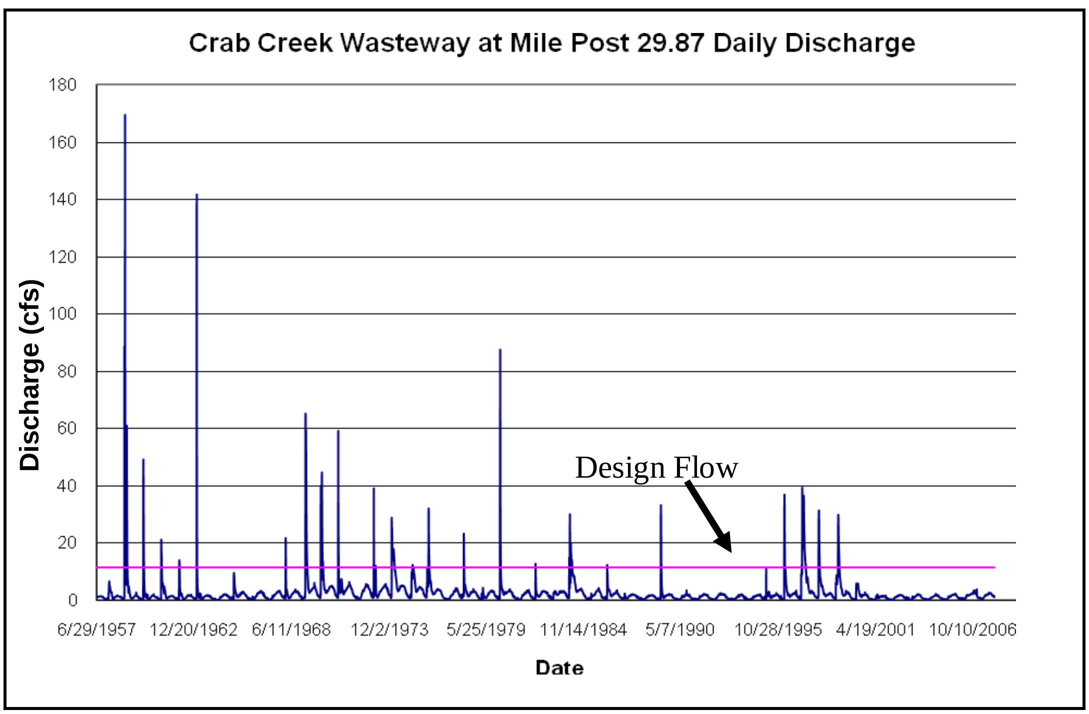

Figure C3.4: Daily stream discharge values for Crab Creek Wasteway at mile post 29.87 determined using the USGS Crab Creek gage

Table C3.1: Crab Creek Wasteway at mile post 29.87 culvert's current fish passage summary

CRAB CREEK WASTEWAY (29.87) INITIAL FISH PASSAGE SUMMARY	
Low Passage Design Flow	0.10 cfs
High Passage Design Flow	285.00 cfs
Percent of Flows Passable	2.10%
Passable Flow Range	0.10 to 5.87 cfs
Depth Barrier	None
Leap Barriers	None
Velocity Barrier	5.87 cfs and Above
Pool Depth Barrier	None

Table C3.2: Crab Creek Wasteway at mile post 29.87 FishXing output for different culvert diameters for the weakest fish

Crab Creek Wasteway at mile post 29.87 (Sockeye Salmon, 0.10 to 150.00)						% Passable Based on Design Flow
Diameter (ft)	% Passable	Flows Passable (cfs)	Barrier	Depth Barrier (cfs)	Velocity Barrier (cfs)	
7	4.10	0.10 to 6.08	Velocity	None	6.08 and above	53.71
8	4.30	0.10 to 6.50	Velocity	None	6.51 and above	57.42
9	4.60	0.10 to 6.93	Velocity	None	6.93 and above	61.22
10	4.90	0.10 to 7.32	Velocity	None	7.32 and above	64.66
11	5.10	0.10 to 7.70	Velocity	None	7.70 and above	68.02
12	5.40	0.10 to 8.06	Velocity	None	8.06 and above	71.20
13	5.60	0.10 to 8.40	Velocity	None	8.40 and above	74.20
14	5.80	0.10 to 8.72	Velocity	None	8.72 and above	77.03
15	6.00	0.10 to 9.05	Velocity	None	9.05 and above	79.95
16	6.20	0.10 to 9.35	Velocity	None	9.36 and above	82.60
17	6.40	0.10 to 9.65	Velocity	None	9.66 and above	85.25
18	6.60	0.10 to 9.94	Velocity	None	9.94 and above	87.81
19	6.80	0.10 to 10.22	Velocity	None	10.23 and above	90.28
20	7.00	0.10 to 10.49	Velocity	None	10.50 and above	92.67
21	7.20	0.10 to 10.76	Velocity	None	10.76 and above	95.05
22	7.30	0.10 to 11.01	Velocity	None	11.02 and above	97.26
23	7.50	0.10 to 11.26	Velocity	None	11.27 and above	99.47
24	7.70	0.10 to 11.52	Velocity	None	11.52 and above	100
25	7.80	0.10 to 11.76	Velocity	None	11.77 and above	100
26	8.00	0.10 to 12.00	Velocity	None	12.00 and above	100
27	8.20	0.10 to 12.23	Velocity	None	12.23 and above	100
28	8.30	0.10 to 12.45	Velocity	None	12.46 and above	100
29	8.50	0.10 to 12.68	Velocity	None	12.69 and above	100
30	8.60	0.10 to 12.91	Velocity	None	12.91 and above	100

Table C3.3: Crab Creek Wasteway at mile post 29.87 FishXing output for different culvert diameters for the strongest fish

Crab Creek Wasteway at mile post 29.87 (Steelhead, 0.10 to 150)						% Passable Based on Design Flow
Diameter (ft)	% Passable	Flows Passable (cfs)	Barrier	Depth Barrier (cfs)	Velocity Barrier (cfs)	
7	48.40	4.53 to 77.07	Depth and Velocity	0 to 4.53	77.07 and above	59.98
8	53.50	4.89 to 85.10	Depth and Velocity	0 to 4.89	85.11 and above	56.80
9	58.20	5.23 to 92.52	Depth and Velocity	0 to 5.23	92.52 and above	53.00
10	62.50	5.76 to 99.43	Depth and Velocity	0 to 5.76	99.43 and above	49.12
11	66.60	6.06 to 105.92	Depth and Velocity	0 to 6.06	105.92 and above	46.47
12	70.50	6.35 to 112.05	Depth and Velocity	0 to 6.35	112.05 and above	43.90
13	74.20	6.63 to 117.88	Depth and Velocity	0 to 6.63	117.89 and above	41.43
14	77.80	6.89 to 123.45	Depth and Velocity	0 to 6.89	123.45 and above	39.13
15	88.10	7.14 to 128.79	Depth and Velocity	0 to 7.14	128.79 and above	36.93
16	95.10	7.39 to 150.0	Depth	0 to 7.39	None	34.72
17	95.00	7.63 to 150.0	Depth	0 to 7.63	None	32.60
18	94.80	7.86 to 150.0	Depth	0 to 7.86	None	30.57
19	94.70	8.08 to 150.0	Depth	0 to 8.08	None	28.62
20	94.50	8.30 to 150.0	Depth	0 to 8.30	None	26.68
21	94.40	8.51 to 150.0	Depth	0 to 8.51	None	24.82
22	94.20	8.72 to 150.0	Depth	0 to 8.72	None	22.97
23	94.10	8.93 to 150.0	Depth	0 to 8.93	None	21.11
24	94.00	9.12 to 150.0	Depth	0 to 9.12	None	19.43
25	93.90	9.31 to 150.0	Depth	0 to 9.31	None	17.76
26	93.70	9.51 to 150.0	Depth	0 to 9.51	None	15.99
27	93.60	9.69 to 150.0	Depth	0 to 9.69	None	14.40
28	93.50	9.87 to 150.0	Depth	0 to 9.87	None	12.81
29	93.40	10.06 to 150.0	Depth	0 to 10.06	None	11.13
30	93.20	10.23 to 150.0	Depth	0 to 10.23	None	9.63

C-4. Crab Creek Wasteway at Mile Post 29.95

Figure C4.1: Upstream from the Crab Creek Wasteway culvert at mile post 29.95

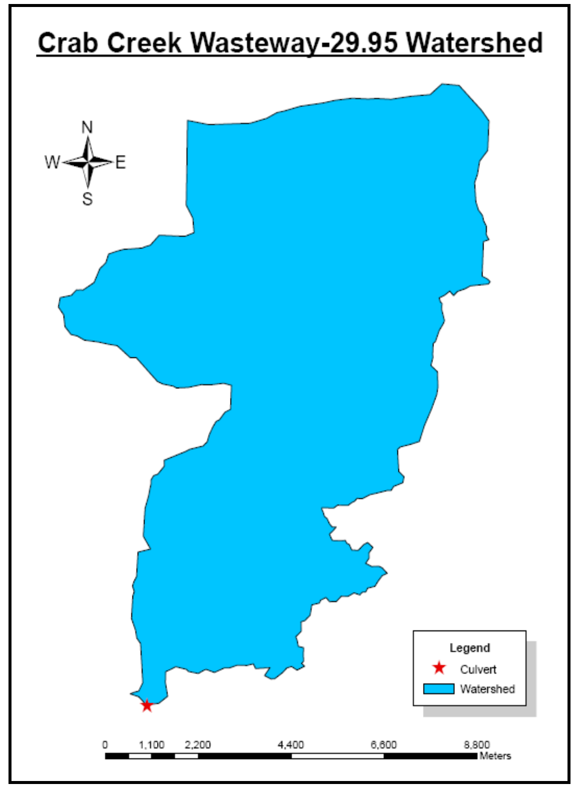

Figure C4.2: Delineated watershed for Crab Creek Wasteway at mile post 29.95

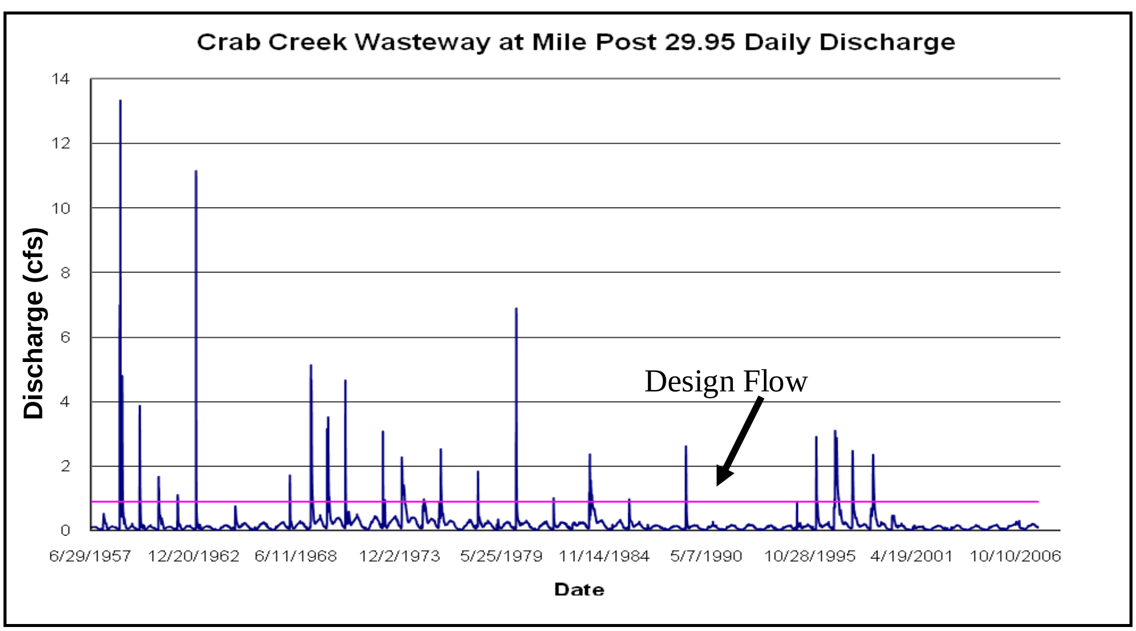

Figure C4.3: Daily stream discharge values for Crab Creek Wasteway at mile post 29.95 determined using the USGS Crab Creek gage

Table C4.1: Crab Creek Wasteway at mile post 29.95 culvert's current fish passage summary

CRAB CREEK WASTEWAY (29.95) INITIAL FISH PASSAGE SUMMARY	
Low Passage Design Flow	0.10 cfs
High Passage Design Flow	25.00 cfs
Percent of Flows Passable	0.00%
Passable Flow Range	None
Depth Barrier	0 to 0.96 cfs
Leap Barriers	None
Velocity Barrier – EB	0.13 cfs and Above
Pool Depth Barrier	None

Table C4.2: Crab Creek Wasteway at mile post 29.95 FishXing output for different culvert diameters for the weakest fish

Crab Creek Wasteway at mile post 29.95 (Sockeye Salmon, 0.10 to 15.00)						% Passable Based on Design Flow
Diameter (ft)	% Passable	Flows Passable (cfs)	Barrier	Depth Barrier (cfs)	Velocity Barrier (cfs)	
3	28.6	0.55 to 4.82	Depth and Velocity	0 to 0.55	4.82 and above	38.20
4	32.8	0.65 to 5.54	Depth and Velocity	0 to 0.65	5.54 and above	26.97
5	37.0	0.73 to 6.24	Depth and Velocity	0 to 0.73	6.24 and above	17.98
6	41.0	0.80 to 6.91	Depth and Velocity	0 to 0.80	6.91 and above	10.11
7	44.6	0.87 to 7.52	Depth and Velocity	0 to 0.87	7.52 and above	2.25
8	47.8	0.93 to 8.05	Depth and Velocity	0 to 0.93	8.06 and above	0.00
9	50.6	0.99 to 8.53	Depth and Velocity	0 to 0.99	8.53 and above	0.00
10	53.0	1.05 to 8.95	Depth and Velocity	0 to 1.05	8.95 and above	0.00
11	55.7	1.10 to 9.40	Depth and Velocity	0 to 1.10	9.40 and above	0.00
12	57.6	1.15 to 9.74	Depth and Velocity	0 to 1.15	9.74 and above	0.00
13	60.4	1.20 to 10.20	Depth and Velocity	0 to 1.20	10.20 and above	0.00
14	62.7	1.24 to 10.58	Depth and Velocity	0 to 1.24	10.58 and above	0.00
15	64.8	1.28 to 10.94	Depth and Velocity	0 to 1.28	10.95 and above	0.00
16	66.9	1.33 to 11.30	Depth and Velocity	0 to 1.33	11.30 and above	0.00
17	68.9	1.37 to 11.64	Depth and Velocity	0 to 1.37	11.64 and above	0.00
18	70.9	1.41 to 11.97	Depth and Velocity	0 to 1.41	11.97 and above	0.00
19	72.4	1.45 to 12.24	Depth and Velocity	0 to 1.45	12.24 and above	0.00
20	74.7	1.49 to 12.61	Depth and Velocity	0 to 1.49	12.61 and above	0.00
21	76.5	1.52 to 12.92	Depth and Velocity	0 to 1.52	12.92 and above	0.00
22	78.2	1.56 to 13.21	Depth and Velocity	0 to 1.56	13.22 and above	0.00
23	80.0	1.59 to 13.51	Depth and Velocity	0 to 1.59	13.51 and above	0.00
24	81.6	1.63 to 13.79	Depth and Velocity	0 to 1.63	13.80 and above	0.00
25	83.3	1.66 to 14.08	Depth and Velocity	0 to 1.66	14.08 and above	0.00
26	85.0	1.70 to 14.36	Depth and Velocity	0 to 1.70	14.36 and above	0.00
27	86.5	1.73 to 14.62	Depth and Velocity	0 to 1.73	14.62 and above	0.00
28	88.1	1.76 to 14.89	Depth and Velocity	0 to 1.76	14.89 and above	0.00
29	88.6	1.79 to 15.00	Depth	0 to 1.79	None	0.00
30	88.4	1.83 to 15.00	Depth	0 to 1.83	None	0.00

Table C4.3: Crab Creek Wasteway at mile post 29.95 FishXing output for different culvert diameters for the strongest fish

Crab Creek Wasteway at mile post 29.95 (Steelhead, 0.10 to 15.00)						% Passable Based on Design Flow
Diameter (ft)	% Passable	Flows Passable (cfs)	Barrier	Depth Barrier (cfs)	Velocity Barrier (cfs)	
3	48.6	7.76 to 15.00	Depth	0 to 7.76	None	0
4	38.4	9.27 to 15.00	Depth	0 to 9.27	None	0
5	29.7	10.58 to 15.00	Depth	0 to 10.58	None	0
6	21.9	11.74 to 15.00	Depth	0 to 11.74	None	0
7	14.8	12.80 to 15.00	Depth	0 to 12.80	None	0
8	8.2	13.78 to 15.00	Depth	0 to 13.78	None	0
9	2.1	14.69 to 15.00	Depth	0 to 14.69	None	0
10	0.0	None	Depth	All Flows	None	0
11	0.0	None	Depth	All Flows	None	0

C-5. Curlew Creek

Figure C5.1: Downstream end of the Curlew Creek culvert

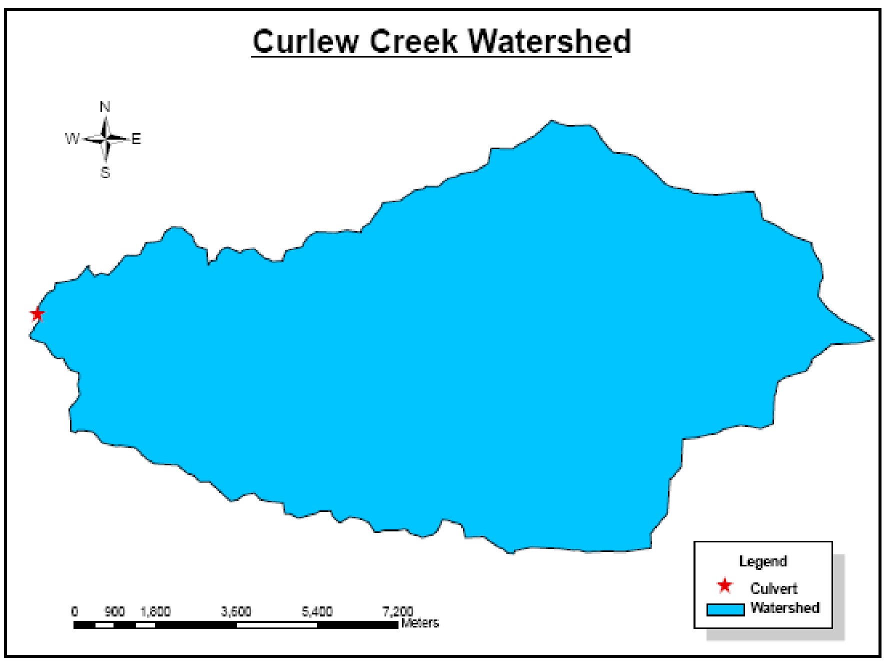

Figure C5.2: Delineated watershed for Curlew Creek

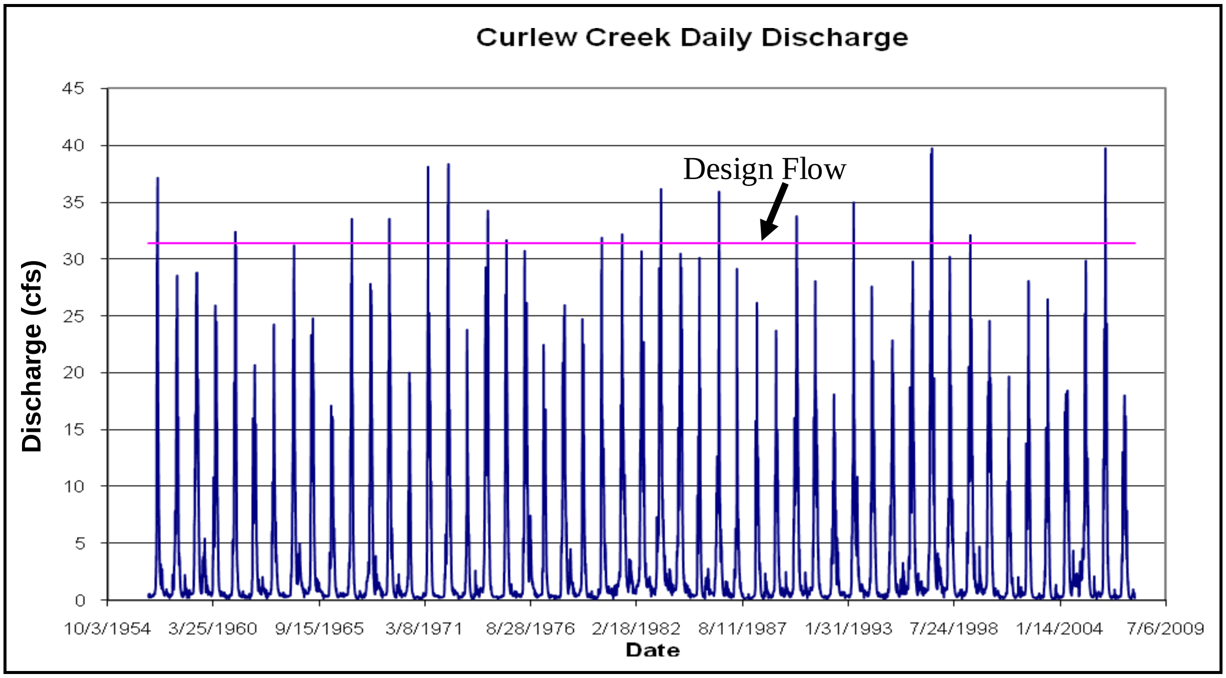

Figure C5.3: Daily stream discharge values for Curlew Creek determined using the USGS Kettle River gage near Ferry, WA

Table C5.1: Curlew Creek culvert's current fish passage summary

CURLEW CREEK INITIAL FISH PASSAGE SUMMARY	
Low Passage Design Flow	0.10 cfs
High Passage Design Flow	40.00 cfs
Percent of Flows Passable	34.40%
Passable Flow Range	0.10 to 13.72 cfs
Depth Barrier	None
Leap Barriers	None
Velocity Barrier – EB	13.73 cfs and Above
Pool Depth Barrier	None

Table C5.2: Curlew Creek FishXing output for different culvert diameters for the weakest fish

Curlew Creek (Sockeye Salmon, 0.10 to 40.00)						% Passable Based on Design Flow
Diameter (ft)	% Passable	Flows Passable (cfs)	Barrier	Depth Barrier (cfs)	Velocity Barrier (cfs)	
6	34.4	0.10 to 13.72	Velocity	None	13.73 and above	43.72
7	37.5	0.10 to 14.96	Velocity	None	14.96 and above	47.67
8	40.1	0.10 to 15.99	Velocity	None	16.00 and above	50.96
9	42.5	0.10 to 16.97	Velocity	None	16.98 and above	54.08
10	44.8	0.10 to 17.89	Velocity	None	17.89 and above	57.01
11	47.0	0.10 to 18.75	Velocity	None	18.75 and above	59.75
12	49.0	0.10 to 19.57	Velocity	None	19.57 and above	62.36
13	51.0	0.10 to 20.36	Velocity	None	20.37 and above	64.88
14	53.0	0.10 to 21.14	Velocity	None	21.15 and above	67.37
15	54.8	0.10 to 21.88	Velocity	None	21.89 and above	69.73
16	56.7	0.10 to 22.62	Velocity	None	22.62 and above	72.08
17	58.4	0.10 to 23.31	Velocity	None	23.31 and above	74.28
18	60.1	0.10 to 23.96	Velocity	None	23.96 and above	76.35
19	61.7	0.10 to 24.63	Velocity	None	24.63 and above	78.49
20	63.3	0.10 to 25.27	Velocity	None	25.27 and above	80.53
21	64.9	0.10 to 25.89	Velocity	None	25.90 and above	82.50
22	66.4	0.10 to 26.49	Velocity	None	26.50 and above	84.42
23	67.9	0.10 to 27.10	Velocity	None	27.10 and above	86.36
24	69.4	0.10 to 27.69	Velocity	None	27.70 and above	88.24
25	70.8	0.10 to 28.25	Velocity	None	28.25 and above	90.03
26	72.2	0.10 to 28.80	Velocity	None	28.81 and above	91.78
27	73.6	0.10 to 29.36	Velocity	None	29.36 and above	93.56
28	74.9	0.10 to 29.90	Velocity	None	29.91 and above	95.28
29	76.3	0.10 to 30.43	Velocity	None	30.44 and above	96.97
30	77.6	0.10 to 30.96	Velocity	None	30.96 and above	98.66
31	78.9	0.10 to 31.46	Velocity	None	31.47 and above	100.00
32	80.1	0.10 to 31.97	Velocity	None	31.98 and above	100.00
33	81.4	0.10 to 32.46	Velocity	None	32.46 and above	100.00
34	82.6	0.10 to 32.95	Velocity	None	32.96 and above	100.00
35	83.8	0.10 to 33.44	Velocity	None	33.45 and above	100.00

Table C5.3: Curlew Creek FishXing output for different culvert diameters for the strongest fish

Curlew Creek (Chinook Salmon, 0.10 to 40.00)						% Passable Based on Design Flow
Diameter (ft)	% Passable	Flows Passable (cfs)	Barrier	Depth Barrier (cfs)	Velocity Barrier (cfs)	
6	100.00	0.10 to 40.00	None	None	None	100
30	100.00	0.10 to 40.00	None	None	None	100

C-6. Matsen Creek

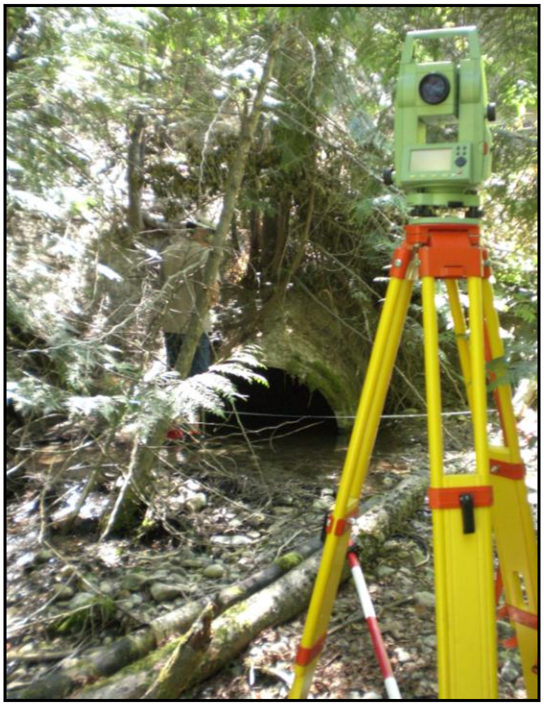

Figure C6.1: Downstream end of the Matsen Creek culvert including the Total Station utilized during survey work

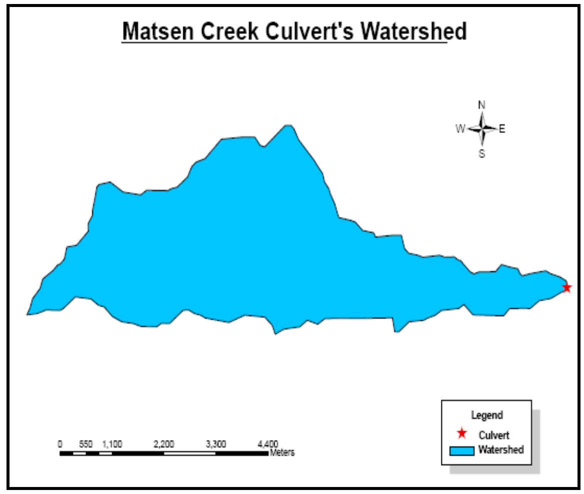

Figure C6.2: Delineated watershed for the Matsen Creek Culvert

Comments:

Culvert was embedded on the downstream end but not on the upstream end.

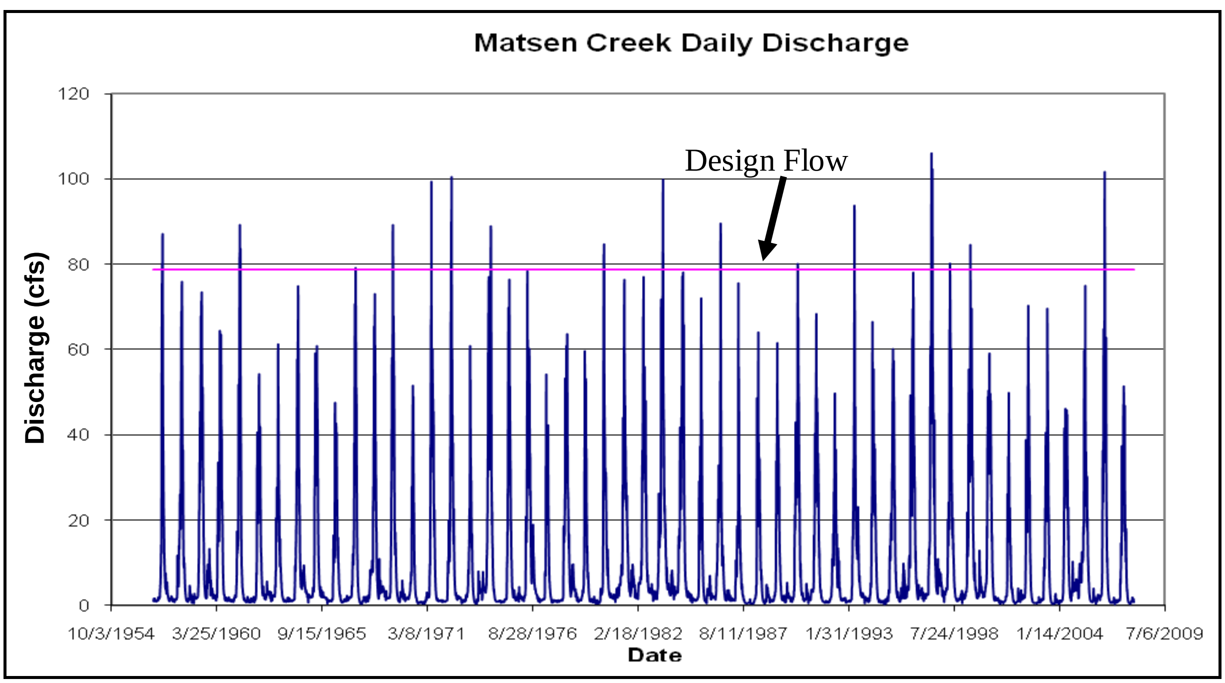

Figure C6.3: Daily stream discharge values for Matsen Creek determined using the USGS Kettle River gage near Laurier, WA

Table C6.1: Matsen Creek culvert's current fish passage summary

MATSEN CREEK INITIAL FISH PASSAGE SUMMARY	
Low Passage Design Flow	0.10 cfs
High Passage Design Flow	15.00 cfs
Percent of Flows Passable	0.00%
Passable Flow Range	None
Depth Barrier	0 to 1.15 cfs
Leap Barriers	None
Velocity Barrier	0.73 cfs and Above
Pool Depth Barrier	None

Table C6.2: Matsen Creek FishXing output for different culvert diameters for the weakest fish

Matsen Creek (Sockeye Salmon, 0.10 to 15.00)						% Passable Based on Design Flow
Diameter (ft)	% Passable	Flows Passable (cfs)	Barrier	Depth Barrier (cfs)	Velocity Barrier (cfs)	
4	30.27	0.10 to 4.54	Velocity	None	4.54 and above	54.37
5	34.27	0.10 to 5.14	Velocity	None	5.14 and above	61.56
6	37.87	0.10 to 5.68	Velocity	None	5.69 and above	68.02
7	41.20	0.10 to 6.18	Velocity	None	6.19 and above	74.01
8	44.27	0.10 to 6.64	Velocity	None	6.64 and above	79.52
9	47.13	0.10 to 7.07	Velocity	None	7.07 and above	84.67
10	49.80	0.10 to 7.47	Velocity	None	7.48 and above	89.46
11	52.40	0.10 to 7.86	Velocity	None	7.86 and above	94.13
12	54.80	0.10 to 8.22	Velocity	None	8.22 and above	98.44
13	57.13	0.10 to 8.57	Velocity	None	8.57 and above	100.00
14	59.40	0.10 to 8.91	Velocity	None	8.91 and above	100.00
15	61.53	0.10 to 9.23	Velocity	None	9.23 and above	100.00
16	63.67	0.10 to 9.55	Velocity	None	9.55 and above	100.00
17	65.60	0.10 to 9.84	Velocity	None	9.85 and above	100.00
18	67.60	0.10 to 10.14	Velocity	None	10.14 and above	100.00
19	69.53	0.10 to 10.43	Velocity	None	10.43 and above	100.00
20	71.33	0.10 to 10.70	Velocity	None	10.70 and above	100.00
21	73.13	0.10 to 10.97	Velocity	None	10.97 and above	100.00
22	74.93	0.10 to 11.24	Velocity	None	11.25 and above	100.00
23	76.67	0.10 to 11.50	Velocity	None	11.50 and above	100.00
24	78.33	0.10 to 11.75	Velocity	None	11.75 and above	100.00
25	79.93	0.10 to 11.99	Velocity	None	12.00 and above	100.00
26	81.60	0.10 to 12.24	Velocity	None	12.25 and above	100.00
27	83.20	0.10 to 12.48	Velocity	None	12.48 and above	100.00
28	84.67	0.10 to 12.70	Velocity	None	12.71 and above	100.00
29	86.27	0.10 to 12.94	Velocity	None	12.94 and above	100.00
30	87.73	0.10 to 13.16	Velocity	None	13.16 and above	100.00

Table C6.3: Matsen Creek FishXing output for different culvert diameters for the strongest fish

Matsen Creek (Chinook Salmon, 0.10 to 15.0)						% Passable Based on Design Flow
Diameter (ft)	% Passable	Flows Passable (cfs)	Barrier	Depth Barrier (cfs)	Velocity Barrier (cfs)	
4	100	All Flows	None	None	None	100
30	100	All Flows	None	None	None	100

C-7. Mill Creek

Figure C7.1: Downstream end of the Mill Creek culvert

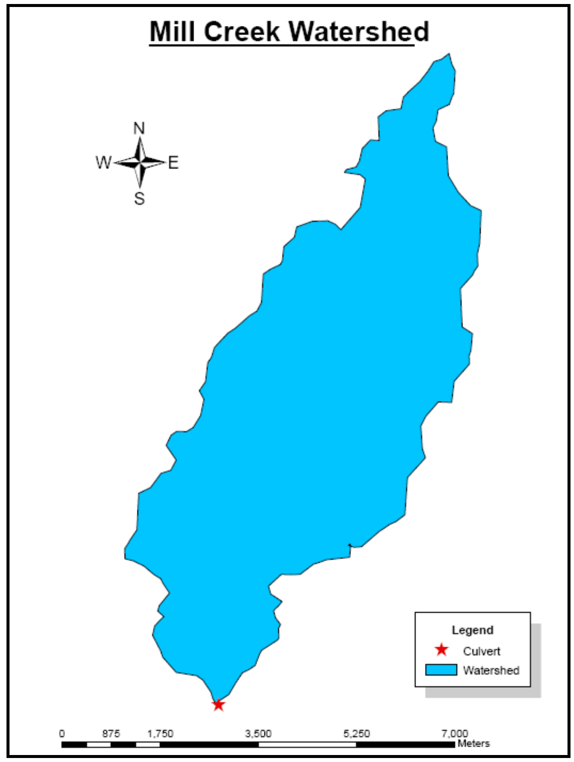

Figure C7.2: Delineated watershed for the Mill Creek culvert

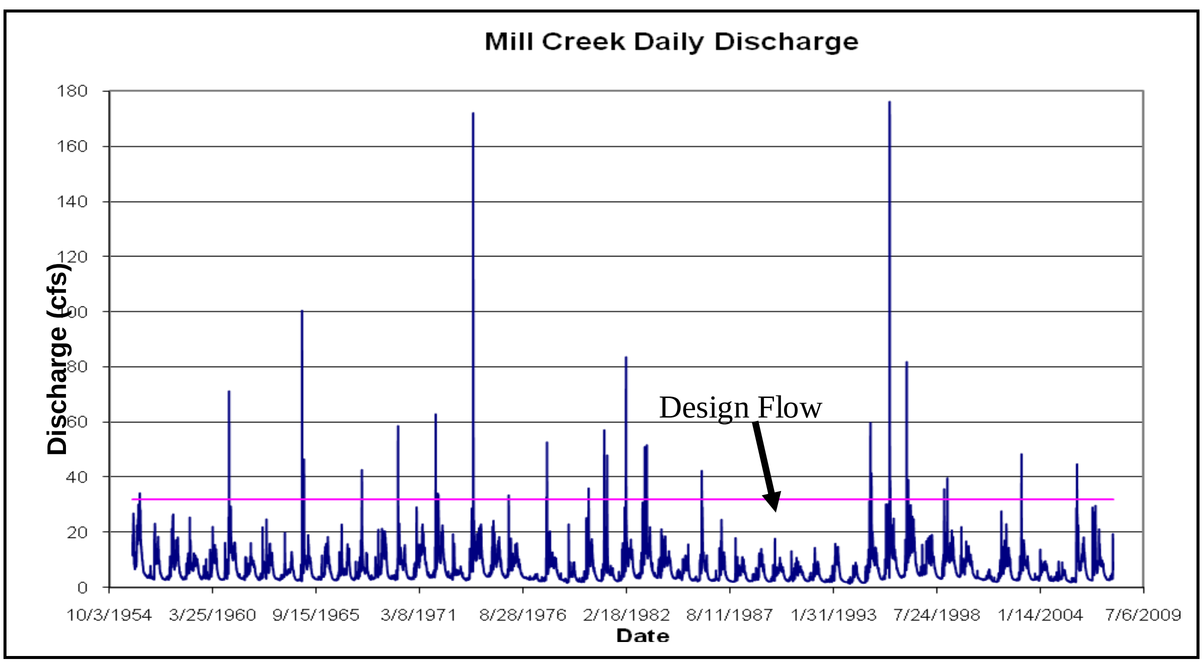

Figure C7.3: Daily stream discharge values for Mill Creek determined using the USGS Klickitat River gage

Table C7.1: Matsen Creek culvert's current fish passage summary

MILL CREEK INITIAL FISH PASSAGE SUMMARY	
Low Passage Design Flow	0.10 cfs
High Passage Design Flow	180.0 cfs
Percent of Flows Passable	6.0%
Passable Flow Range	0.10 to 10.72 cfs
Depth Barrier	None
Leap Barriers	None
Velocity Barrier – EB	10.72 cfs and Above
Pool Depth Barrier	None

Table C7.2: Mill Creek FishXing output for different culvert diameters for the weakest fish

Mill Creek (Bull Trout, 0.10 to 50.00)						% Passable Based on Design Flow
Diameter (ft)	% Passable	Flows Passable (cfs)	Barrier	Depth Barrier (cfs)	Velocity Barrier (cfs)	
6.5	24.10	0.10 to 12.05	Velocity	None	12.05 and above	37.59
7	25.20	0.10 to 12.59	Velocity	None	12.59 and above	39.27
8	27.20	0.10 to 13.59	Velocity	None	13.59 and above	42.39
9	29.10	0.10 to 14.53	Velocity	None	14.53 and above	45.32
10	30.90	0.10 to 15.40	Velocity	None	15.40 and above	48.03
11	32.50	0.10 to 16.21	Velocity	None	16.21 and above	50.56
12	34.00	0.10 to 16.99	Velocity	None	16.99 and above	52.99
13	35.50	0.10 to 17.72	Velocity	None	17.73 and above	55.27
14	36.90	0.10 to 18.44	Velocity	None	18.44 and above	57.52
15	38.30	0.10 to 19.13	Velocity	None	19.13 and above	59.67
16	39.70	0.10 to 19.79	Velocity	None	19.80 and above	61.73
17	40.90	0.10 to 20.43	Velocity	None	20.43 and above	63.72
18	42.20	0.10 to 21.05	Velocity	None	21.06 and above	65.66
19	43.40	0.10 to 21.67	Velocity	None	21.67 and above	67.59
20	44.60	0.10 to 22.25	Velocity	None	22.25 and above	69.40
21	45.70	0.10 to 22.82	Velocity	None	22.82 and above	71.18
22	46.90	0.10 to 23.39	Velocity	None	23.39 and above	72.96
23	47.90	0.10 to 23.92	Velocity	None	23.93 and above	74.61
24	49.00	0.10 to 24.46	Velocity	None	24.46 and above	76.29
25	50.10	0.10 to 24.99	Velocity	None	24.99 and above	77.95
26	51.10	0.10 to 25.49	Velocity	None	25.49 and above	79.51
27	52.10	0.10 to 25.98	Velocity	None	25.98 and above	81.04
28	53.00	0.10 to 26.47	Velocity	None	26.47 and above	82.56
29	54.00	0.10 to 26.96	Velocity	None	26.96 and above	84.09
30	55.00	0.10 to 27.44	Velocity	None	27.44 and above	85.59

Table C7.3: Mill Creek FishXing output for different culvert diameters for the strongest fish

Mill Creek (Steelhead, 0.10 to 50.0)					
Diameter (ft)	% Passable	Flows Passable (cfs)	Barrier	Depth Barrier (cfs)	Velocity Barrier (cfs)
7	100.00	All Flows	None	None	None
30	100.00	All Flows	None	None	None

C-8. Summit Creek

Figure C8.1: Downstream end of the Summit Creek culvert

Figure C8.2: Downstream of the Summit Creek culvert

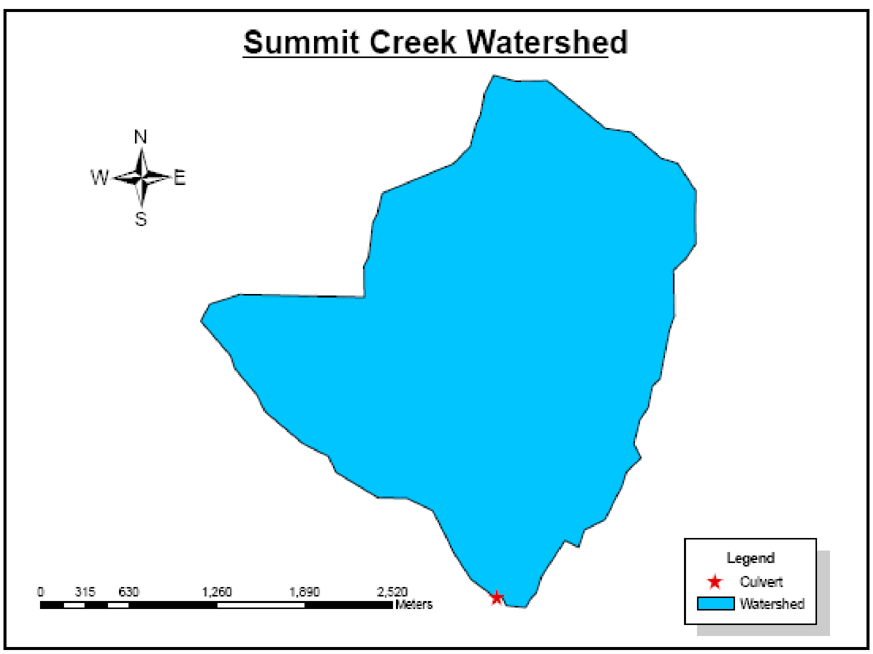

Figure C8.3: Delineated watershed for the Summit Creek culvert

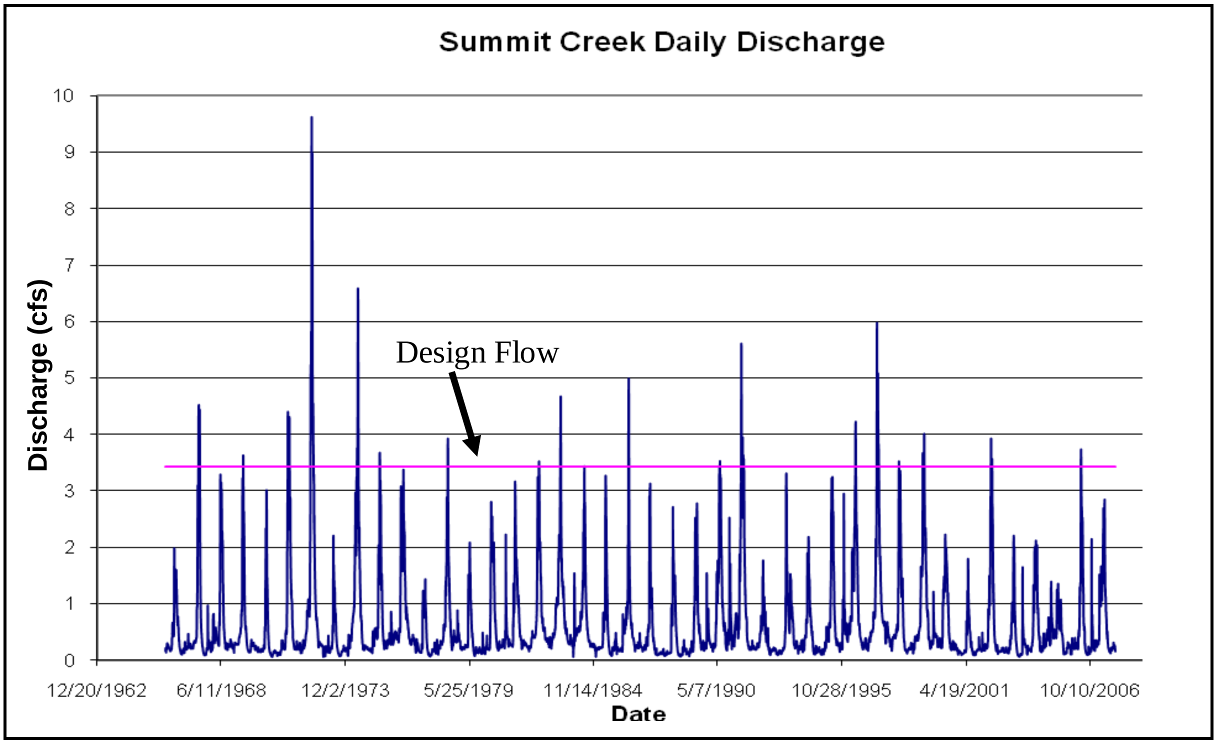

Figure C8.4: Daily stream discharge values for Summit Creek determined using the USGS Okanogan River gage

Table C8.1: Summit Creek culvert's current fish passage summary

SUMMIT CREEK INITIAL FISH PASSAGE SUMMARY	
Low Passage Design Flow	0.10 cfs
High Passage Design Flow	10.00 cfs
Percent of Flows Passable	0.00%
Passable Flow Range	None
Depth Barrier	0 to 1.09 cfs
Leap Barriers	None
Velocity Barrier – Long	0.12 cfs and Above
Pool Depth Barrier	None

Table C8.2: Summit Creek FishXing output for different culvert diameters for the weakest fish

Summit Creek (Bull Trout, 0.10 to 10.0)						% Passable Based on Design Flow
Diameter (ft)	% Passable	Flows Passable (cfs)	Barrier	Depth Barrier (cfs)	Velocity Barrier (cfs)	
3	33.70	0.10 to 3.37	Velocity	None	3.37 and above	98.54
4	39.80	0.10 to 3.98	Velocity	None	3.98 and above	100.00
5	45.00	0.10 to 4.50	Velocity	None	4.51 and above	100.00
6	49.70	0.10 to 4.97	Velocity	None	4.98 and above	100.00
7	53.00	0.10 to 5.30	Velocity	None	5.30 and above	100.00
8	56.90	0.10 to 5.69	Velocity	None	5.69 and above	100.00
9	60.50	0.10 to 6.05	Velocity	None	6.05 and above	100.00
10	63.90	0.10 to 6.39	Velocity	None	6.40 and above	100.00
11	67.20	0.10 to 6.72	Velocity	None	6.72 and above	100.00
12	70.30	0.10 to 7.03	Velocity	None	7.04 and above	100.00
13	73.30	0.10 to 7.33	Velocity	None	7.33 and above	100.00
14	76.10	0.10 to 7.61	Velocity	None	7.62 and above	100.00
15	78.90	0.10 to 7.89	Velocity	None	7.89 and above	100.00
16	81.50	0.10 to 8.15	Velocity	None	8.15 and above	100.00
17	84.10	0.10 to 8.41	Velocity	None	8.41 and above	100.00
18	86.50	0.10 to 8.65	Velocity	None	8.66 and above	100.00
19	89.10	0.10 to 8.91	Velocity	None	8.91 and above	100.00
20	91.40	0.10 to 9.14	Velocity	None	9.14 and above	100.00
21	93.70	0.10 to 9.37	Velocity	None	9.37 and above	100.00
22	95.90	0.10 to 9.59	Velocity	None	9.59 and above	100.00
23	98.00	0.10 to 9.80	Velocity	None	9.81 and above	100.00
24	100.00	0.10 to 10.03	Velocity	None	10.03 and above	100.00
25	100.00	0.10 to 10.24	Velocity	None	10.25 and above	100.00
26	100.00	0.10 to 10.45	Velocity	None	10.45 and above	100.00
27	100.00	0.10 to 10.64	Velocity	None	10.65 and above	100.00
28	100.00	0.10 to 10.84	Velocity	None	10.84 and above	100.00
29	100.00	0.10 to 11.04	Velocity	None	11.04 and above	100.00
30	100.00	0.10 to 11.24	Velocity	None	11.24 and above	100.00

Table C8.3: Summit Creek FishXing output for different culvert diameters for the strongest fish

Summit Creek (Steelhead0.10 to 20.0)						% Passable Based on Design Flow
Diameter (ft)	% Passable	Flows Passable (cfs)	Barrier	Depth Barrier (cfs)	Velocity Barrier (cfs)	
3	100.00	All Flows	None	None	None	100
20	100.00	All Flows	None	None	None	100
30	100.00	All Flows	None	None	None	100

C-9. Tallant Creek at Mile Post 225.6

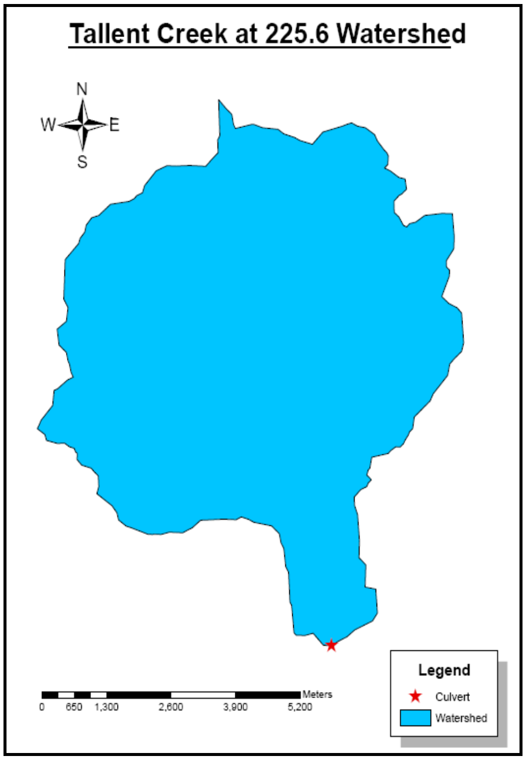

Figure C9.1: Delineated watershed for the Tallant Creek culvert at mile post 225.6

Table C9.1: Tallant Creek at mile post 225.6 culvert's current fish passage summary

TALLANT CREEK(225.6) INITIAL FISH PASSAGE SUMMARY	
Low Passage Design Flow	0.10 cfs
High Passage Design Flow	45.00 cfs
Percent of Flows Passable	12.70%
Passable Flow Range	0.10 -5.70 cfs
Depth Barrier	None
Leap Barriers	None
Velocity Barrier	5.7 cfs-Above
Pool Depth Barrier	None

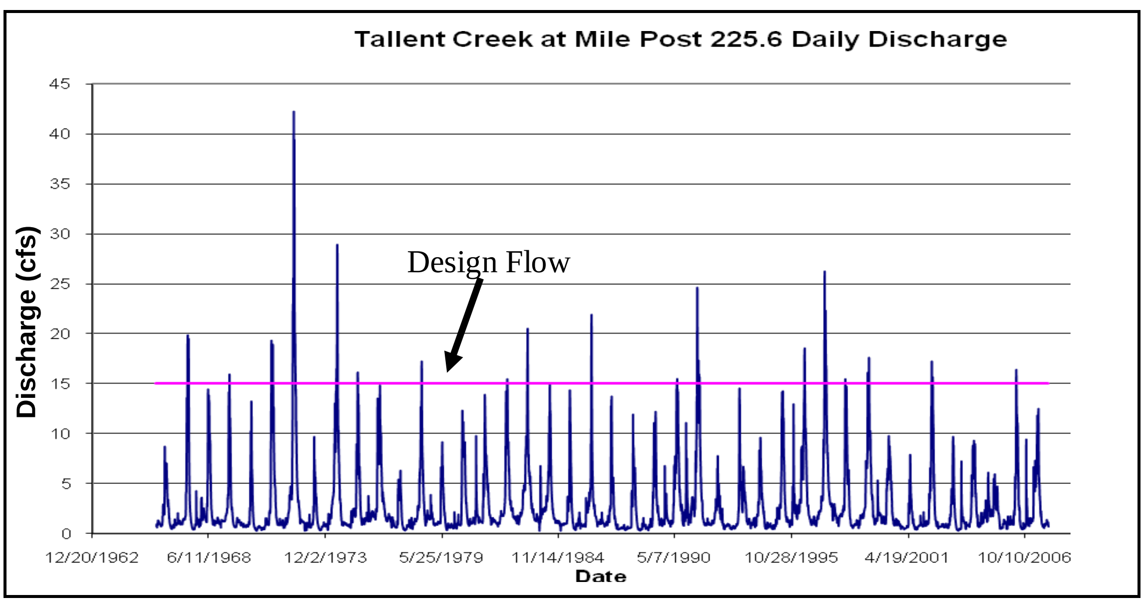

Figure C9.2: Daily stream discharge values for Tallant Creek at mile post 225.6 determined using the USGS Okanogan River gage

Table C9.2: Tallant Creek at mile post 225.6 FishXing output for different culvert diameters for the weakest fish

Tallant Creek at mile post 225.6 (Bull Trout, 0.10 to 45.0)						% Passable Based on Design Flow
Diameter (ft)	% Passable	Flows Passable (cfs)	Barrier	Depth Barrier (cfs)	Velocity Barrier (cfs)	
5	12.50	0.10 to 5.70	Velocity	None	5.70 and above	37.97
6	13.70	0.10 to 6.24	Velocity	None	6.25 and above	41.57
7	14.50	0.10 to 6.63	Velocity	None	6.63 and above	44.17
8	15.60	0.10 to 7.11	Velocity	None	7.11 and above	47.37
9	16.40	0.10 to 7.45	Velocity	None	7.46 and above	49.63
10	17.50	0.10 to 7.95	Velocity	None	7.95 and above	52.96
11	18.40	0.10 to 8.38	Velocity	None	8.38 and above	55.83
12	19.50	0.10 to 8.85	Velocity	None	8.86 and above	58.96
13	20.10	0.10 to 9.14	Velocity	None	9.15 and above	60.89
14	20.80	0.10 to 9.45	Velocity	None	9.46 and above	62.96
15	21.60	0.10 to 9.78	Velocity	None	9.79 and above	65.16
16	22.00	0.10 to 9.99	Velocity	None	10.00 and above	66.56
17	23.20	0.10 to 10.50	Velocity	None	10.51 and above	69.95
18	24.30	0.10 to 11.01	Velocity	None	11.01 and above	73.35
19	24.70	0.10 to 11.21	Velocity	None	11.21 and above	74.68
20	24.20	0.10 to 10.98	Velocity	None	10.98 and above	73.15
21	25.50	0.10 to 11.53	Velocity	None	11.53 and above	76.82
22	26.40	0.10 to 11.96	Velocity	None	11.96 and above	79.68
23	27.00	0.10 to 12.22	Velocity	None	12.22 and above	81.41
24	26.60	0.10 to 12.05	Velocity	None	12.05 and above	80.28
25	27.20	0.10 to 12.30	Velocity	None	12.31 and above	81.95
26	28.30	0.10 to 12.82	Velocity	None	12.83 and above	85.41
27	28.90	0.10 to 13.05	Velocity	None	13.06 and above	86.94
28	30.00	0.10 to 13.55	Velocity	None	13.55 and above	90.27
29	29.60	0.10 to 13.39	Velocity	None	13.39 and above	89.21
30	30.30	0.10 to 13.71	Velocity	None	13.71 and above	91.34
40	35.20	0.10 to 15.89	Velocity	None	15.89 and above	100.00
50	38.50	0.10 to 17.39	Velocity	None	17.40 and above	100.00

Table C9.3: Tallant Creek at mile post 225.6 FishXing output for different culvert diameters for the strongest fish

Tallant Creek at mile post 225.6 (Steelhead, 0.10 to 45.0)						% Passable Based on Design Flow
Diameter (ft)	% Passable	Flows Passable (cfs)	Barrier	Depth Barrier (cfs)	Velocity Barrier (cfs)	
5	21.70	0.10 to 12.14	Depth and Velocity	0 to 8.08	12.14 and above	27.05
6	29.90	0.10 to 13.44	Depth and Velocity	0 to 8.58	13.44 and above	32.38
7	25.40	0.10 to 14.58	Depth and Velocity	0 to 9.80	14.58 and above	31.85
8	28.50	0.10 to 15.66	Depth and Velocity	0 to 9.98	15.67 and above	33.51
9	28.90	0.10 to 16.73	Depth and Velocity	0 to 11.19	16.73 and above	25.45
10	30.80	0.10 to 17.69	Depth and Velocity	0 to 11.82	17.69 and above	21.25
11	32.20	0.10 to 18.50	Depth and Velocity	0 to 12.42	18.50 and above	17.26
12	35.90	0.10 to 19.59	Depth and Velocity	0 to 12.32	19.59 and above	17.92
13	35.50	0.10 to 20.36	Depth and Velocity	0 to 13.55	20.37 and above	9.73
14	37.10	0.10 to 21.29	Depth and Velocity	0 to 14.07	21.29 and above	6.26
15	37.70	0.10 to 21.17	Depth and Velocity	0 to 14.58	21.72 and above	2.86
16	38.50	0.10 to 22.35	Depth and Velocity	0 to 15.07	22.35 and above	0.00
17	40.10	0.10 to 23.05	Depth and Velocity	0 to 15.54	22.05 and above	0.00
18	41.90	0.10 to 23.83	Depth and Velocity	0 to 16.01	23.83 and above	0.00
19	43.00	0.10 to 24.55	Depth and Velocity	0 to 16.46	24.55 and above	0.00
20	43.70	0.10 to 25.52	Depth and Velocity	0 to 16.89	25.53 and above	0.00
21	44.60	0.10 to 25.82	Depth and Velocity	0 to 17.32	25.82 and above	0.00
22	47.60	0.10 to 26.27	Depth and Velocity	0 to 16.87	26.27 and above	0.00
23	47.70	0.10 to 27.35	Depth and Velocity	0 to 18.14	27.36 and above	0.00
24	47.30	0.10 to 27.71	Depth and Velocity	0 to 18.54	27.72 and above	0.00
25	50.70	0.10 to 28.39	Depth and Velocity	0 to 17.93	28.39 and above	0.00
26	49.70	0.10 to 28.81	Depth and Velocity	0 to 19.30	28.82 and above	0.00
27	50.40	0.10 to 29.24	Depth and Velocity	0 to 19.68	29.24 and above	0.00
28	51.80	0.10 to 29.76	Depth and Velocity	0 to 20.05	29.77 and above	0.00
29	50.70	0.10 to 30.63	Depth and Velocity	0 to 21.27	30.64 and above	0.00
30	55.20	0.10 to 30.73	Depth and Velocity	0 to 19.66	30.74 and above	0.00

C-10. Tallant Creek at mile post 224.4

Figure C10.1: Tallant Creek downstream end of the culvert at mile post 224.4

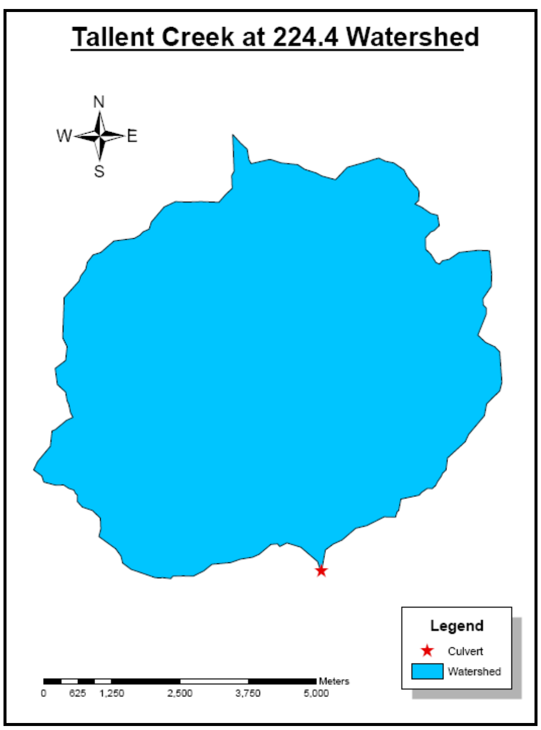

Figure C10.2: Delineated watershed for the Tallant Creek culvert at mile post 224.4

Table C10.1: Tallant Creek at mile post 224.4 culvert's current fish passage summary

TALLANT CREEK (224.4) INITIAL FISH PASSAGE SUMMARY	
Low Passage Design Flow	0.10 cfs
High Passage Design Flow	40.00 cfs
Percent of Flows Passable	0.00%
Passable Flow Range	None
Depth Barrier	0 to 0.25 cfs
Leap Barriers	None
Velocity Barrier	0.10 cfs-above
Pool Depth Barrier	None

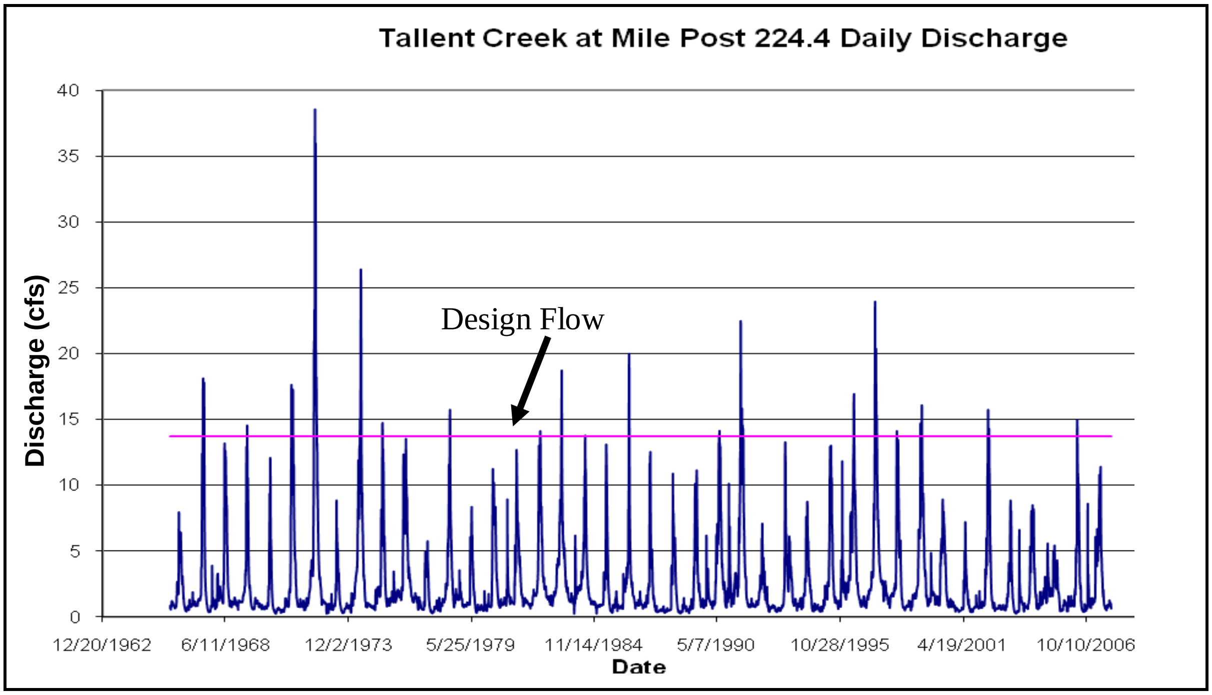

Figure C10.3: Daily stream discharge values for Tallant Creek at mile post 224.4 determined using the USGS Okanogan River gage

Table C10.2: Tallant Creek at mile post 224.4 FishXing output for different culvert diameters for the weakest fish

Tallant Creek at mile post 224.4 (Bull Trout, 0.10 to 40.00)						% Passable Based on Design Flow
Diameter (ft)	% Passable	Flows Passable (cfs)	Barrier	Depth Barrier (cfs)	Velocity Barrier (cfs)	
4	4.00	0.10 to 1.60	Velocity	None	1.60 and above	11.68
5	4.50	0.10 to 1.80	Velocity	None	1.81 and above	13.14
6	5.00	0.10 to 1.99	Velocity	None	1.99 and above	14.53
7	5.40	0.10 to 2.15	Velocity	None	2.15 and above	15.69
8	5.80	0.10 to 2.31	Velocity	None	2.31 and above	16.86
10	6.50	0.10 to 2.58	Velocity	None	2.59 and above	18.83
12	7.10	0.10 to 2.84	Velocity	None	2.84 and above	20.73
14	7.70	0.10 to 3.07	Velocity	None	3.07 and above	22.41
16	8.20	0.10 to 3.28	Velocity	None	3.28 and above	23.94
18	8.70	0.10 to 3.48	Velocity	None	3.49 and above	25.40
20	9.20	0.10 to 3.68	Velocity	None	3.68 and above	26.86
22	9.70	0.10 to 3.86	Velocity	None	3.86 and above	28.18
24	10.10	0.10 to 4.02	Velocity	None	4.03 and above	29.34
26	10.50	0.10 to 4.20	Velocity	None	4.20 and above	30.66
28	10.90	0.10 to 4.35	Velocity	None	4.35 and above	31.75
30	11.30	0.10 to 4.50	Velocity	None	4.50 and above	32.85

Table C10.3: Tallant Creek at mile post 224.4 FishXing output for different culvert diameters for the strongest fish

Tallant Creek at mile post 224.4 (Steelhead, 0.10 to 40.0)						% Passable Based on Design Flow
Diameter (ft)	% Passable	Flows Passable (cfs)	Barrier	Depth Barrier (cfs)	Velocity Barrier (cfs)	
4	83.00	6.88 to 40.00	Depth	0 to 6.88	None	49.78
5	80.90	7.72 to 40.00	Depth	0 to 7.72	None	43.65
6	79.00	8.48 to 40.00	Depth	0 to 8.48	None	38.10
7	77.30	9.18 to 40.00	Depth	0 to 9.18	None	32.99
8	75.60	9.82 to 40.00	Depth	0 to 9.82	None	28.32
10	72.70	11.0 to 40.00	Depth	0 to 11.00	None	19.71
12	70.00	12.07 to 40.00	Depth	0 to 12.07	None	11.90
14	67.50	13.05 to 40.00	Depth	0 to 13.05	None	4.74
16	65.30	13.96 to 40.00	Depth	0 to 13.96	None	0.00
18	63.10	14.82 to 40.00	Depth	0 to 14.82	None	0.00
20	61.10	15.63 to 40.00	Depth	0 to 15.63	None	0.00
22	59.20	16.40 to 40.00	Depth	0 to 16.40	None	0.00
24	57.30	17.14 to 40.00	Depth	0 to 17.14	None	0.00
26	55.50	17.84 to 40.00	Depth	0 to 17.84	None	0.00
28	53.80	18.52 to 40.00	Depth	0 to 18.52	None	0.00
30	52.20	19.17 to 40.00	Depth	0 to 19.17	None	0.00

C-11. Thorton Creek

Figure C11.1: Downstream end of the Thorton Creek culvert

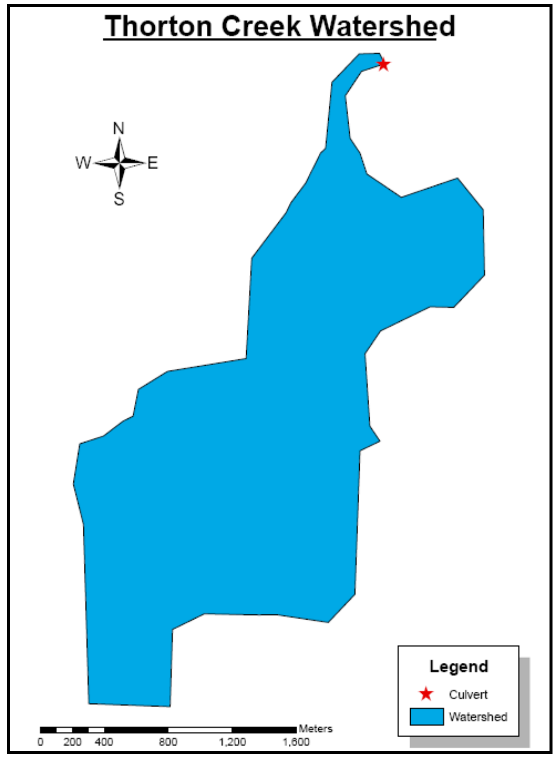

Figure C11.2: Delineated watershed for the Thorton Creek culvert

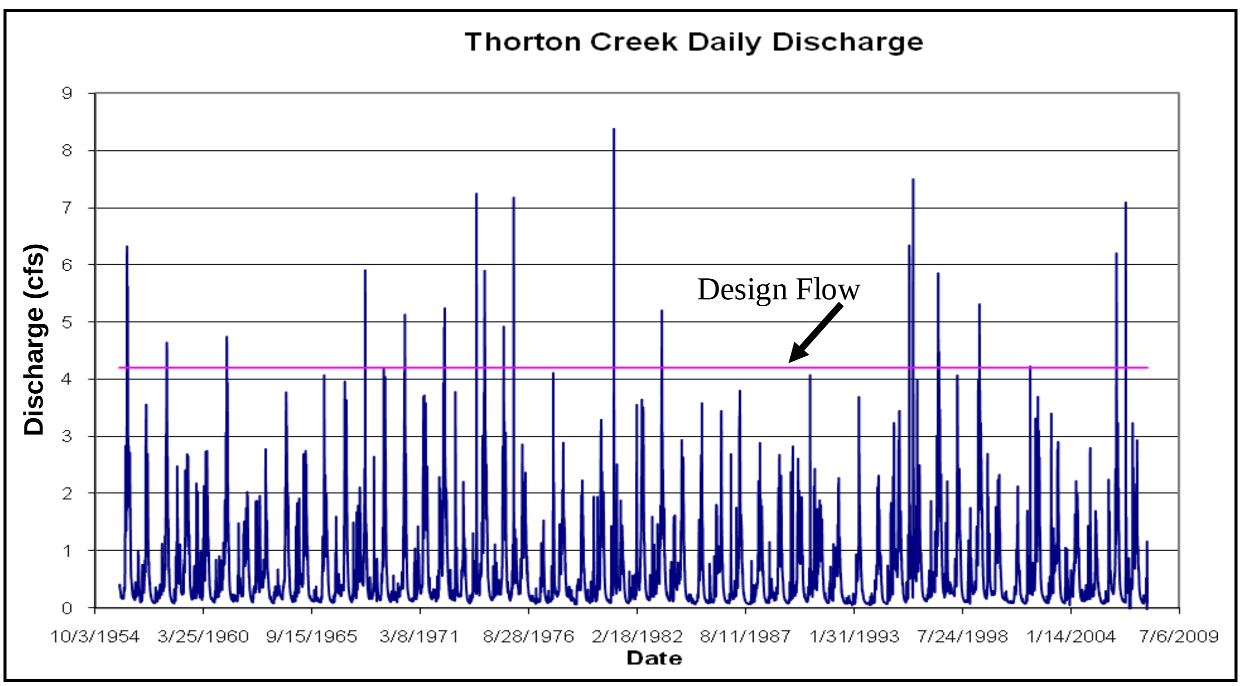

Figure C11.3: Daily stream discharge values for Thorton Creek determined using the USGS American River gage

Table C11.1: Thorton Creek culvert's current fish passage summary

THORTON CREEK INITIAL FISH PASSAGE SUMMARY	
Low Passage Design Flow	0.10 cfs
High Passage Design Flow	10.00 cfs
Percent of Flows Passable	0.00%
Passable Flow Range	None
Depth Barrier	0 to 1.03 cfs
Leap Barriers	None
Velocity Barrier – EB	0.10 cfs and Above
Pool Depth Barrier	2.19 to 10.00 cfs

Table C11.2: Thorton Creek FishXing output for different culvert diameters for the strongest fish

Thorton Creek (Steelhead, 0.10 to 10.0)						% Passable Based on Design Flow
Diameter (ft)	% Passable	Flows Passable (cfs)	Barrier	Depth Barrier (cfs)	Velocity Barrier (cfs)	
3	41.20	5.92 to 10.00	Depth	0 to 5.92	None	0.00
4	31.50	6.88 to 10.00	Depth	0 to 6.88	None	0.00
5	23.10	7.72 to 10.00	Depth	0 to 7.72	None	0.00
6	15.40	8.48 to 10.00	Depth	0 to 8.48	None	0.00
7	8.30	9.17 to 10.00	Depth	0 to 9.17	None	0.00
8	1.80	9.82 to 10.00	Depth	0 to 9.82	None	0.00
9	0.00	None	Depth	All Flows	None	0.00

Table C11.3: Thorton Creek FishXing output for different culvert diameters for the weakest fish

Thorton Creek (Bull Trout, 0.10 to 10.0)						% Passable Based on Design Flow
Diameter (ft)	% Passable	Flows Passable (cfs)	Barrier	Depth Barrier (cfs)	Velocity Barrier (cfs)	
3	21.20	0.10 to 2.10	Velocity	None	2.10 and above	49.88
4	24.70	0.10 to 2.44	Velocity	None	2.45 and above	57.96
5	27.70	0.10 to 2.74	Velocity	None	2.75 and above	65.08
6	30.50	0.10 to 3.02	Velocity	None	3.02 and above	71.73
7	33.00	0.10 to 3.26	Velocity	None	3.27 and above	77.43
8	35.30	0.10 to 3.50	Velocity	None	3.50 and above	83.13
9	37.50	0.10 to 3.71	Velocity	None	3.72 and above	88.12
10	39.60	0.10 to 3.92	Velocity	None	3.93 and above	93.11
11	41.70	0.10 to 4.13	Velocity	None	4.13 and above	98.10
12	43.60	0.10 to 4.32	Velocity	None	4.32 and above	100.00
13	45.50	0.10 to 4.51	Velocity	None	4.51 and above	100.00
14	47.30	0.10 to 4.68	Velocity	None	4.69 and above	100.00
15	49.00	0.10 to 4.85	Velocity	None	4.86 and above	100.00
16	50.70	0.10 to 5.02	Velocity	None	5.02 and above	100.00
17	52.30	0.10 to 5.18	Velocity	None	5.18 and above	100.00
18	53.90	0.10 to 5.33	Velocity	None	5.34 and above	100.00
19	55.40	0.10 to 5.48	Velocity	None	5.49 and above	100.00
20	56.90	0.10 to 5.63	Velocity	None	5.64 and above	100.00
21	58.30	0.10 to 5.77	Velocity	None	5.78 and above	100.00
22	59.70	0.10 to 5.91	Velocity	None	5.92 and above	100.00
23	61.10	0.10 to 6.05	Velocity	None	6.05 and above	100.00
24	62.40	0.10 to 6.18	Velocity	None	6.19 and above	100.00
25	63.70	0.10 to 6.31	Velocity	None	6.31 and above	100.00
26	65.00	0.10 to 6.44	Velocity	None	6.44 and above	100.00
27	66.30	0.10 to 6.56	Velocity	None	6.57 and above	100.00
28	67.60	0.10 to 6.69	Velocity	None	6.69 and above	100.00
29	68.80	0.10 to 6.81	Velocity	None	6.81 and above	100.00
30	70.00	0.10 to 6.93	Velocity	None	6.93 and above	100.00

C-12. Unnamed Creek on I-82 at Mile Post 68.32

Figure C12.1: The downstream end of the Unnamed Creek culvert on I-82 at mile post 68.32

Table C12.1: Unnamed Creek on I-82 at mile post 68.32 culvert's current fish passage summary

UNNAMED CREEK AT MP 68.32 INITIAL FISH PASSAGE SUMMARY	
Low Passage Design Flow	0.10 cfs
High Passage Design Flow	55.00 cfs
Percent of Flows Passable	1.30%
Passable Flow Range	0.45 to 1.18 cfs
Depth Barrier	0 to 0.45 cfs
Leap Barriers	None
Velocity Barrier - Long	1.18 cfs-Above
Pool Depth Barrier	None

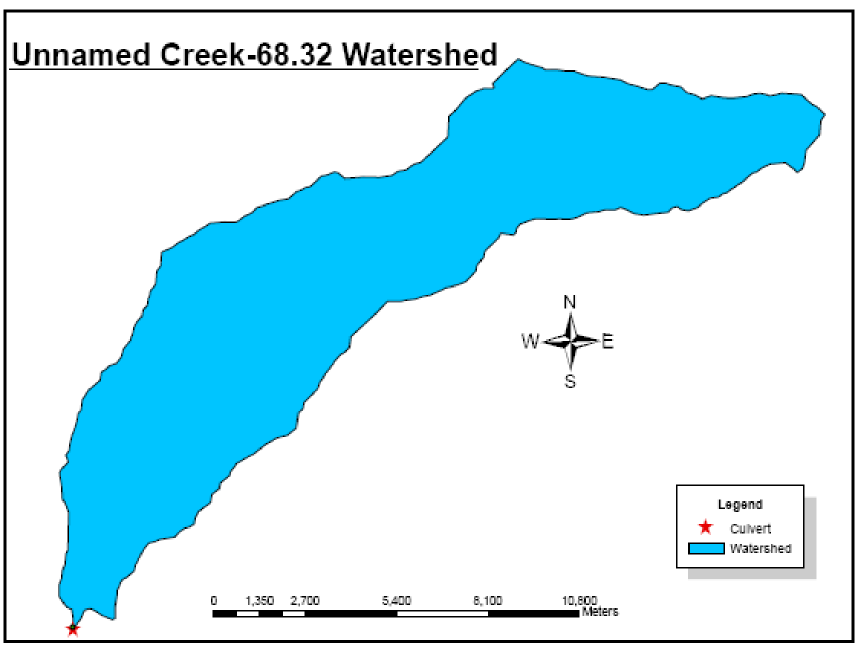

Figure C12.2: Delineated watershed for the Unnamed Creek culvert on I-82 at mile post 68.32

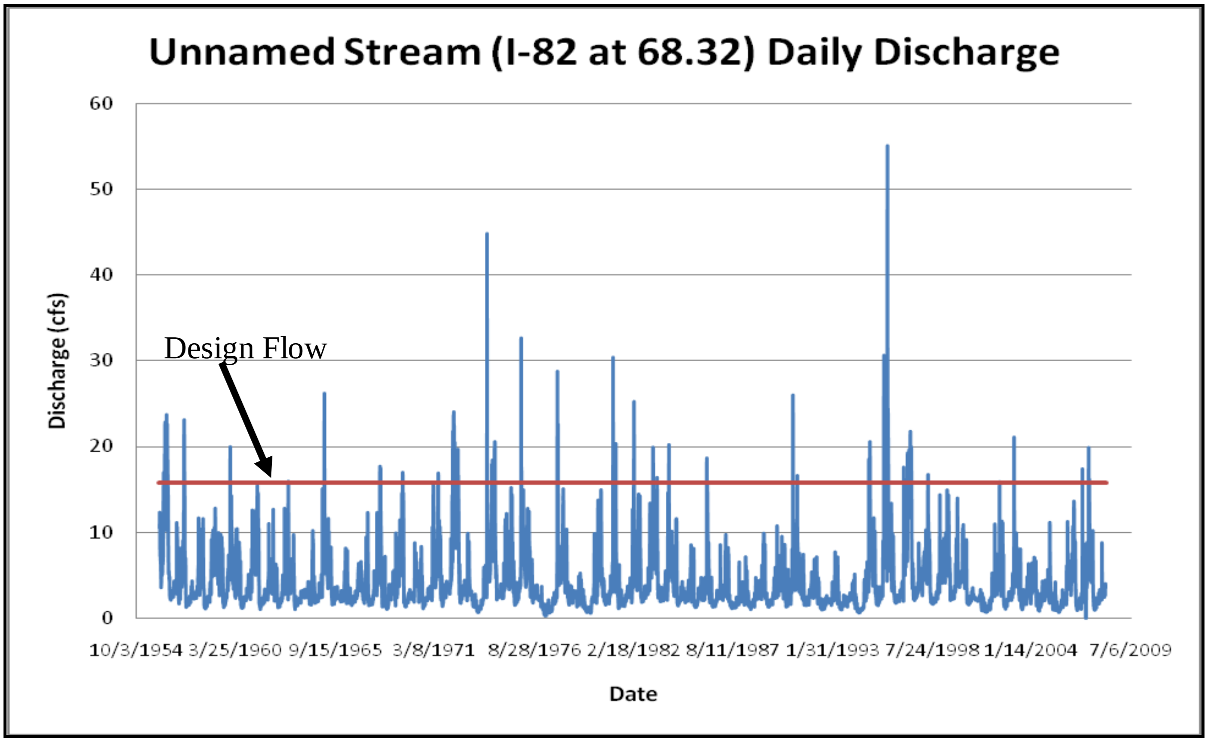

Figure C12.3: Daily stream discharge values for Unnamed Creek on I-82 at mile post 68.32 determined using the USGS Yakima River gage

Table C12.2: Unnamed Creek on I-82 at mile post 68.32 FishXing output for different culvert diameters for the strongest fish

Unnamed Creek on I-82 at mile post 68.32 (0.10 to 55.00)						% Passable Based on Design Flow
Diameter (ft)	% Passable	Flows Passable (cfs)	Barrier	Depth Barrier (cfs)	Velocity Barrier (cfs)	
8	100	All Flows	None	None	None	100
30	100	All Flows	None	None	None	100

Table C12.3: Unnamed Creek on I-82 at mile post 68.32 FishXing output for different culvert diameters for the weakest fish

Unnamed Creek on I-82 at mile post 68.32 (Bull Trout, 0.10 to 55.00)						% Passable Based on Design Flow
Diameter (ft)	% Passable	Flows Passable (cfs)	Barrier	Depth Barrier (cfs)	Velocity Barrier (cfs)	
8	12.70	0.10 to 6.98	Velocity	None	6.99 and above	44.15
9	13.60	0.10 to 7.44	Velocity	None	7.45 and above	47.06
10	14.30	0.10 to 7.87	Velocity	None	7.88 and above	49.78
11	15.10	0.10 to 8.27	Velocity	None	8.28 and above	52.31
12	15.80	0.10 to 8.66	Velocity	None	8.66 and above	54.78
13	16.40	0.10 to 9.03	Velocity	None	9.03 and above	57.12
14	17.10	0.10 to 9.39	Velocity	None	9.39 and above	59.39
15	17.70	0.10 to 9.73	Velocity	None	9.73 and above	61.54
16	18.30	0.10 to 10.06	Velocity	None	10.07 and above	63.63
17	18.90	0.10 to 10.38	Velocity	None	10.38 and above	65.65
18	19.50	0.10 to 10.69	Velocity	None	10.69 and above	67.61
19	20.00	0.10 to 10.99	Velocity	None	10.99 and above	69.51
20	20.60	0.10 to 11.28	Velocity	None	11.29 and above	71.35
21	21.10	0.10 to 11.57	Velocity	None	11.57 and above	73.18
22	21.60	0.10 to 11.85	Velocity	None	11.85 and above	74.95
23	22.10	0.10 to 12.12	Velocity	None	12.13 and above	76.66
24	22.60	0.10 to 12.39	Velocity	None	12.39 and above	78.37
25	23.00	0.10 to 12.65	Velocity	None	12.65 and above	80.01
26	23.50	0.10 to 12.91	Velocity	None	12.91 and above	81.66
27	24.00	0.10 to 13.16	Velocity	None	13.16 and above	83.24
28	24.40	0.10 to 13.40	Velocity	None	13.41 and above	84.76
29	24.90	0.10 to 13.65	Velocity	None	13.65 and above	86.34
30	25.30	0.10 to 13.88	Velocity	None	13.88 and above	87.79

C-13. Unnamed Creek on I-82 at Mile Post 72.38

Figure C13.1: The downstream end of the Unnamed Creek culvert on I-82 at mile post 72.38

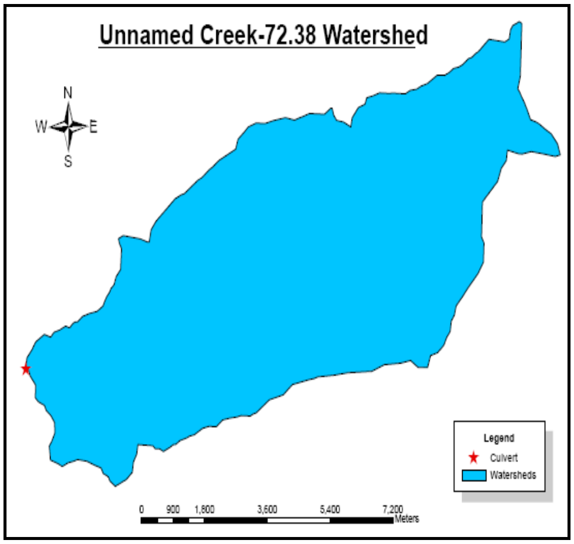

Figure C13.2: Delineated watershed for the Unnamed culvert on I-82 at mile post 72.38

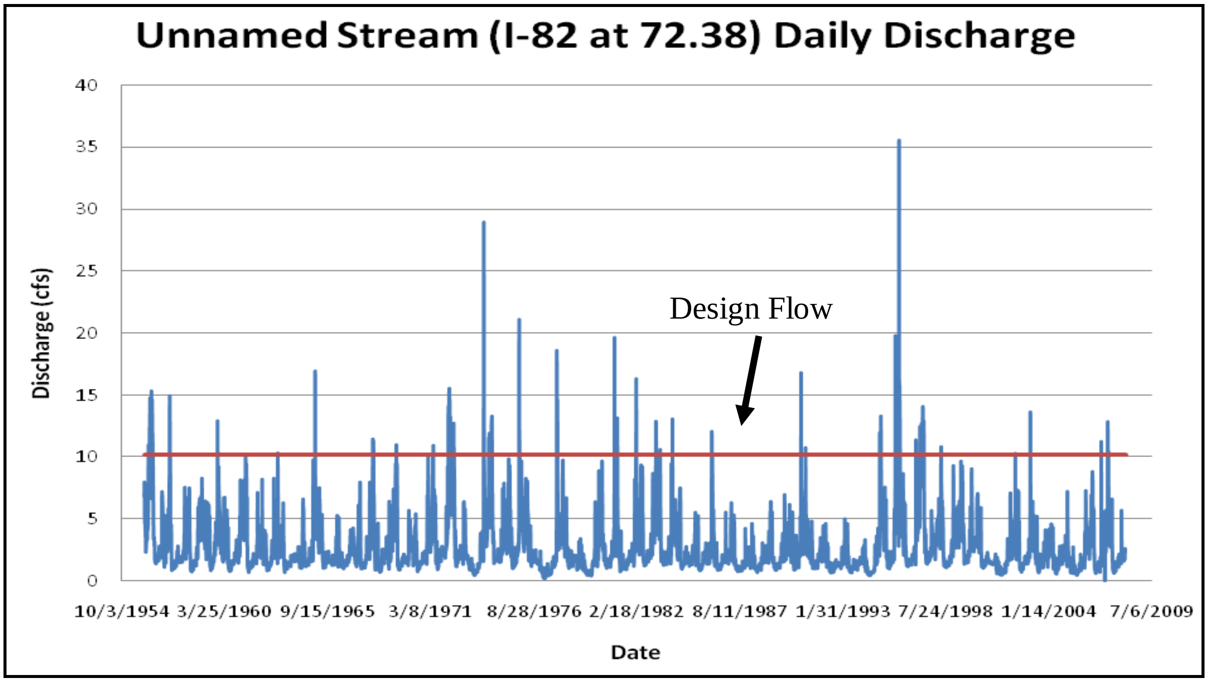

Figure C13.3: Daily stream discharge values for Unnamed Creek on I-82 at mile post 72.38 determined using the USGS Yakima River gage

Table C13.1: Unnamed Creek on I-82 at mile post 72.38 culvert's current fish passage summary

UNNAMED CREEK AT MP 72.38 INITIAL FISH PASSGE SUMMARY	
Low Passage Design Flow	0.10 cfs
High Passage Design Flow	35.00 cfs
Percent of Flows Passable	4.40%
Passable Flow Range	0.50 to 2.03 cfs
Depth Barrier	0 to 0.50 cfs
Leap Barriers	None
Velocity Barrier – Long	2.03 cfs and Above
Pool Depth Barrier	None

Table C13.2: Unnamed Creek on I-82 at mile post 72.38 FishXing output for different culvert diameters for the weakest fish

Unnamed Creek on I-82 at mile post 72.38 (Sockeye Salmon, 0.10 to 35.00)						% Passable Based on Design Flow
Diameter (ft)	% Passable	Flows Passable (cfs)	Barrier	Depth Barrier (cfs)	Velocity Barrier (cfs)	
4	7.60	0.41 to 3.05	Depth and Velocity	0 to 0.41	3.05 and above	25.88
6	9.10	0.52 to 3.71	Depth and Velocity	0 to 0.52	3.71 and above	31.27
8	10.50	0.61 to 4.27	Depth and Velocity	0 to 0.61	4.27 and above	35.88
10	11.70	0.68 to 4.77	Depth and Velocity	0 to 0.68	4.77 and above	40.10
12	12.80	0.75 to 5.22	Depth and Velocity	0 to 0.75	5.23 and above	43.82
14	13.80	0.81 to 5.64	Depth and Velocity	0 to 0.81	5.64 and above	47.35
16	14.80	0.87 to 6.02	Depth and Velocity	0 to 0.87	6.03 and above	50.49
18	15.60	0.93 to 6.39	Depth and Velocity	0 to 0.93	6.39 and above	53.53
20	16.50	0.98 to 6.73	Depth and Velocity	0 to 0.98	6.73 and above	56.37
22	17.30	1.03 to 7.06	Depth and Velocity	0 to 1.03	7.06 and above	59.12
24	18.10	1.07 to 7.37	Depth and Velocity	0 to 1.07	7.38 and above	61.76
26	18.80	1.12 to 7.67	Depth and Velocity	0 to 1.12	7.68 and above	64.22
28	19.50	1.16 to 7.96	Depth and Velocity	0 to 1.16	7.96 and above	66.67
30	20.20	1.20 to 8.24	Depth and Velocity	0 to 1.20	8.24 and above	69.02
40	23.30	1.39 to 9.51	Depth and Velocity	0 to 1.39	9.51 and above	79.61
50	26.00	1.55 to 10.63	Depth and Velocity	0 to 1.55	10.64 and above	89.02

Table C13.3: Unnamed Creek on I-82 at mile post 72.38 FishXing output for different culvert diameters for the strongest fish

Unnamed Creek on I-82 at mile post 72.38 (Steelhead, 0.10 to 35.00)						% Passable Based on Design Flow
Diameter (ft)	% Passable	Flows Passable (cfs)	Barrier	Depth Barrier (cfs)	Velocity Barrier (cfs)	
4	91.80	2.97 to 35.00	Depth	0 to 2.97	None	70.88
5	90.50	3.42 to 35.00	Depth	0 to 3.42	None	66.47
6	89.30	3.82 to 35.00	Depth	0 to 3.82	None	62.55
8	87.40	4.51 to 35.00	Depth	0 to 4.51	None	55.78
10	85.60	5.11 to 35.00	Depth	0 to 5.11	None	49.90
12	84.10	5.65 to 35.00	Depth	0 to 5.65	None	44.61
14	82.70	6.14 to 35.00	Depth	0 to 6.14	None	39.80
16	81.40	6.59 to 35.00	Depth	0 to 6.59	None	35.39
18	80.20	7.02 to 35.00	Depth	0 to 7.02	None	31.18
20	79.00	7.42 to 35.00	Depth	0 to 7.42	None	27.25
22	77.90	7.80 to 35.00	Depth	0 to 7.80	None	23.53
24	76.90	8.16 to 35.00	Depth	0 to 8.16	None	20.00
26	75.90	8.51 to 35.00	Depth	0 to 8.51	None	16.57
28	75.00	8.84 to 35.00	Depth	0 to 8.84	None	13.33
30	74.00	9.16 to 35.00	Depth	0 to 9.16	None	10.20
40	69.80	10.63 to 35.00	Depth	0 to 10.63	None	0.00

C-14. Unnamed Creek on SR 20

Figure C14.1: Inlet of the Unnamed Creek on SR 20

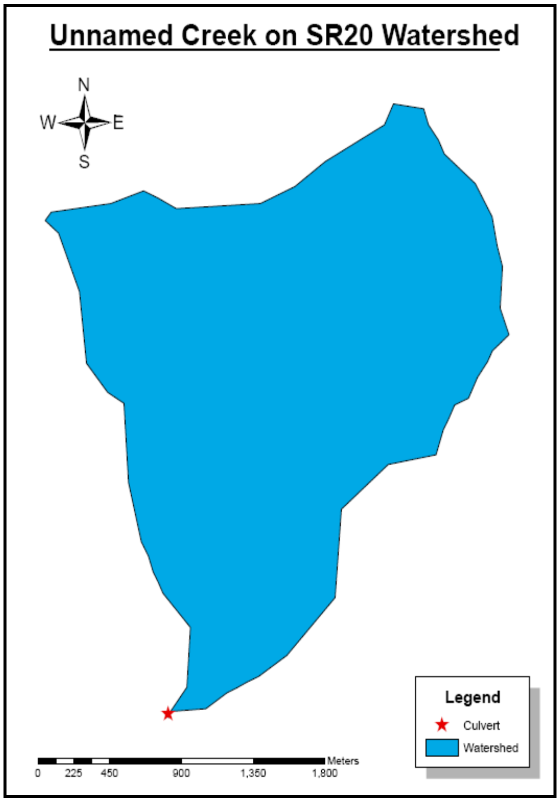

Figure C14.2: Delineated watershed for the Unnamed *Creek* culvert on SR 20

Table C14.1: Unnamed Creek on SR 20 culvert's current fish passage summary

UNNAMED CREEK ON SR20 INITIAL FISH PASSGAE SUMMARY	
Low Passage Design Flow	0.10 cfs
High Passage Design Flow	10.00 cfs
Percent of Flows Passable	0.00%
Passable Flow Range	None
Depth Barrier	0 to 0.53 cfs
Leap Barriers	None
Velocity Barrier - EB	0.10 cfs and Above
Pool Depth Barrier	None

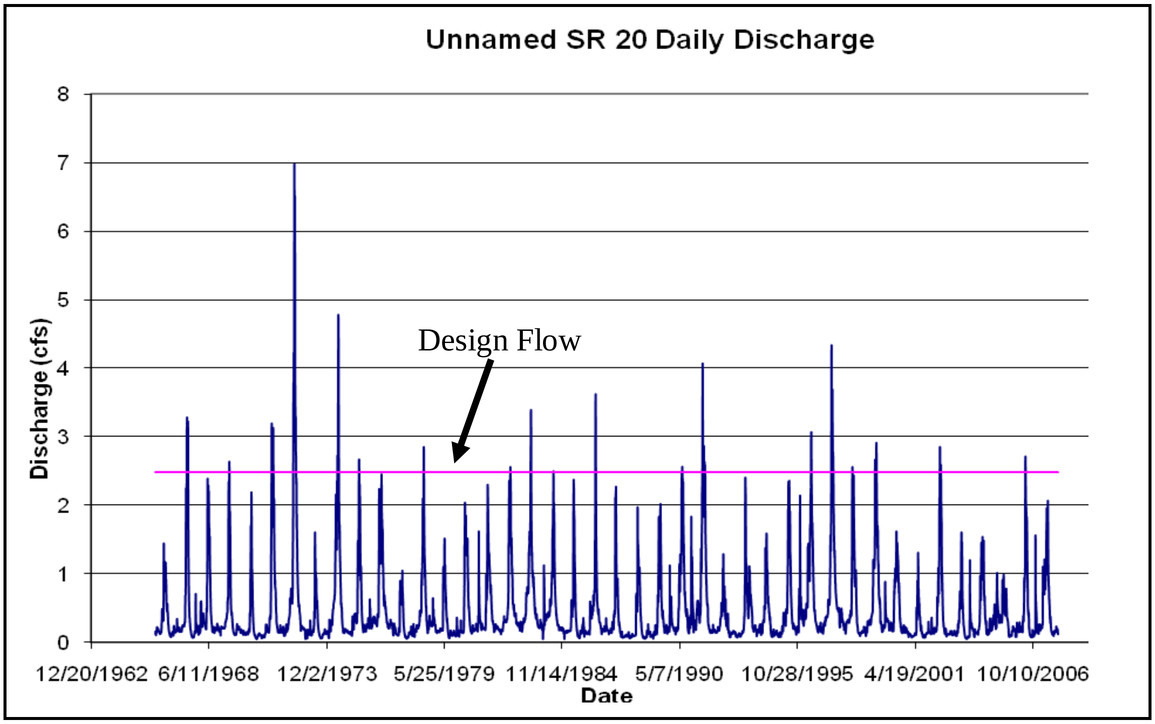

Figure C14.3: Daily stream discharge values for Unnamed Creek on SR 20 determined using the USGS Okanogan River gage

Table C14.2: Unnamed Creek on SR 20 FishXing output for different culvert diameters for the strongest fish

Unnamed Creek on SR 20 (Steelhead, 0.10 to 30.00)						% Passable Based on Design Flow
Diameter (ft)	% Passable	Flows Passable (cfs)	Barrier	Depth Barrier (cfs)	Velocity Barrier (cfs)	
2	64.4	0.10 to 19.25	Velocity	None	19.25 and above	100.00
3	100.0	All Flows	None	None	None	100.00
30	100.0	All Flows	None	None	None	100.00

Table C14.3: Unnamed Creek on SR 20 FishXing output for different culvert diameters for the weakest fish

Unnamed Creek on SR 20 (Bull Trout, 0.10 to 30.00)						% Passable Based on Design Flow
Diameter (ft)	% Passable	Flows Passable (cfs)	Barrier	Depth Barrier (cfs)	Velocity Barrier (cfs)	
2	2.30	0.18 to 0.88	Depth and Velocity	0 to 0.18	0.88 and above	28.23
3	2.70	0.23 to 1.04	Depth and Velocity	0 to 0.23	1.05 and above	32.66
4	3.10	0.27 to 1.18	Depth and Velocity	0 to 0.27	1.18 and above	36.69
6	3.70	0.33 to 1.43	Depth and Velocity	0 to 0.33	1.43 and above	44.35
8	4.20	0.38 to 1.64	Depth and Velocity	0 to 0.38	1.64 and above	50.81
10	4.70	0.43 to 1.83	Depth and Velocity	0 to 0.43	1.83 and above	56.45
12	5.10	0.47 to 1.99	Depth and Velocity	0 to 0.47	2.00 and above	61.29
14	5.50	0.51 to 2.15	Depth and Velocity	0 to 0.51	2.15 and above	66.13
16	5.90	0.55 to 2.30	Depth and Velocity	0 to 0.55	2.30 and above	70.56
18	6.20	0.58 to 2.43	Depth and Velocity	0 to 0.58	2.43 and above	74.60
20	6.50	0.61 to 2.56	Depth and Velocity	0 to 0.61	2.57 and above	78.63
22	6.80	0.64 to 2.69	Depth and Velocity	0 to 0.64	2.69 and above	82.66
24	7.10	0.67 to 2.80	Depth and Velocity	0 to 0.67	2.80 and above	85.89
26	7.40	0.70 to 2.92	Depth and Velocity	0 to 0.70	2.92 and above	89.52
28	7.70	0.73 to 3.02	Depth and Velocity	0 to 0.73	3.03 and above	92.34
30	7.90	0.75 to 3.13	Depth and Velocity	0 to 0.75	3.13 and above	96.77
40	9.10	0.87 to 3.61	Depth and Velocity	0 to 0.87	3.61 and above	100.00
50	10.20	0.97 to 4.03	Depth and Velocity	0 to 0.97	4.04 and above	100.00

C-15. Whistler Canyon Creek

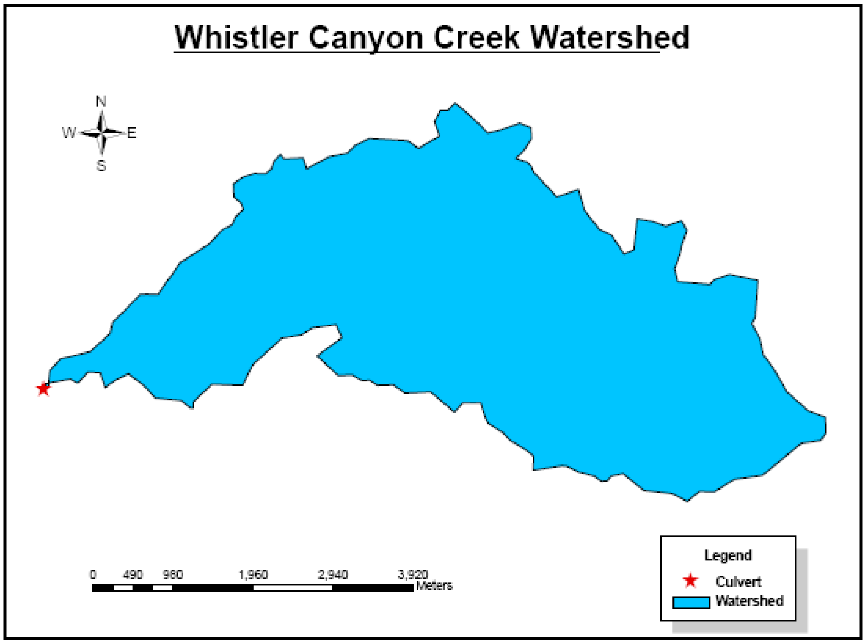

Figure C15.1: Delineated watershed for the Whistler Canyon Creek culvert

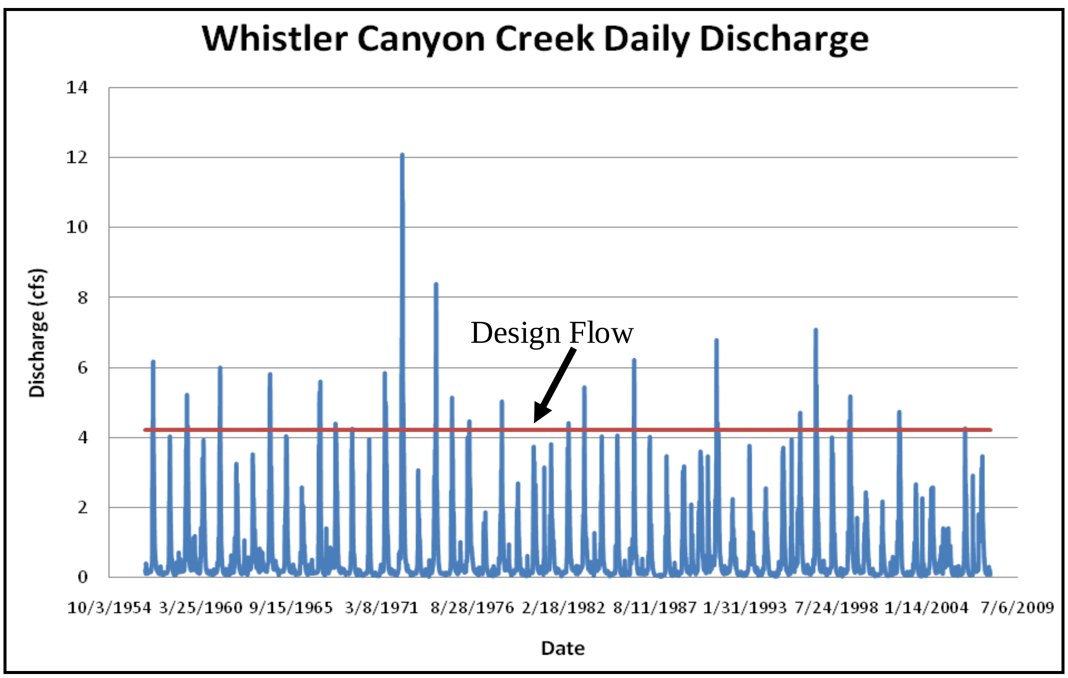

Figure C15.2: Daily stream discharge values for Whistler Canyon Creek determined using the USGS Similkameen River gage

Table C15.1: Whistler Canyon Creek culvert's current fish passage summary

WHISTLER CANYON CREEK INITIAL FISH PASSAGE SUMMARY	
Low Passage Design Flow	0.10 cfs
High Passage Design Flow	15.00 cfs
Percent of Flows Passable	39.10%
Passable Flow Range	0.10 to 5.83 cfs
Depth Barrier	None
Leap Barriers	None
Velocity Barrier – Long	5.83 cfs and Above
Pool Depth Barrier	None

Table C15.2: Whistler Canyon Creek FishXing output for different culvert diameters for the weakest fish

Whistler Canyon Creek (Bull Trout, 0.10 to 15.0)						% Passable Based on Design Flow
Diameter (ft)	% Passable	Flows Passable (cfs)	Barrier	Depth Barrier (cfs)	Velocity Barrier (cfs)	
3	38.40	0.10 to 5.82	Velocity	None	5.83 and above	100.00
4	71.60	0.10 to 10.77	Velocity	None	10.77 and above	100.00
5	88.30	0.10 to 13.25	Velocity	None	13.26 and above	100.00
6	100.00	All Flows	None	None	None	100.00
20	100.00	All Flows	None	None	None	100.00
30	100.00	All Flows	None	None	None	100.00

Table C15.3: Whistler Canyon Creek FishXing output for different culvert diameters for the strongest fish

Whistler Canyon Creek (Steelhead, 0.10 to 15.0)						% Passable Based on Design Flow
Diameter (ft)	% Passable	Flows Passable (cfs)	Barrier	Depth Barrier (cfs)	Velocity Barrier (cfs)	
3	100.00	All Flows	None	None	None	100.00
10	100.00	All Flows	None	None	None	100.00
30	100.00	All Flows	None	None	None	100.00

Appendix D

D-1. Information for the Most Common Fish Species in the Western United States (Bell, 1991)

Occurrence	Age at Maturity	Weight (range)	Time in F.W. (Rearing)	Time in Ocean	Time of Adult Migration	Spawning Time	Downstream Migration
Fall Chinook Salmon							2-3 inches
Main Columbia R., Snake R., & tribs.	3-5 yrs	15-40 lbs (avg. less than 20 lbs)	Up to 1 yr	2-5 yrs	August to December	September thru January	April to June
Large Streams	3-5 yrs	15-20 lbs	December to June	2-5 yrs	Mid July to late September	Mid September to late October	April to June
Medium Streams	3-5 yrs	15-20 lbs	December to June	2-5 yrs	Early September to late October	Mid September to late October	April to June
Small Streams	3-5 yrs	15-20 lbs	December to June	2-5 yrs	Mid September to late October	Late September to late October	April to June
Coastal WA, Medium Streams	3-5 yrs	15-20 lbs	3-5 months	2-5 yrs	August thru November	September to mid December	January to August
Coastal WA, Small Streams	3-5 yrs	15-20 lbs	3-5 months	2-5 yrs	Late September thru November	October to January	January to August
Spring Chinook Salmon							3-5 inches
Columbia R., Snake R., & upper tribs.	4-6 yrs	10-20 lbs (avg. 15 lbs)	1 yr or longer	2-5 yrs	January thru May	Late July to late September	During 2nd spring and summer
Large Streams	4-6 yrs	10-20 lbs (avg. 15 lbs)	Year around	2-5 yrs	Early April to late July	Early August to early October	March, July
Coastal WA, Medium Streams	4-6 yrs	10-20 lbs (avg. 15 lbs)	1 yr. + sea-ward migration	2-5 yrs	March to early June	August to mid October	During 2nd spring at 5-6 inches

Occurrence	Age at Maturity	Weight (range)	Time in F.W. (Rearing)	Time in Ocean	Time of Adult Migration	Spawning Time	Downstream Migration
Summer Chinook Salmon							
Columbia R. and upper tribs.	4-6 yrs	10-30 lbs (avg. 14 lbs)	1 yr or longer	2-5 yrs	June to mid August	September to mid November	During 2nd spring
Coho Salmon							3.5-4.5 inches
Large Streams	3 yrs	5-20 lbs (avg. 8 lbs)	1 yr. + (year around)	2 yrs	Early October to late December (peak in Nov)	Mid November to early January	March to July
Medium Streams	3 yrs	5-20 lbs (avg. 8 lbs)	Year around	2 yrs	Mid October to mid January	Mid November to early January	April to June
Small Streams	3 yrs	5-20 lbs (avg. 8 lbs)	Year around	2 yrs	Early November to early January	Mid November to early January	April to June
Coastal WA, Medium Streams	3 yrs	5-20 lbs (avg. 8 lbs)	1 yr. +	2 yrs	September to January (peaks Oct & Nov)	Mid October to March (mainly Nov to Jan)	March to July of 2nd yr (peaks April-June)
Coastal WA, Small Streams	3 yrs	5-20 lbs (avg. 8 lbs)	1 yr. +	2 yrs	October to January (early and late runs)	November thru February (peak late Nov-mid Jan)	
Lower and Middle Columbia R., and tribs.	3 yrs	5-20 lbs (avg. 8 lbs)	1 yr. + (year around)	2 yrs	Late August to February (peak in Oct)	September to March	March to July

Occurrence	Age at Maturity	Weight (range)	Time in F.W. (Rearing)	Time in Ocean	Time of Adult Migration	Spawning Time	Downstream Migration
Sockeye Salmon							3.5-5 inches
Columbia R. to Alaska, in some large streams that provide lake habitat	3-5 yrs	3-8 lbs (avg. 6 lbs)	1-3 yrs	1-4 yrs	2 runs: late July to early August & September to October	August to November	April to June (sea-ward)
Kokanee (landlocked Sockeye Salmon)							
CA, OR, WA, & B.C. in large, cool lakes and reservoirs	2-7 yrs (mostly 3-5 yrs)	1/8-1 lbs (8-18 inches, avg. 12 inches)	Life		Late July to December	August to January, 2 runs: August to October and October to February	September to March
Steelhead-Coastal streams and river systems, northern CA to Alaska							6-8 inches
Summer Run							
WA Streams	3-6 yrs	5-30 lbs	1-3 yrs (avg. 2 yrs)	1-4 yrs	April to November	February to June	March to June
Columbia R. "A" Group	3-4 yrs	4-12 lbs (avg. 5-6 lbs)	1-2 yrs	2-3 yrs	June to early August	February to March	March to June
Columbia R. "B" Group	5-6 yrs	8-20 lbs (avg. 9 lbs)	1-2 yrs	3-4 yrs	August thru October	April to May	March to June

Occurrence	Age at Maturity	Weight (range)	Time in F.W. (Rearing)	Time in Ocean	Time of Adult Migration	Spawning Time	Downstream Migration
Steelhead-Coastal streams and river systems, northern CA to Alaska							6-8 inches
Winter Run							
WA Streams	3-6 yrs	5-28 lbs (avg. 8 lbs)	1-3 yrs (avg. 2 yrs)	1-4 yrs	November to mid June	February to June	March to June
Columbia R.	3-6 yrs	6-20 lbs (avg. 8 lbs)	1-2 yrs (avg. 2 yrs)	1-4 yrs	November thru May	February thru May	March to June
Spring Run							
Columbia R.	3-5 yrs	5-20 lbs	1-2 yrs	2-3 yrs	Late February to early June	Late December to March	Spring and summer of following year
Rainbow Trout							
Throughout Pacific slope; widely distributed thru hatcheries into other regions	3-4 yrs	1/4-42 lbs (avg. 1/2 lbs)	Life			Normally spring; hatchery brood-stocks of fall spawners have been developed	
Coastal Cutthroat Trout							
Northern CA to Prince William Sound in southeast Alaska	3-4 yrs; sea-run 2-5 yrs	Resident 1/4-17 lbs; sea-run 1/2-4 lbs (avg. 1 lbs)	Life; or sea-run 1-3 yrs, normal 2 yrs	Sea-run 1/2-1 yrs	Sea-run July to December	Resident February to May; sea-run December to June	Sea-run March to June

Occurrence	Age at Maturity	Weight (range)	Time in F.W. (Rearing)	Time in Ocean	Time of Adult Migration	Spawning Time	Downstream Migration
Dolly Varden (Char)--Bull Trout							
Native to Pacific slope from McCloud R., CA to Kamchatka and west to Japan; widely distributed in both lakes and streams. Sea-runs occur in some areas, particularly in B.C. and Alaska with fish of large size	4-6 yrs	1/4-20 lbs (avg. 1/2-3 lbs)	Life (sea-run 2-3 yrs)	Sea-run migrate from ocean to lakes each fall	Mid August to early November (ocean to lake)	September to November	Sea-run spring and early summer, mainly May and June as 4-5 inch smolts