FishXing: Evaluation of Fish Passage Culvert Model And Comparison with Oregon Department of Forestry's Compliance With Fish Passage and Peak Flow Requirements at Stream Crossings

By

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Disclaimer

This project uses preliminary culvert assessment from Oregon Department of Forestry's fish passage stream crossing monitoring project, Oregon Department of Forestry: Compliance With Fish Passage and Peak Flow Requirements at Stream Crossings, and compares it with output generated using FishXing, a fish passage model developed at Humboldt State University. Oregon Department of Forestry's (ODF) evaluation as to whether a culvert meets the requirements to provide fish passage may be changed as further review of the regulations takes place by ODF staff. Both this evaluation of FishXing and the Oregon Department of Forestry: Compliance With Fish Passage and Peak Flow Requirements at Stream Crossings were being written at the same time. Therefore, a final evaluation of culvert performance from ODF is not available for comparison in this evaluation of FishXing. It is assumed that the evaluation of only a few culverts may be changed from the preliminary ODF results used in this comparison with FishXing, and that the overall comparison with FishXing should stand. Oregon Department of Forestry (ODF): Compliance With Fish Passage and Peak Flow Requirements at Stream Crossings is now available on the ODF Monitoring website under the heading technical reports.

Abstract

FishXing (fish crossing), a computer aided stream crossing culvert model designed to analyze fish passage through culverts was compared with results of an Oregon Department of Forestry fish passage monitoring report. FishXing was created at Humboldt State University through sponsorship from the US Forest Service, USDA, Stream Team, Six Rivers National Forest, San Dimas Technology and Development Center, The Watershed Stewards Project, and the Federal Highway Administration. A comparison was made between results generated using FishXing with results found by ODF in the Oregon Department of Forestry (ODF): Compliance With Fish Passage and Peak Flow Requirements at Stream Crossings monitoring project. Stream crossing culvert data from the ODF fish passage study was used to run FishXing. The ODF monitoring project investigated 74 fish passage culvert installations that were constructed following approval of Written Plans filed with ODF in 1998. (An approved Written Plan is equivalent to a permit with ODF). Information about culvert installations was analyzed using FishXing. Four different trials were run for each culvert using both adult and juvenile Coho Salmon and Cutthroat trout using the FishXing software. Three trials used the default values for swimming abilities of adult and juvenile Coho salmon and adult Cutthroat trout. Juvenile Cutthroat trout were also included in the comparison; however, FishXing did not contain a default setting for them. Therefore, a velocity of 2 feet per second (fps), the current target velocity for stream crossings on fish

bearing streams in the state of Oregon, was used for juvenile Cutthroat trout (ODFW 2).

After making comparisons with the preliminary ODF results, further study was done to assess the accuracy of the calculations carried out within FishXing. This was based on Manning's equation ($V=1.49/n*R^{2/3}*S^{1/2}$) and other formulas given in the "Help" section of FishXing. Flow calculations were also compared with the Haestad Culvert Master program. The results produced using Manning's equation show no statistical difference from those generated using FishXing. Furthermore, there was an insignificant statistical difference found between FishXing-generated output and that of Culvert Master. Positive and negative attributes concerning FishXing are addressed at the end of the report.

Approved: ______________________________

Brian W. Kramer, PE Senior Instructor

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INTRODUCTION

PROBLEM STATEMENT

In 1994 the Oregon Department of Forestry, ODF, adopted new criteria for fish passage based on research performed up to that time. Although not a driving factor in the ODF decision to update fish passage requirements, an increasing number of salmonid species were listed as threatened or endangered under the Federal Endangered Species Act at that time. The new ODF criteria for stream crossings "... require that adult and juvenile fish migration shall not be impaired by water crossing structures constructed after September 1, 1994 for all type F streams" (Robison. 1997). A type F stream is fish bearing under ODF terminology.

Prior to the update of ODF regulations, fish passage was already a general requirement at any manmade structure placed in fish bearing streams. However, little, if any, enforcement or monitoring of culvert installations in forests was conducted to ensure fish passage was possible (Paul. 2002). Prior to the changes in 1994, the priority of culvert design was a culvert that would pass the extreme design discharge, usually the 25 or 50 year return event, at least cost. In a 1997 memorandum on fish passage, George Robison, ODF forest hydrologist, wrote,

"… many types of common installations used in the past will not provide for fish passage" (Robison. 1997).

There are thousands of existing culverts installed on fish bearing streams in Oregon. Many of these installations took place prior to specific regulations for fish passage being developed in 1994. Projects have been developed to assess fish passage through culverts in the state of Oregon by the Oregon Department of Fish and Wildlife in conjunction with the Oregon Department of Transportation as well as the US Forest Service.

Analysis from FishXing, a program developed by the Forest Service at Humboldt State University to aid in evaluation and design of fish passage culverts, can be used to evaluate culvert installations on existing live stream crossings. This can help decide which existing culverts need to be replaced, and those which do not obstruct fish passage. For culverts that FishXing predicts obstruct fish passage, the cause of the obstruction can be identified in the FishXing output.

A study by the Forest Service Region 6, Oregon and Washington, found that the majority of culverts sampled do not provide fish passage for all species and age classes (USFS Region 6). This study found that over 80% of the culverts inventoried prevent fish passage at some level. Approximately 10% of the crossings in each state provide questionable passage, and less than 10% of all the culverts sampled provide unhindered fish passage (Figure 1).

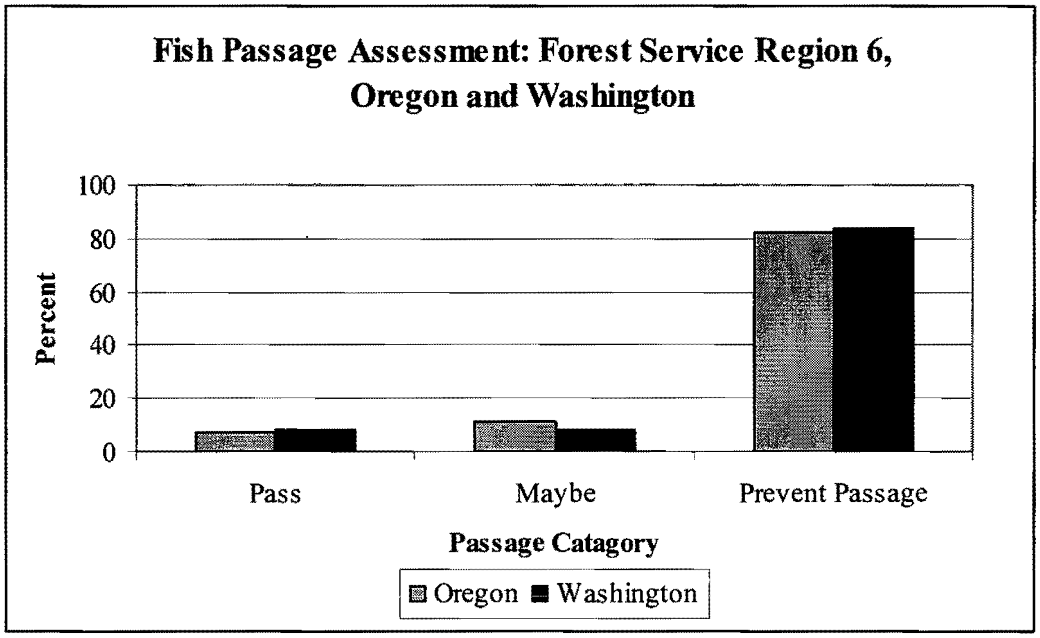


Figure 1: Culvert Assessment in Forest Service Region 6. This chart demonstrates the percent of culverts inventoried that prevent fish passage, are questionable as to whether or not they prevent fish passage, and those culverts which are believed to provide fish passage at all require flows (USFS Region 6).

STUDY OBJECTIVE

This project has been developed to evaluate FishXing, a Windows-based program designed to evaluate fish passage through culverts. This was done four ways:

- To determine if FishXing could replicate the results of the Oregon Department of Forestry: Compliance With Fish Passage and Peak Flow Requirements at Stream Crossings monitoring study, further referred to as the ODF fish passage study.
- To verify that calculations conducted in FishXing produce values similar to other commonly accepted methods. Uniform flow calculations were checked with Manning's equation. Water surface profile calculations were checked with Haestad Culvert Master.
- To determine the ease of use of FishXing.
- To identify the positive and negative attributes of using FishXing, as well as suggestions to improve future versions of FishXing.

This project assumes that the results from the ODF fish passage study meet current culvert installation criteria for fish passage in the state of Oregon.

LITERATURE REVIEW

Culvert installations on fish bearing streams have the potential to block or obstruct fish passage. Fish passage can be blocked or obstructed by outfall barriers, excessive water velocity, and insufficient water depth in culverts as seen in Figure 2 (Wiest. 1998. Photo McCammon. 2002). Thousands of culvert crossings have been installed on streams with little to or no thought to the effects they may have on fish populations. "A single, poorly installed culvert can eliminate the fish population of an entire stream system" (Wiest. 1998).

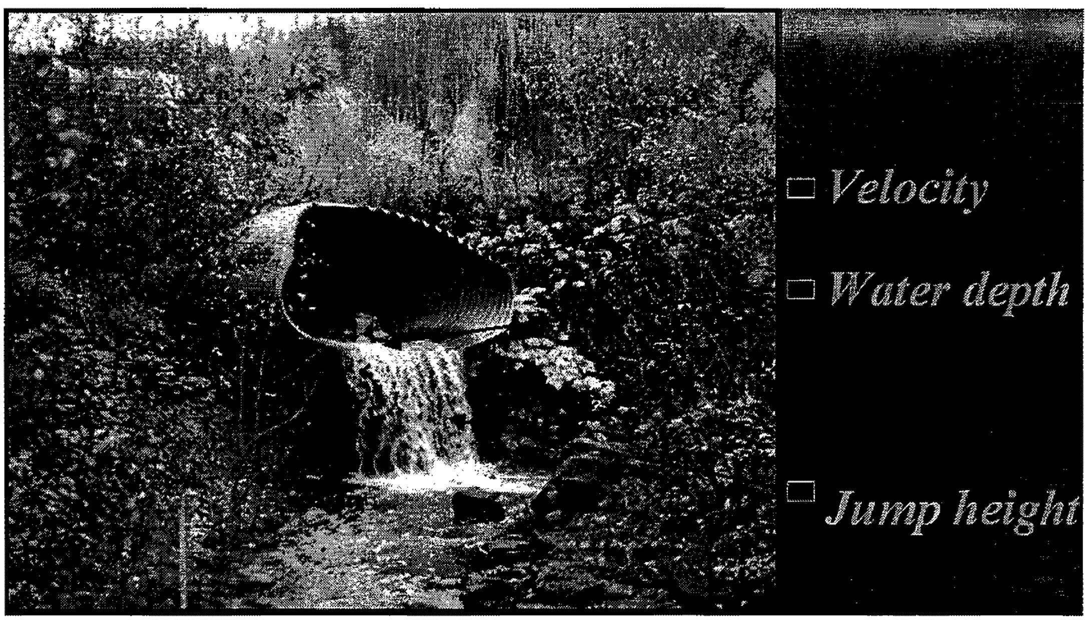


Figure 2: A culvert showing an outfall barrier/excess jump height, excess velocity, and insufficient water depth (McCammon. 2002).

In 1994, ODF updated their administrative rules with regard to the construction of new culverts. The rules required that new culverts installations pass the 50 year peak flow and that adult and juvenile fish migration on type F streams are not impaired by water crossing structures (Robison. 1997). Prior to this update of the ODF administrative rules, the main objective with stream crossing structures was to pass the design flow at the lowest cost (Robison. 1997).

The State of Oregon has required fish passage past man-made structures prior to establishment of statehood in 1859. Over the past 150 years fish passage has been a general requirement on all artificial in-stream obstructions (ODFW 1). Fish passage design is based on the weakest species or life stage of fish requiring upstream access (ODFW 2).

The spawning success of migrating adult salmon has been shown to decrease due to culvert crossings. This can be attributed to excess energy fish exert swimming through a culvert, or a delay in migration because of an obstruction associated with a road crossing. These obstructions may lead to pre-spawning mortality (ODFW 2). "Culverts are by far the most common type of crossing device and the most likely to cause barriers to fish migration" (Wiest. 1998).

In 1995, 532 fish presence surveys were conducted in coastal basins of Oregon as part of the Oregon Plan for Salmon and Watersheds. Of these 532 surveys, the confirmed end of fish use on 79 (14.8%) stream surveys was the result of human installed barriers. Of the streams where fish presence ended as a result of human structures, 96% of these structures were related to culverts (OCSRI. 1997).

METHODS

SITE SELECTION AND DESCRIPTION

Culvert installations were selected from notifications filed in 1998 with ODF for instream work. A total of 100 sites were selected throughout the state of Oregon. Ninety-three percent of these sites were in western Oregon. The map in Figure 3 shows the 100 stream-crossing locations visited by the monitoring field crew of the ODF fish passage study. At these sites, stream-crossing data was collected. The data collected documented the type of crossing (culvert, bridge, or ford) and the relevant information about the crossing listed on page 21.

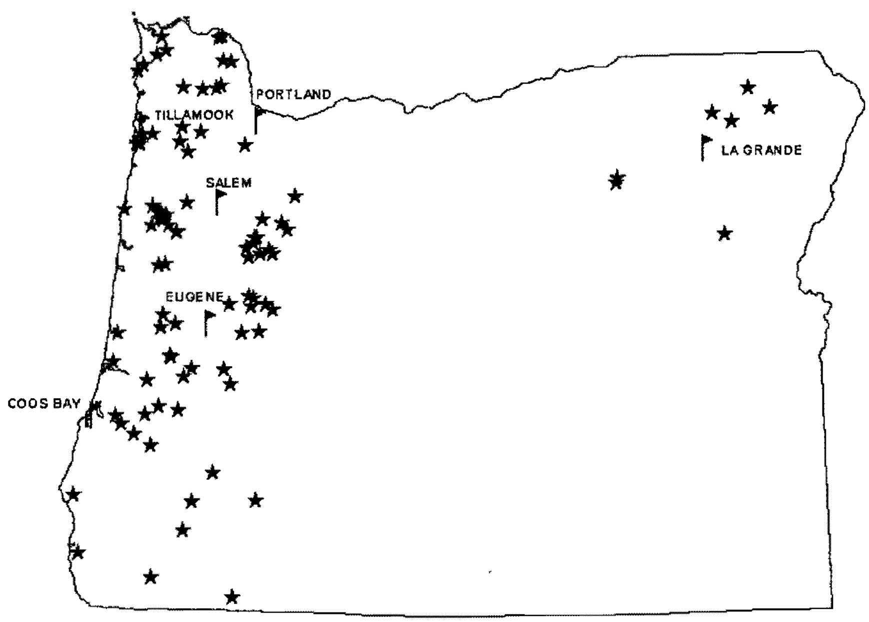


Figure 3: Stream-crossings included in ODF fish passage monitoring study. (Paul. 2002.)

Slopes of culvert installations ranged from –2.25% to 8.53% in direction of the stream flow. For culverts installed with negative grade, the inlet is installed at an elevation lower than the outlet to maintain backwater conditions, or to retain sediment within the culvert. Six ODF-approved culvert installation techniques were evaluated using FishXing. These ODF-approved stream-crossing methods are listed in Table 1. Table 1 includes open bottom pipe arches and bridges as well as the six other approved methods. ODF assumes that bridges and open bottom pipe arch culverts provide fish passage, and therefore these crossings are not included in the comparison with FishXing.

The ODF approved techniques range from use of a flat culvert gradient, defined as less than 0.5% slope, to incorporating a baffle weir structure that is designed to retain sediment and slow water velocity through the culvert for sites with the greatest gradient. FishXing was used to evaluate 72 of the 100 sites surveyed that comprised of circular or pipe arch culverts. The remaining crossings used open bottom pipe arches and bridges. Two of the 74 culverts did not have the information required for evaluation with FishXing. Therefore the sample size used in the comparison was 72 culverts. Circular culvert sizes ranged from 36 inches to 133 inches. Pipe arch culvert sizes ranged from 45 X 36 inches to 172 X 110 inches.

Alternative	Design Option	Key Specifications That Allow Juvenile Fish Passage *	Appropriate Stream Characteristics
1 **	Non-stream simulation culvert	Culvert installed with ≤ 0.5% gradient to achieve low velocities.	Streams ≤ 0.5% gradient.
2 ♣	Culvert with outlet backwatering	Culvert placed at/below stream grade with downstream control structure(s) that back up water throughout the culvert.	Streams ≤ 5% with well defined channel. Can also mitigate existing problem culverts with outlet structures.
3 **	Partially buried culvert (non-stream simulation)	Sink culvert at inlet to lower resulting gradient to ≤ 0.5%. Difference between stream grade and resulting culvert grade is less than 2%. Depth of sinking ≤ 2 feet. Caution against creating an inlet drop.	Use on streams < 2.5% with deep valley fill. No bedrock at inlet, if inlet must be sunk to achieve resulting culvert gradient.
4 ∇	Culvert partially buried at inlet and outlet (stream simulation)	Resulting culvert grade = stream grade (but ≤ 4%). Culvert width = to channel width. May need to manually seed culvert with rock to initiate sediment deposition. Oversize to pass 50-year flow.	Streams ≤ 4%. Deep valley fill to sink culvert in. Mobile gravel and cobble substrate to build up in culvert. If fines dominate the natural streambed, this alternative may not work.
5 ∇	Culvert partially buried at both ends but deeper at inlet (stream simulation)	Resulting culvert grade is 1.5% < stream grade and ≤ 7%. Sink at least 1 foot. If resulting culvert grade > 4%, seed culvert. Oversize culvert to pass 50-year flow.	Streams ≤ 9%. Deep valley fill and mobile cobble and gravel streambed. If fines dominate the natural streambed, this alternative may not work.
6 ♣	Baffled culvert	Culvert with flow obstructions inside the culvert to increase depth or roughness. Oversize culvert to pass 50-year flow.	Streams up to 12%. Valley fill not a factor.
7 °	Open-bottom arch	Culvert placed on footings with a natural streambed below.	Only used in bedrock streams and shallow valley fill to insure stable footings
8 °	Bridge	Structure spans the channel and is placed on piers and/or abutments located in or near the stream.	Need to place footings on bedrock.

Key to Table 1

* = All designs require no jump at the outlet of crossing structures.
** = Design relies on low gradient (< 0.5%), and resulting low velocity to pass fish.
♣ = Design creates low enough velocities to pass juvenile fish with structures either downstream or within the culvert.
∇ = Design relies on sediment retention to pass juvenile fish. Sediment retention must be adequate to simulate a natural streambed condition that provides velocity refuge for fish.
° = Design relies on maintaining natural streambed to pass fish.

Table 1: ODF fish passage design options. Current guidelines have been revised as of June 1999 (OWEB, 1999), and vary somewhat from what is described here. (Paul. 2002)

Using FishXing to Evaluate Culverts

FishXing was used to evaluate culverts installed on forest streams under ODF written plans submitted and approved in 1998. Culvert parameters were entered into FishXing from ODF data. These culverts were analyzed using FishXing and then compared to findings of the ODF fish passage study. Two species of fish, Coho salmon and Cutthroat trout, were used to evaluate FishXing at adult and juvenile age classes. FishXing incorporates default-swimming abilities for each species of fish, with the exception of juvenile Cutthroat trout, which did not have a default setting. The default settings used by FishXing for these species are based on work done by Bell (1973 and 1991) and Hunter and Mayor (1986).

DESCRIPTION OF FISHXING AND OPERATING PARAMETERS

FishXing is a Windows-based program designed to assess fish passage through culverts. It is capable of analyzing circular, pipe-arch, box, and open-bottom-arch culverts. FishXing can be used for evaluation of existing culvert installations, and in assessing design of new culverts installations or replacements.

For a landholder, road manager, or watershed manager with a large number of stream-crossings on a road network, FishXing can provide a quick means of assessing fish passage at each crossing. This is based on common parameters within the program. These parameters are fish swimming velocities and a consistent means for calculating flow velocities. A field crew is required to gather data at each stream-crossing. This information can be filled in on a FishXing field data sheet, Figures 4 and 5, and then entered into FishXing. This data sheet is currently only available on the FishXing website. The following is a list of data collected to run FishXing:

- Date the site was visited and names of the crew members conducting the survey
- Location of the stream crossing, road, watershed, map location, etc
- Fish species and age class of concern and if fish presence observed during the survey
- Existing culvert and habitat information
- Culvert material, shape, embedded depth and material, and inlet and outlet properties
- Stream gradient
- Tailwater properties and channel cross-section survey
- Existing road fill volume, grade, and grade break
- A sketch of the crossing location

Surveyors: ____________________ Date: ________

Fish Passage Inventory Data Sheet

Road:	Mile Post:
Named Stream:	Watershed:
Fisheries Information	
Fish Species/Age Classes of Concern:	Presence observed during survey? upstream downstream none Species/age class: ____________
Length of upstream habitat (ft) – Historical:	Currently Accessible:
Upstream Culverts: yes no No. of culverts: Barrier(s): yes no Distance to 1st culvert barrier (ft):	**Downstream Culverts:** yes no No. of culverts: Barrier(s) yes no Distance to 1st culvert barrier (ft):
Culvert Information	
Culvert Type: Circular Pipe Arch Box Open Arch Other: Height (ft): ________ Width (ft): ________ Length (ft): ________	
Material: SSP CSP Aluminum Plastic Concrete Log/wood Other: Corrugations (*width x depth*) (in): __________ Spiral Rustline Height (ft): _____ Pipe Condition: good abraded rust-through Other:	
Embedded: yes no Depth (ft)- Inlet: ______ Outlet: ______ Location (beginning/end) (ft): ______ Describe substrate:	
Barrel Retrofit (weirs/baffles): yes no Type: Sketch on back Description:	
Inlet type: projecting headwall wingwalls mitered Inlet/Channel Alignment (deg): ______	**Outlet configuration** At stream grade freefall into pool Cascade over riprap Outlet Apron: yes no Describe:
Tailwater Control: pool tailout log weir boulder weir concrete weir channel x-section(no pool)	
Upstream Channel Widths (ft): (1) (2) (3) (4) (5)	

Figure 4: FishXing data sheet page 1. FishXing website at http://www.stream.fs.fed.us/fishxing/fieldform.pdf

Surveyed Elevations Use inlet as datum	Inlet Bottom Elev. (ft): _____ Outlet Bottom Elev. (ft): ____ Pool Bottom Elev. (ft): ______ TW Control Elev. (ft): ______ OHW Elev. at Control (ft): ___	Breaks in Slope: yes no No. ______ (1) Dist. from inlet (ft): _____ Elev. at Break (ft): ______ (2) Dist. from inlet (ft): _____ Elev. at Break (ft): ______ (3) Dist. from inlet (ft): _____ Elev. at Break (ft): ______
Fill Volume	Lu (ft): ______ Su (%): ______ Road Width (ft): ______ Base Fill Width (ft): ______ Ld (ft): ______ Sd (%): ______ Top Fill Width (ft): ______	

Tailwater Cross-Section

Use culvert inlet bottom as datum

Station (ft)															
Elevation (ft)															
Notes															

Channel Roughness – Describe substrate size/shape:

Channel Slope at Tailwater Control

Length (ft):

Upstream Rod Ht (ft):

Downstream Rod Ht (ft):

Calculate Channel Slope (ft/ft):

Add sketches and additional comments below:

Figure 5: FishXing data sheet page 2. FishXing website at http://www.stream.fs.fed.us/fishxing/fieldform.pdf

Using the data from the field data sheet, one has the information necessary to evaluate culverts using FishXing. This is used to assess a culvert's likelihood to allow fish passage. Culverts with lower probabilities for providing fish passage can be determined. These crossings can be ranked on importance of replacement based on the cost to replace them, amount of recoverable habitat, and if the culvert provides access to a critical species or run of fish. FishXing can be used to develop a more fish-friendly road crossing.

Without the aid of a computer program such as FishXing, performing hydraulic calculations necessary for culvert design is a long and tedious task, with many opportunities for error. Once a user is confident that FishXing produces valid results, the repetitive calculations required for culvert installation and evaluation can be done with FishXing with the likelihood of errors limited to data entry.

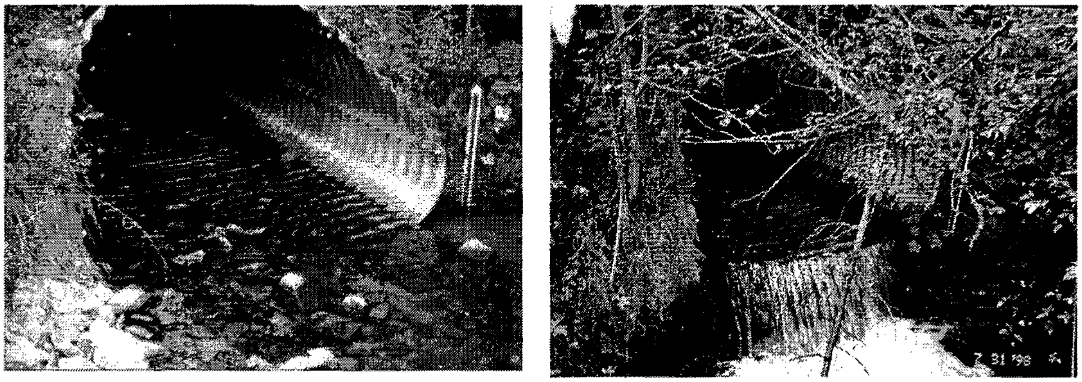
Tailwater effects influencing a culvert can be assessed with three different methods in FishXing. These are Constant Tailwater, User Defined Rating Curve, and Downstream Cross-Section. As the name describes, the Constant Tailwater Method holds the outlet elevation at a steady depth through the entire range of flow through a culvert, as set by the user. This method is most useful in two situations, which are culverts that are backwatered the majority of the time and culverts that are perched, allowing water to fall freely to the stream below. The User Define Rating Curve requires that the user develop a rating curve for the culvert based on knowledge of the culvert installation and associated hydraulics. The Downstream Cross-Section method requires the user to have a detailed cross-section of the stream bottom below the culvert. FishXing then uses this to develop a stage discharge relationship for the culvert of interest.

A consistent method of evaluating fish passage culverts can be found using FishXing. FishXing uses the same approach to evaluate each culvert. This is to compare calculated velocities against fish swim speeds, and comparing it to the time a fish can sustain these speeds. Entrance jumps are evaluated in the same manner. Using equations and default swim speed values within FishXing, a list of culverts that do not obstruct fish passage, culverts that obstruct fish passage at certain flows, and culverts which block fish passage at all flows can be developed. Using this list and information about culvert parameters such as upstream and downstream barriers, recoverable stream habitat, human and fish use of the stream, the remaining functional life of the culvert to pass water, and cost to repair or replace a culvert. A person with the responsibility to improve fish passage can begin to develop a schedule to fix culverts that block fish passage. FishXing can be used to identify culverts that will require minimal time and money to return fish passage past a road crossing and those that will require a greater investment to return fish passage to a stream. A method such as this would aid in appropriating time and money in the most effective manner to benefit the greatest population of fish.

Forest Practices Overview Related to Stream-crossings

In 1994, the Oregon Forest Practices Act was modified. This modification places greater importance on juvenile fish passage at road crossings in fish bearing streams. Until this time, fish passage was a general requirement at stream-crossings, but was not particular to juvenile passage. Prior to 1994, the main concern at forest road crossings was to pass the 25 year flood at the least cost and damage to the road structure, and meet the minimum requirements to provide fish passage. This implied that culverts were installed at a slope and size that met the minimum standards required to pass flow. As a result of this method, inlet controlled culverts were installed. Inlet controlled culverts are very efficient at transporting water, however fish passage requires inefficient movement of water, slower water velocity, and deep water. Culverts installed as inlet control create passage problems for juvenile and adult fish. Steep culvert installations often erode away the stream bottom at the outlet of the culvert overtime, this can cause a culvert to become perched above the stream, as shown in Figure 6, thus fish are required to jump at the culvert entrance in order to swim upstream. A reduction in usable fish habitat occurs, if jumps are too high and fish cannot enter the culvert.

Undersized culverts constrict stream flow at the water inlet. The reduced width in stream flow concentrates water and increases water velocities from those in the surrounding stream environment. High water velocities through culverts and jumps at the culvert entrances increase the stress experienced by fish that are swimming upstream though a culvert. High stress situations during migration have been shown to reduce spawning success (ODFW, 2).



1979 1998

Figure 6: The degradation of a culvert outlet, fish entrance over time (Sylte. 2000).

Part of the reason for the 1994 change in ODF fish passage regulations was based on research that showed that the upstream migration of juvenile fish was an important factor in maintaining healthy fish populations. Healthy fish populations are maintained by providing fish passage throughout a watershed. This allows juveniles to escape from high water temperatures in the main channel during summer, avoid predators, move upstream to smaller channels to find refuge before a flood, or return upstream after a high flow event if they were carried downstream during a high flow event (OCSRI. 1997). Changes in regulations have been based on the scientific knowledge available at the time; this incorporated the present knowledge of adult and juvenile fish swimming abilities and instream habitat requirements (Paul. 2002).

Changes were made in culvert design parameters to make them more "fish friendly" or easier for fish to pass through. The guidance changed to include many different forms of culvert installations with varying stream gradients and scenarios (Table 1). ODF hydrologist, George Robison, developed stream-crossing guides in 1995 and 1997 to help Forest Practices Foresters and landowners adjust to the new changes in the regulations. (A newer stream-crossing guide was released in June 1999, but it was not available for culvert installations used in the ODF fish passage study). As a result of the 1994 change, velocities are to be kept low on all new culvert installations, under 2 feet per second, and jumps are to be kept under 6 inches and require a jump pool at the culvert entrance (Robison. 1997). Robison noted that many previous culvert designs would not provide fish passage. Following the new regulations, all new stream-crossing culverts and bridges are required to pass the 50 year peak flow event, and are not to impair juvenile and adult fish migration when migration normally occurs, effective September 1, 1994.

Oregon Department of Forestry created a compliance report entitled Compliance With Fish Passage and Peak Flow Requirements at Stream Crossings (the ODF fish passage study). This report evaluates the compliance of fish passage structures that were installed under 1998 instream operating notifications filed with ODF. The monitoring took place over the summers of 1998, 1999, and 2000.

ODF FISH PASSAGE STUDY

Oregon Department of Forestry developed the ODF fish passage study monitoring program that spanned the summers of 1998, 1999, and 2000. The purpose was to evaluate the compliance of new stream-crossing structures with the new Forest Practices' stream-crossing requirements. The ODF fish passage study used the summer of 1998 as a pilot study. In the executive summary by Liz Dent, the goals of the pilot study are stated as:

> 1) "Test and refine the efficiency and effectiveness of site-selection and data collection protocols developed to address the stream-crossing monitoring questions."
> 2) "Provide preliminary data to answer the monitoring questions [below] on compliance with stream-crossing rules and guidelines"

The four main monitoring questions for both the pilot study and the ODF fish passage study were:

> 1) What percent of stream-crossings are in compliance with their written plans?
> 2) What percent of stream-crossings have a high likelihood to pass juvenile fish?
> 3) What percent of stream-crossings have been designed and installed in accordance with ODF guidelines?
> 4) What percent of stream-crossings have been designed and installed with adequate capacity for a 50-year flow? (Dent. 2000)

ODF fish passage instructions were changed in 1995 and 1997. Due to the changes in the rules, some landowners, operators, and Forest Practices Foresters are uncertain as to how they should interpret and implement the new rules. The ODF fish passage study was designed to identify some of the confusion experienced by people affected by the new regulations as well as to see how well the new regulations are being followed in the field. This would identify regulations that need to be clarified, omitted, or added to achieve the goals of ODF, ODFW and the Oregon Plan for Salmon and Watersheds.

The ODF fish passage study did not include a measurement of water velocity to see that stream velocity was under that specified for fish passage, nor were culverts checked during the period when upstream or downstream fish movement normally occurs to see that culverts provide fish passage. The ODF fish passage study was designed to determine how well the current regulations are being followed in the field as well as on Written Plans. Written Plans are required by ODF for any instream work on forestlands and they serve as a permit.

ODFW guidelines and ODF fish passage policy are, if certain conditions are created and maintained, there is a high likelihood of providing fish passage. These conditions are streambed simulation, continuous crushed rock or backwatering the length of the culvert to a minimum depth. The guidelines are designed to ensure that one or both of these conditions are created and maintained. The goal of the ODF fish passage study was to determine the compliance of culvert installations as well as the effectiveness of the ODF guidelines. In other words, it is assumed that when the guidelines are implemented correctly, conditions that are believed to provide a high likelihood of fish passage are actually created and maintained. The ODF fish passage study evaluated the validity of this assumption. (Paul. 2002).

The executive summary by Liz Dent states that the following information was collected in the field for the relevant culvert installations:

> At each stream-crossing a number of parameters were measured including: structure type and dimensions, culvert gradient, culvert outlet drop, design and depth of countersinking, outlet mitigation design and dimensions, sediment retention patterns within culverts, valley and channel conditions (stream gradient), baffle/weir design and dimensions, and the cross-sectional area under bridges.

The following data was collected to verify that information on Written Plans was correct. Culvert length, and diameter or height and width were measured using a hip chain. The culvert slope was measured using an engineers level and 25 foot survey rod. On culverts with bare bottoms, the survey rod was placed on the same location of corrugation, raised or recessed, for the upstream and downstream measurements to ensure accuracy. When stream simulation or countersinking measures were taken, slope was measured by placing the rod on the surface of the substrate within the culvert. The downstream elevation control was determined by the elevation of the first riffle downstream of the culvert or elevation of downstream backwater structures. A visual inspection was conducted to determine the mean particle size within the substrate of the stream as defined in Table 2 by ODF.

Bedrock ....> 13 feet diameter	Bigger than a car or continuous underlayer
Boulders...........> 10 inches to 13 feet	Basketball to car size
Large cobble......> 6 inches to 10 inches	Cantaloupe to basketball
Small cobble.......> 2.5 inches to 6 inches	Tennis ball to cantaloupe
Course gravel.....> 0.6 inches to 2.5 inches	Marble to tennis ball
Fine gravel........> 0.1 inches to 0.6 inches	Ladybug to marble
Sand...............< 0.1 inch	Smaller tha ladybug, but visible as particle: also gritty as you rub through hands
Fines.............. Not visible as particles	Silt clay muck (not gritty)

Table 2: Particle size classification. Defined in Oregon Road/Stream Restoration Guide: Spring 1999, Advanced Fish Passage Training Version. (Robison. 1999).

Culvert data collected in the manner described was used to evaluate stream-crossing designs. The information was compared with the Written Plan to assess compliance in following through on the Written Plan filed with ODF. The physical parameters of the recently installed structure were compared against the regulations and guidelines set forth by ODF in the Forest Practices Act and Guidance Manual to determine if the structure meets the requirements set forth by the regulations. In this project, results from the ODF fish passage study are compared to the output generated by FishXing. This information will be used to evaluate FishXing with ODF stream-crossing regulations.

Currently there are eight methods for stream-crossings that ODF will accept (Table 1). These are used to address different crossing situations. Six of these eight crossing methods are for full pipe culvert crossings. The other two categories are bridges and bottomless arches. In special cases experimental designs may also be used; these must be approved by ODF. When an experimental design is approved, follow up monitoring on the design is required. If the guidance is correctly followed, and the proper stream-crossing method is chosen, ODF feels there is a high likelihood that the stream-crossing will provide fish passage.

Figure 7 provides a schematic of stream-crossing placement and cost. This chart can be used to determine the stream-crossing methods that best suit a given stream crossing location. Starting with a slope profile where the crossing is to be installed, a designer may refer to Figure 7 to find which stream crossings methods are most economic, and if they require further review by ODF staff.

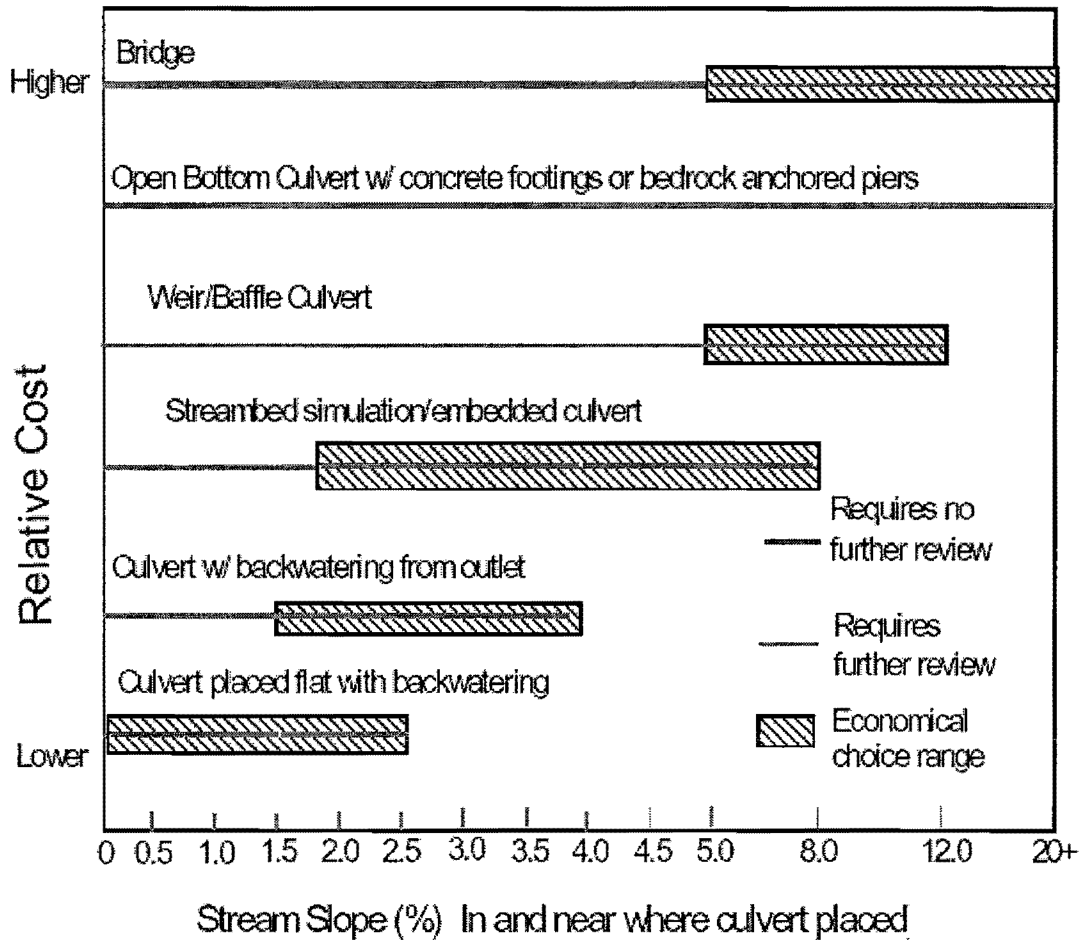


Figure 7: Stream crossing options in terms of stream slopes and relative cost (Robison. 1999).

It was acknowledged by the ODF monitoring staff at the time of the ODF fish passage study that further investigation into actual fish passage is needed. However, ODF did not have the funding, equipment, or expertise to carry out a study of this sort. ODF believes that an in depth fish passage study would be more appropriately undertaken by ODFW or by other fisheries biologists (Paul. 2001).

Results

FishXing and ODF Results Comparison

The number of culverts with similar results from FishXing and ODF does not show convincing evidence, 67% agreement in all 4 runs, that FishXing output and ODF culvert evaluation are highly compatible. Four major factors contribute to the differences between FishXing and ODF evaluations of culverts. These factors are: (1) high outlet velocities as a result of using the Constant Tailwater Method, (2) inadequate pool depth message resulting from use of the Constant Tailwater Method, (3) streams with high gradients using streambed simulation and baffle techniques, and (4) ineffective backwater culvert function observed by the ODF monitoring crew.

The first factor contributing to differences between the ODF and FishXing results was that the Constant Tailwater Method in FishXing was the only option available to calculate tailwater conditions in this report. ODF collected the data used in a manner that met the needs of the ODF fish passage study. Therefore downstream channel measurements were not obtained. This project used the data from the ODF fish passage study without discovering the need for complete downstream channel measurement until all data was collected.

Culvert analysis executed with FishXing used the Constant Tailwater Method. The Constant Tailwater Method does not change the water level at the outlet of the culvert under different flow levels. The control point used for the Constant Tailwater Method was the elevation of the first downstream riffle or backwater structure. As a result, unusually high outlet water velocities are generated with FishXing as flow increases. This option was used, as there was not enough information to use the other two methods available: 1) User Defined Rating Curve and 2) Downstream Cross Section methods. Nomagraphs were examined in the Handbook of Steel Drainage & Highway Construction Products, Fifth Edition, but did not provide adequate information for embedded culvert installations.

Tables 3 and 4 show the differences in calculated outlet velocity, pool depth, tailwater depth and the comments column when using the Constant Tailwater Method or the User Defined Rating Curve Method to determine the tailwater level. This was possible by creating a User Defined Rating Curve. Items listed in the comments column prevent fish passage according to FishXing output for the given run. Tables 3 and 4 use the exact same culvert parameters with just the tailwater option switched from the Constant Tailwater to the User Defined Rating Cure option.

Design Flows			Constant Tailwater Method			Culvert 6			
Low Passage Flow: 1 cfs									
High Passage Flow: 8.5 cfs									
Table 1. Uniform Flow Calculations.									
							Min Rqd.	Vertical	
		Normal	Critical	Outlet	Tailwater	Pool	Leap	Leap	
Discharge	Velocity	Depth	Depth	Velocity	Depth	Depth	Velocity	Distance	Comments
(cfs)	(cfs)	(ft/s)	(ft)	(ft)	(ft/s)	(ft)	(ft)	(ft/s)	(ft)
0	0	0	0	0	0	0.3			
0.09	0.45	0.1	0.04	1.06	0	0.3	0	0	Depth; Pool
0.31	0.69	0.2	0.09	1.65	0	0.3	0	0	Depth; Pool
0.63	0.88	0.3	0.14	2.03	0	0.3	0	0	Depth; Pool
1	1.02	0.39	0.19	2.34	0	0.3	0	0	LPF; Depth; Pool
1.04	1.04	0.4	0.2	2.37	0	0.3	0	0	Depth; Pool
1.54	1.18	0.5	0.25	2.66	0	0.3	0	0	Pool
2.13	1.31	0.6	0.31	2.92	0	0.3	0	0	Pool
2.8	1.43	0.7	0.36	3.15	0	0.3	0	0	Pool
3.55	1.54	0.8	0.42	3.37	0	0.3	0	0	Pool
4.37	1.64	0.9	0.47	3.57	0	0.3	0	0	Pool
5.25	1.74	1	0.53	3.77	0	0.3	0	0	Pool
6.21	1.82	1.1	0.58	3.95	0	0.3	0	0	Pool
7.22	1.91	1.2	0.64	4.12	0	0.3	0	0	Pool
8.28	1.98	1.3	0.69	4.28	0	0.3	0	0	Pool
8.5	2	1.32	0.7	4.31	0	0.3	0	0	HPF; Pool
9.39	2.06	1.4	0.75	4.44	0	0.3	0	0	Pool
10.54	2.13	1.5	0.8	4.59	0	0.3	0	0	Pool
11.73	2.19	1.6	0.85	4.73	0	0.3	0	0	Pool
12.95	2.25	1.7	0.9	4.86	0	0.3	0	0	Pool
14.19	2.3	1.8	0.95	5	0	0.3	0	0	Pool
15.45	2.36	1.9	1	5.12	0	0.3	0	0	Pool

Table 3: Constant Tailwater output display from FishXing for culvert #6. Slope 0.19%, 48 inch round culvert, embedded 3 inches.

Design Flows			User Defined Rating Curve			Culvert 6			
Low Passage Flow: 1 cfs									
High Passage Flow: 8.5 cfs									
Table 1. Uniform Flow Calculations.									
							Min Rqd.	Vertical	
		Normal	Critical	Outlet	Tailwater	Pool	Leap	Leap	
Discharge	Velocity	Depth	Depth	Velocity	Depth	Depth	Velocity	Distance	Comments
(cfs)	(cfs)	(ft/s)	(ft)	(ft)	(ft/s)	(ft)	(ft)	(ft/s)	(ft)
0	0	0	0	0	0	0.3			
0.09	0.45	0.1	0.04	1.06	0.03	0.33	0	0	Depth
0.31	0.69	0.2	0.09	1.52	0.1	0.4	0	0	Depth
0.63	0.88	0.3	0.14	1.43	0.2	0.5	0	0	Depth
1	1.02	0.39	0.19	1.36	0.31	0.61	0	0	LPF; Depth
1.04	1.04	0.4	0.2	1.38	0.31	0.61	0	0	Depth
1.54	1.18	0.5	0.25	1.52	0.41	0.71	0	0	
2.13	1.31	0.6	0.31	1.6	0.51	0.81	0	0	
2.8	1.43	0.7	0.36	1.78	0.58	0.88	0	0	
3.55	1.54	0.8	0.42	1.92	0.67	0.97	0	0	
4.37	1.64	0.9	0.47	2.02	0.76	1.06	0	0	
5.25	1.74	1	0.53	2.09	0.86	1.16	0	0	
6.21	1.82	1.1	0.58	2.14	0.96	1.26	0	0	
7.22	1.91	1.2	0.64	2.23	1.06	1.36	0	0	
8.28	1.98	1.3	0.69	2.33	1.14	1.44	0	0	
8.5	2	1.32	0.7	2.34	1.16	1.46	0	0	HPF
9.39	2.06	1.4	0.75	2.41	1.23	1.53	0	0	
10.54	2.13	1.5	0.8	2.5	1.31	1.61	0	0	
11.73	2.19	1.6	0.85	2.59	1.39	1.69	0	0	
12.95	2.25	1.7	0.9	2.67	1.47	1.77	0	0	
14.19	2.3	1.8	0.95	2.75	1.55	1.85	0	0	
15.45	2.36	1.9	1	2.84	1.62	1.92	0	0	

Table 4: User Defined Rating Curve output display from FishXing for culvert # 6. Slope 0.19%, 48 in round culvert embedded 3 in.

Note the difference in the values for Outlet Velocity, Tailwater Depth, and Pool Depth in Tables 3 and 4 and Figure 8. These differences are the result of using the User Defined Tailwater Method rather than the Constant Tailwater Method within FishXing. The Downstream Cross Section Method produces similar changes when compared with the Constant Tailwater Method.

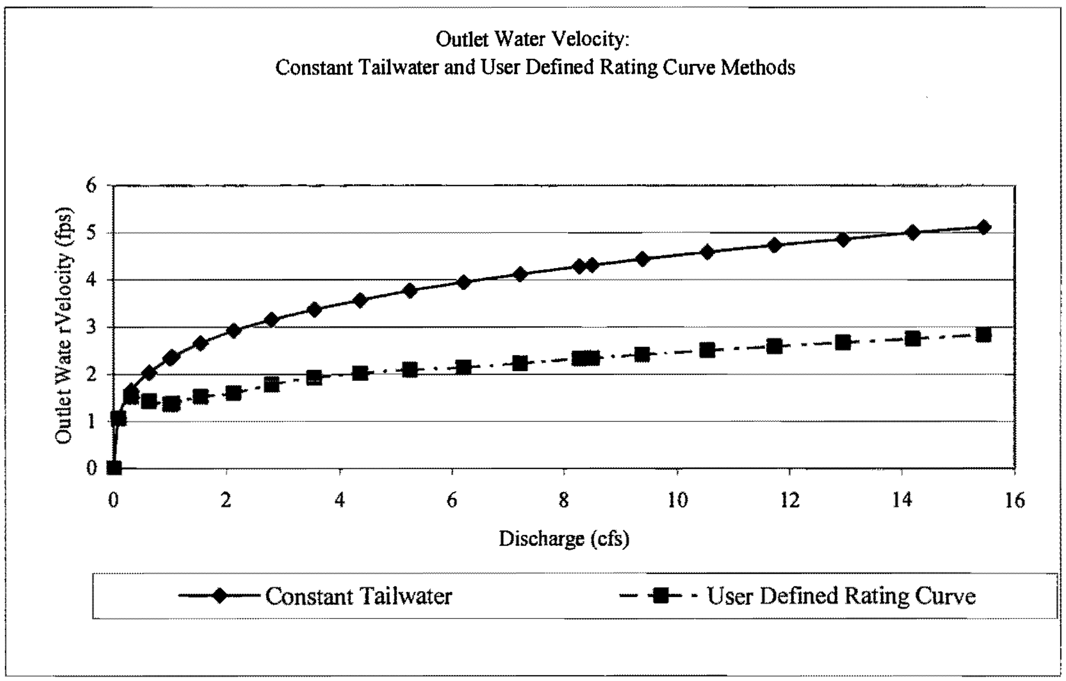


Figure 8: Difference in calculated outlet velocity. Created using the Constant Tailwater Method and User Defined Rating Curve Method. The User Defined Rating Curve used here was created with a nomagraph from the Handbook of Steel Drainage and Highway Construction Products, 1995. Culvert #6, slope 0.19%, 48 inch round culvert, embedded 3 inches.

The Constant Tailwater Method was involved with the second factor leading to differences in results between ODF and FishXing results. For some of the culverts installed at gradients of less than 0.15%, a message of inadequate pool depth was displayed in the Uniform Flow Output Table at all levels for the simulation using adult fish, Table 3. However, both the minimum swimming depth set in FishXing and the minimum required depth for the downstream pool were met or exceeded in all cases. There were no perched culverts in this range of slope requiring fish to jump to enter a culvert, where a jump pool would be critical. With more information gathered in the field, such as a downstream channel cross section being taken, the Downstream Cross Section method could be used, and the inadequate pool message would be resolved. Using one of the other two methods would modle the rising and falling depth of water as flows increased and decreased. Tables 3 and 4 illustrate the difference in uniform flow output generated by FishXing using the Constant Tailwater Method and User Defined Rating Curve methods. A user of FishXing should have better site information than that used in this test of FishXing. Users should collect data as listed on the FishXing field data sheet to enable them to use either the User Define Rating Curve or Downstream Cross Section method for determining tailwater conditions. An example of the FishXing data sheet is available in Figures 4 and 5, pages 12 and 13, or from the FishXing web page.

The third factor for differences found between FishXing and the ODF fish passage study was found on streams with high gradients. On some of these steeper gradients, ODF approved the use of streambed simulation or baffle type culverts.

Streambed simulation culverts are believed to allow fish passage by providing a base within the culvert that is similar to the stream reach in which the culvert is located. By providing these similar conditions within a culvert, it is believed that fish capable of swimming in the natural stream should be able to pass through a streambed simulation culvert.

Baffle culvert designs slow water velocities, increase water depth, and can create resting areas within the culvert by offsetting weirs within the culvert. FishXing offers no means to effectively evaluate baffle weir culvert designs because of the many different types of baffle weir designs and complex hydraulics associated with each design. "Only a limited number of baffle types, spacing, and sizing have been studied, making incorporation of baffles into FishXing impractical" (Love. 2002).

When the monitoring crew visited these culverts, the culverts designed as streambed simulation of baffle were observed to be retaining sediment. Therefore, these met the ODF criteria for streambed simulation or baffle design. However, FishXing cannot take into account the complex flow conditions associated with different streambed simulation and baffle culvert designs. This results in high velocity values being calculated with FishXing. Therefore culvert analysis with FishXing indicates that the majority of culverts using these designs are velocity barriers to fish passage. If using only FishXing to evaluate fish passage culverts, one would believe from viewing FishXing output that functioning streambed simulation or baffle culverts are not providing fish passage. This may result in misappropriation of time and effort to fix a problem that doesn't really exist.

The fourth factor that produced different assessment between FishXing and ODF was related to flat gradient and backwatered culvert designs. Using the data for the juvenile Cutthroat trout (required velocity set to ODFW Guidelines and Criteria for Stream-Road Crossings of 2 fps or less), 5 culverts were found to provide fish passage using FishXing, but did not pass ODF criteria. Three of these culverts at very low gradients were designed to maintain backwater through the culvert barrel. ODF requires backwatered culvert designs maintain a depth of at least 8 inches through the length of the culvert barrel year round. The fourth culvert has a beaver dam in it blocking fish passage. The fifth culvert that appears to pass both FishXing and ODF criteria but doesn't because of a long stretch of rip rap placed downstream of the culvert. This rip rap runs approximately 75 feet until the stream returns to a pond area. Any water coming out of the culvert flows under the rip rap until it joins the pond area. This culvert may provide fish passage in the future if sediment transport is capable of filling in the void spaces between the rocks, and can maintain a stream channel through the rip rap section. Figures 9 and 10 show these two types of culvert installations.

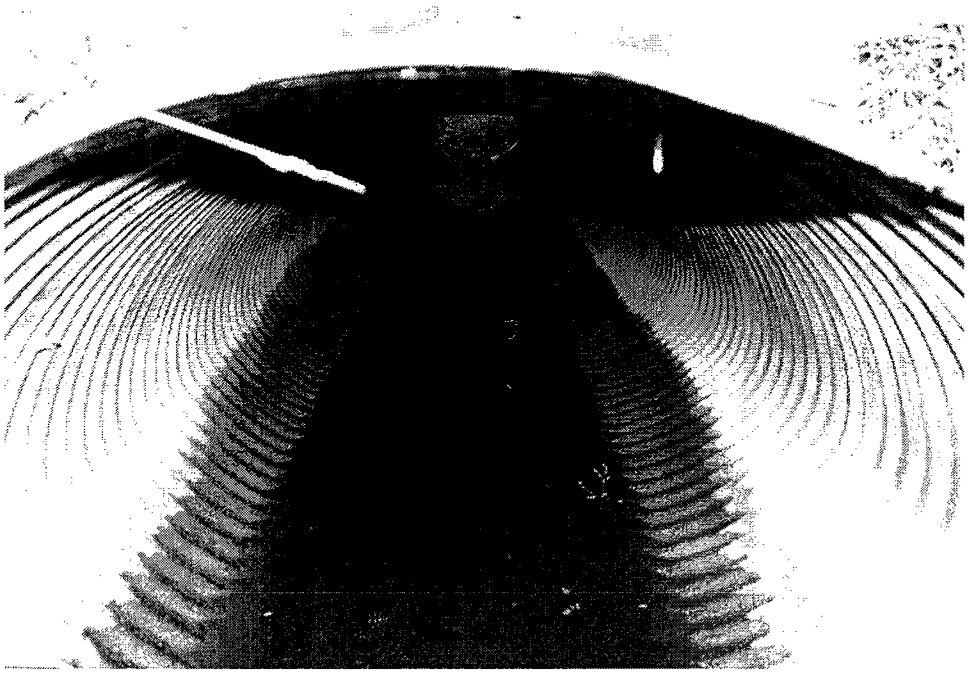


Figure 9: Culvert # 61.

Culvert # 61 in Figure 9 was installed as a backwatered culvert, but when visited in August of 2001 the depth measured 0.2 feet or 2.4 inches, not the 8 inch requirement for a backwatered culvert as required by ODF. Downstream structures can be used to maintain the 8-inch depth for a backwater culvert design. When this culvert was visited in August of 2001, there were no signs of backwater structures associated with this crossing.

Figure 10: Culvert # 74.

Large rip rap on the downstream end of culvert #74 shown in Figure 10 essentially causes subsurface flow for approximately 75 ft. At this point the flow enters the stream below. While the culvert installation meets ODF criteria, the downstream rip rap prevents fish movement upstream to the culvert. Over time, sediment transport may fill in the spaces between the rip rap and return flow to the surface, thus connecting the culvert to the downstream section and allowing fish to reach and swim through the culvert.

ODF Results Compared To 4 Different Runs of FishXing Results

In this project, the definition used for a successful fish passage culvert in FishXing output is a culvert with one or more field in the Uniform Output Table with no constraints to fish passage. This definition takes into account that the uniform flow calculations use an average velocity, when it is understood that velocity is variable through the cross-section of a culvert as can be seen in Figure 11. This project assumes that fish will use lower velocity zones along the bottom and sides of a culvert, thus be able to pass at average velocities slightly greater than their swimming abilities.

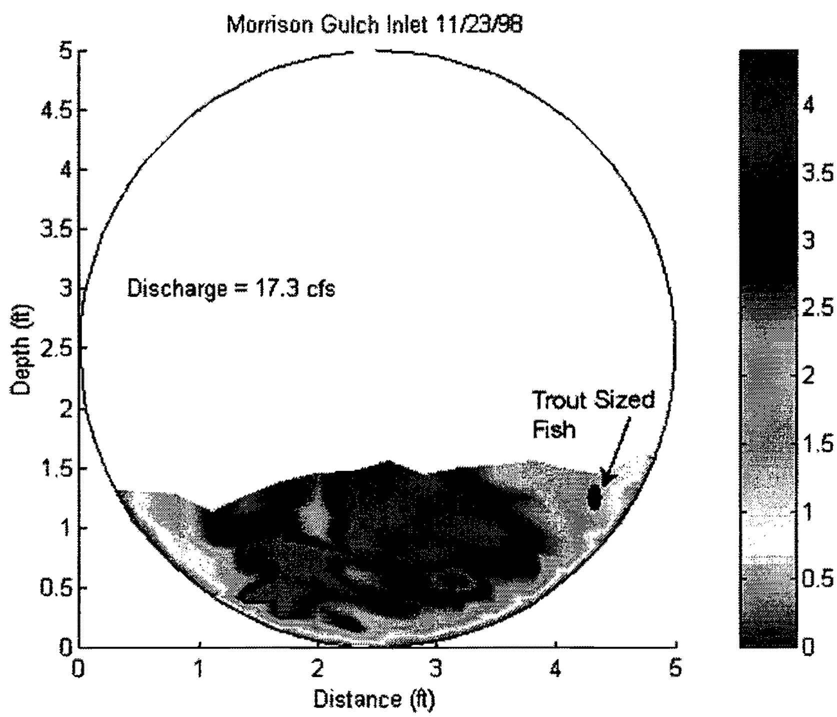


Figure 11: Variable velocity through a culvert. Average velocity in the inlet of a 60-inch CMP is 3.3 feet per second. However, there are regions of lower velocities near the culvert wall that fish can swim through. (FishXing Help files).

The water surface profile calculations within FishXing provide a more complete analysis of culvert performance than the uniform flow calculations; however, only 3 flows, low, medium, and high, can be evaluated at a time with this method, requiring a trial and error approach to find fish passage flows. FishXing version 3 will try to automate the water surface profile calculations that meet fish passage criteria (Love. 2002). Uniform flow calculations were chosen for this comparison because the range of flows where fish passage can occur is easily identified. Uniform flow output tables can be seen as Tables 3 and 4. Values are given at every 1/10th of a foot by depth. The minimum depth required for fish passage used was 0.5 feet for adult fish and 0.3 feet for juveniles. ODF requires a minimum depth of 0.8 feet for backwatered culverts. However, not all culverts were backwater designs, and so the minimum depths of 0.5 and 0.3 feet were used for analysis to allow a wider range of flows for steeper culvert installations.

Figure 12 shows the percent of crossings in the ODF fish passage study using each of the ODF approved crossing strategies. Figures 13-16 and Tables 5-8 show the results generated by FishXing compared to ODF's analysis for each of the four simulated fish runs, adult Coho salmon, juvenile Coho salmon, adult Cutthroat trout, and juvenile Cutthroat trout.

The "Other" category is for culverts that did not specify what strategy was being used to achieve fish passage or used an agreed upon experimental design. ODF assessed the culvert installations and made a decision as to whether the culvert was believed to be able to provide fish passage in these cases.

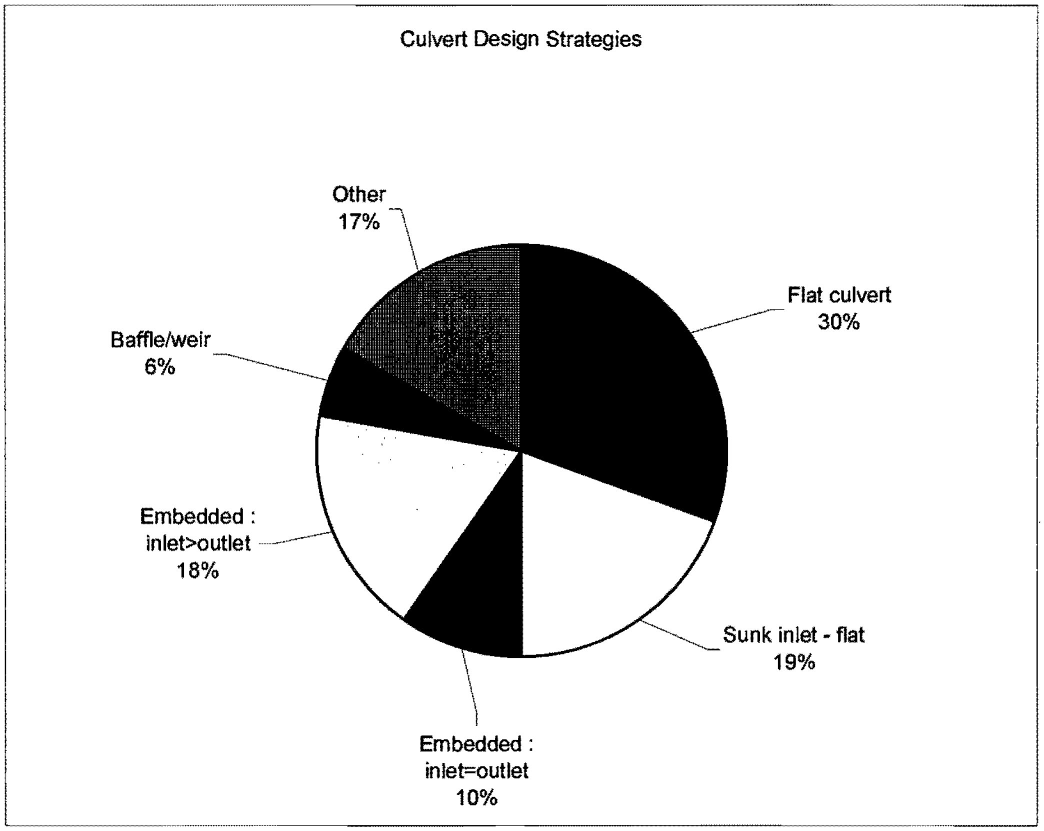


Figure 12: Percent of culverts installed using each crossing strategy. See table 1 for crossing definitions.

ADULT COHO SALMON

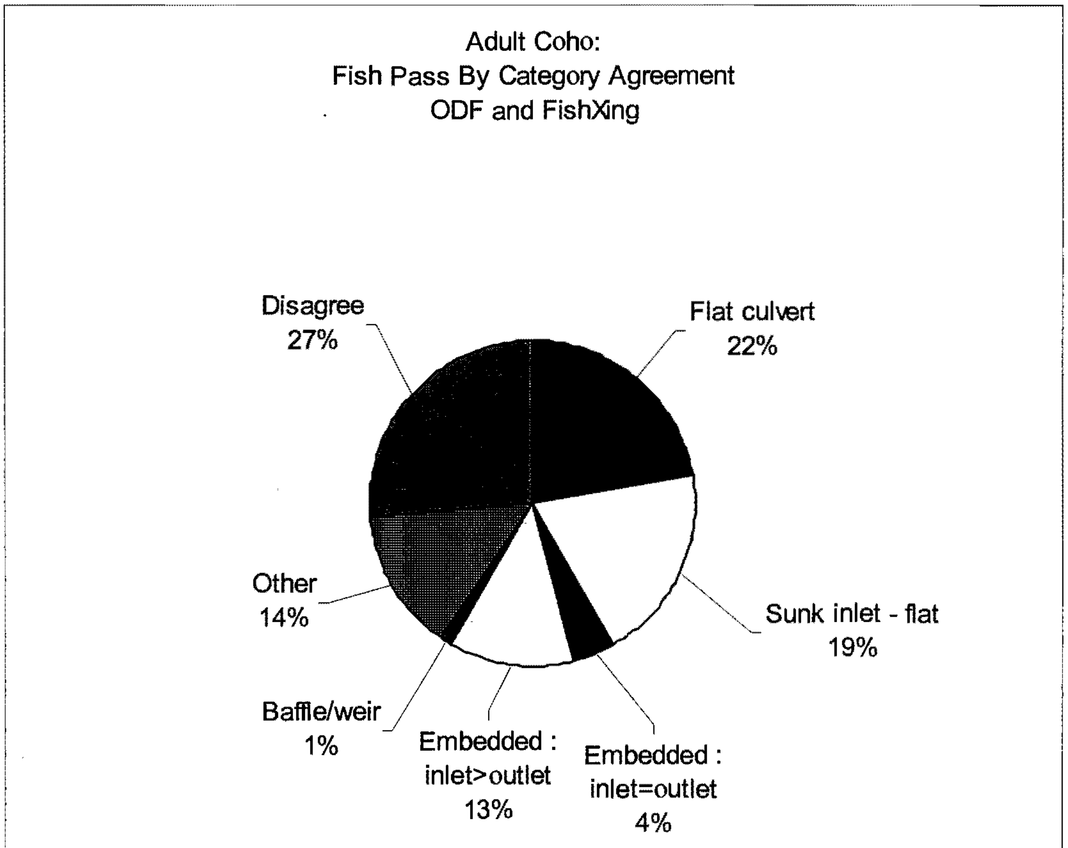


Figure 13: By category, the percent of all crossing that have the same assessment by FishXing and ODF. 27% of the crossings for adult Coho salmon had different assessment by FishXing and the ODF fish passage study.

Adult Coho salmon were the strongest-swimming fish used in this FishXing analysis. The swimming capabilities of the Coho salmon used were 6.0 ft/sec for 30 minutes at the sustained swimming level (Bell. 1991), 9.5 ft/sec for 5 seconds at the burst swim speed level, and a leaping velocity capability of 9.5 ft/sec (Hunter and Mayer. 1986). These and all other references to fish swimming abilities are the default sources used within FishXing for all species, except juvenile Cutthroat trout which do not have a default. A 400 mm (15.75 in) Coho salmon was used to determine the default values for this project. This is a slightly smaller than average size range for Coho salmon; however, length only has minimal influence on calculated burst swim speed.

In Table 5, results by category for adult Coho salmon are shown. There were several reasons why FishXing and the ODF evaluations of culverts did not yield equivalent results. One reason for this was some culverts that were supposed to be backwatered using the flat culvert installation were not. As a result, these culverts did not meet the requirements set forth by ODF for this installation technique. Other culverts, on flat installations, had a display message of inadequate pool depth making them impassable to according to FishXing analysis.

Comparison between FishXing and ODF Study			
Culvert Category	Culverts in Agreement	Culverts in Category	% Agreement by Category
Flat culvert	16	22	73
Sunk inlet - flat	14	14	100
Embedded : inlet=outlet	3	7	43
Embedded : inlet>outlet	9	13	69
Baffle/weir	1	4	25
Other	10	12	83
Total Across Catagories	53	72	74

Table 5: Number of culverts in agreement between FishXing and the ODF fish passage study for each category for adult Coho salmon.

JUVENILE COHO SALMON

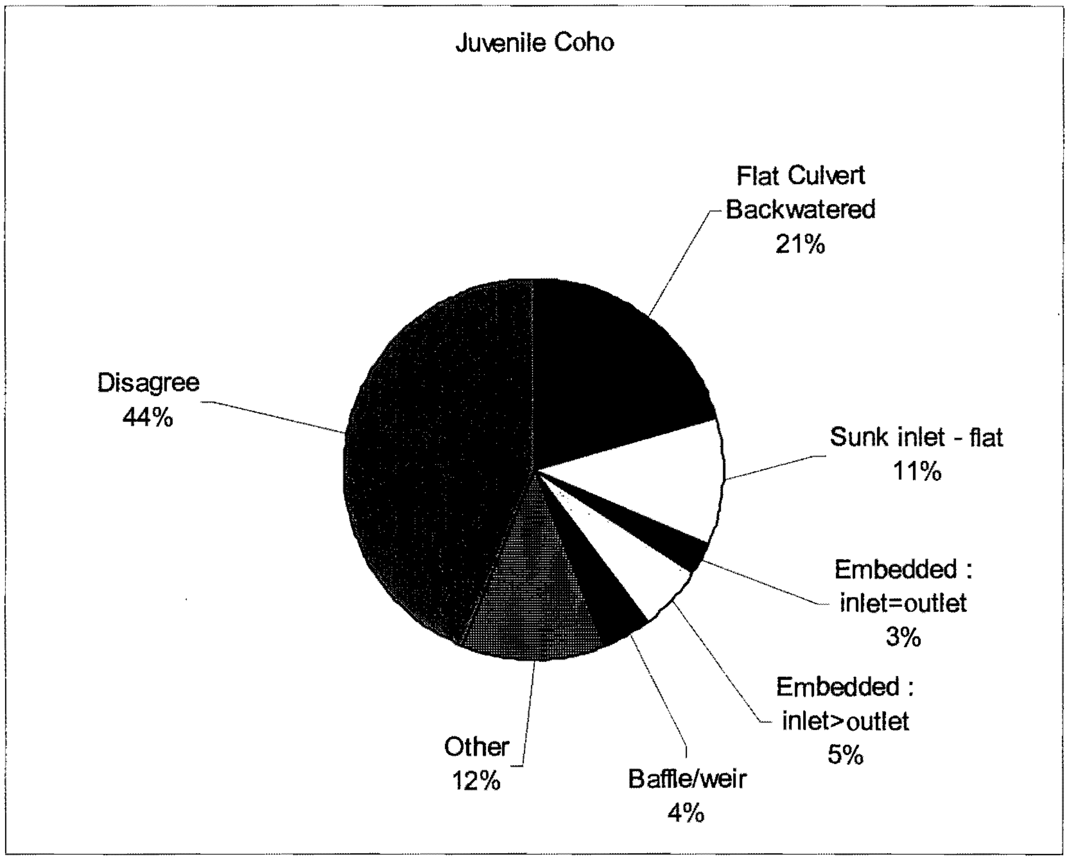


Figure 14: By category, the percent of all crossings that have the same assessment by FishXing and ODF. 44% of the crossings for juvenile Coho salmon had different assessment by FishXing and the ODF fish passage study.

The juvenile Coho salmon were the weakest swimming fish in the study. A 60 mm (2.4 in) juvenile Coho was used in FishXing. For a juvenile Coho salmon of this size, FishXing used a sustained swimming speed of 1.1 feet per second for 30 minutes (Hunter and Mayer. 1986), a burst swimming speed of 4.0 feet per second for 5 seconds and a leap velocity of 4.0 feet per second (Bell. 1991).

Culverts installed at gradients above 0.30% resulted in average water velocities too great for the juvenile Coho swim through.

The analysis of juvenile Coho shows close correlation between FishXing and ODF monitoring with the flat culvert, baffle, and "other" culvert installation strategies. Some differences in results with the backwatered installation were observed. This occurred because culverts were not installed to maintain 8 inches of backwater through their length. Therefore, these culverts do not meet ODF criteria for backwatered culverts. With the baffle option, one culvert using this method met ODF criteria to provide fish passage, while no juvenile Coho salmon were determined to be able to swim through these culverts using the FishXing analysis. The majority of the culverts placed in the "other" category were either flat culvert installations or sunken flat installations which provide fish passage, but did not provide enough information in the culvert design for ODF to determine what fish passage approach was being used. In table 6, the results by category for juvenile Coho salmon are shown.

Comparison between FishXing and ODF Study			
Culvert Category	Culverts in Agreement	Culverts in Category	% Agreement by Category
Flat Culvert Backwatered	15	22	68
Sunk inlet - flat	7	14	50
Embedded : inlet=outlet	2	7	29
Embedded : inlet>outlet	4	13	31
Baffle/weir	3	4	75
Other	9	12	75
Total Across Catagories	40	72	56

Table 6: Number of culverts in agreement between FishXing and ODF for each category for juvenile Coho.

ADULT CUTTHROAT TROUT

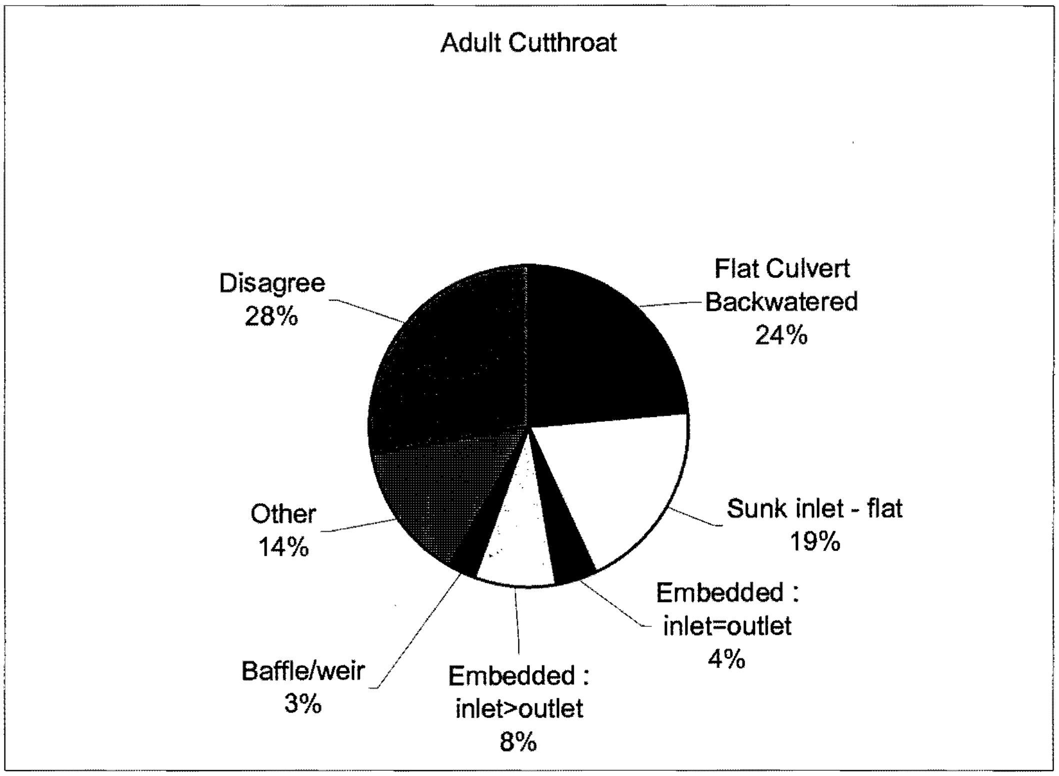


Figure 15: By category, the percent of all crossings that have the same assessment by FishXing and ODF. 28% of the crossings for adult Cutthroat trout had different assessment by FishXing and the ODF fish passage study.

Adult Cutthroat trout were the second-strongest-swimming fish used in the comparison between FishXing and the ODF Fish Passage monitoring study. A 400 mm Cutthroat trout was used in the FishXing trials. The sustained swimming speed used by FishXing for this size Cutthroat trout is 4.0 feet per second for a period of 30 minutes (Bell. 1973). The burst speed is 8.0 feet per second for a period of 5 seconds and the leap velocity is 8 feet per second (Bell. 1973)

The adult Cutthroat had similar results to the adult Coho. There were culverts that appeared to provide fish passage by ODF criteria, but they were not installed so that a backwater pool was maintained through a culvert. Therefore, they did not pass the ODF assessment. FishXing, however, characterized them as passing culverts, which caused differences between the ODF and FishXing assessments. Another problem was inadequate pool depth comment displayed by FishXing for some of the flat culvert installations. The culverts meet requirements for fish passage set by the user; however, the FishXing output shows the entrance pool depth as inadequate. The agreement with the baffled culverts is stronger with the adult Cutthroat trout than the adult Coho salmon. There were only four baffle designs; therefore no significant analysis can be accomplished.

In Table 7, results by category for adult Cutthroat trout are shown. With the inlet embedded deeper than the outlet there is closer correlation between ODF results and FishXing for the Coho than Cutthroat.

Comparison between FishXing and ODF Study			
Culvert Category	Culverts in Agreement	Culverts in Category	% Agreement by Category
Flat Culvert Backwatered	17	22	77
Sunk inlet - flat	14	14	100
Embedded : inlet=outlet	3	7	43
Embedded : inlet>outlet	6	13	46
Baffle/weir	2	4	50
Other	10	12	83
Total Across Catagories	52	72	72

Table 7: Number of culverts in agreement between FishXing and ODF for each category for adult Cutthroat.

JUVENILE CUTTHROAT TROUT

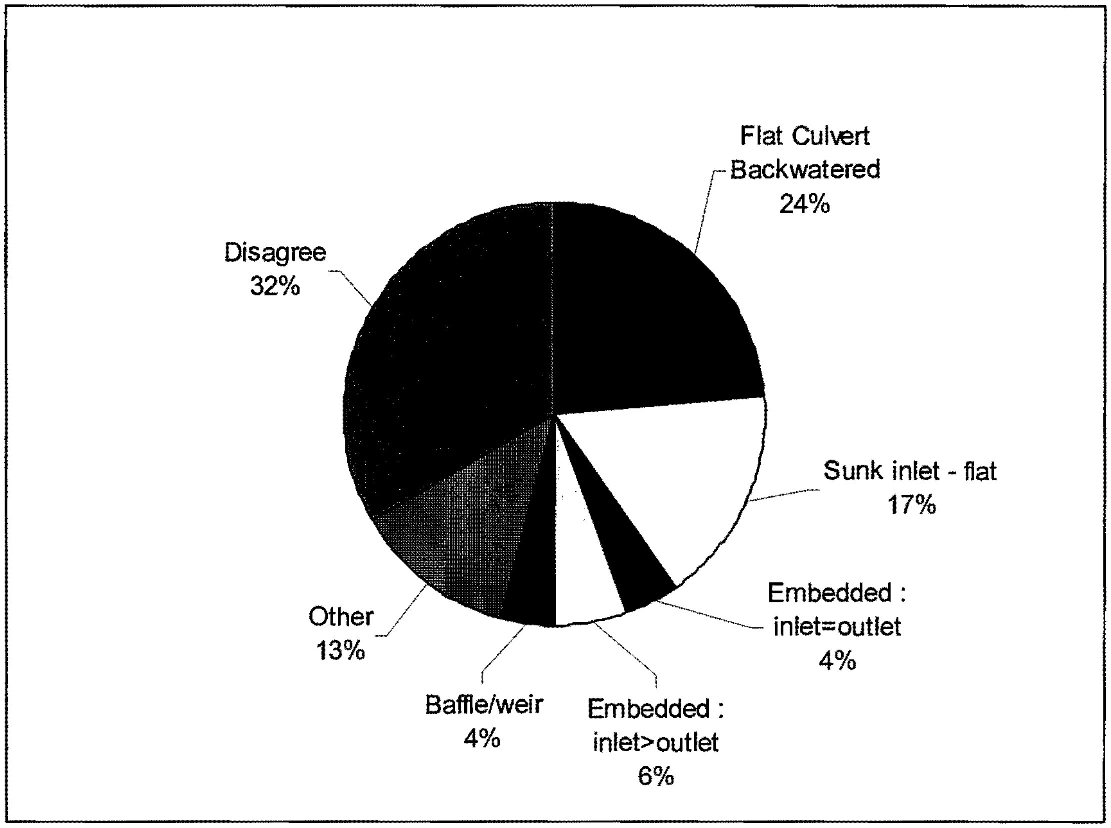


Figure 16: By category, the percent of crossings that have the same assessment by FishXing and ODF. 32% of the crossings for juvenile Cutthroat trout had different assessment by FishXing and the ODF fish passage study.

Juvenile Cutthroat trout did not have a default swim speed set in FishXing. Therefore the velocity used for the juvenile Cutthroat trout was set to the maximum design velocity in the state of Oregon, which is 2 feet per second (ODFW 1997). A user-defined burst speed of 4.0 feet per second for a period of 8 seconds was used along with a leap velocity of 4.5 feet per second.

According to FishXing average velocity calculations the maximum culvert gradient that juvenile Cutthroat trout are capable of passing is a 2.18% slope.

Juvenile Cutthroat trout with a swim speed of 2 feet per second (ODFW 1997) had a high correlation with the ODF monitoring data for the flat culvert installation, flat sunken inlet culvert installation, baffle installation, and "other" category. However, for two techniques used on steeper stream systems the agreement between ODF and FishXing diminishes. These two strategies use embedded culverts to create streambed simulation to provide for fish passage. However, the culvert parameters that are entered into FishXing only allow for increased roughness on the channel bottom with embedded culverts. This limits the amount of streambed simulation that can be accounted for by FishXing, such as meander patterns that can develop within a culvert over time. At low flow, these meander patterns increase the length of the thalweg, thereby reducing the gradient within the culvert. The effect streambed simulation culverts have on reducing slope decreases inversely as flow and water depth increase. At higher flows, the water surface slope will be equal to the slope the culvert is installed at, or the constant slope of the substrate within the culvert. Culvert parameters entered into FishXing are as follows: depth the culvert is sunk into the streambed, roughness of streambed material and culvert itself, slope of the culvert installation, size and length of the culvert, and if fish are required to jump to enter the culvert. Therefore, some of the more complex designs using stream simulation and baffles cannot properly be analyzed with FishXing.

Arranged by category the number of culverts with the same evaluation by FishXing and ODF can be seen in Table 8.

Comparison between FishXing and ODF Study			
Culvert Category	Culverts in Agreement	Culverts in Category	% Agreement By Category
Flat culvert Backwatered	17	22	77
Sunk inlet - flat	12	14	86
Embedded : inlet=outlet	3	7	43
Embedded : inlet>outlet	4	13	31
Baffle/weir	3	4	75
Other	9	12	75
Total Across Catagories	48	72	67

Table 8: Number of culverts in agreement between FishXing and ODF for each category for juvenile Cutthroat trout.

Velocity Comparisons

Uniform Flow and Manning's Equation

Uniform flow velocity comparisons were made using output generated with FishXing and compared with velocity calculations done using the equations given in the Help-section of FishXing. These two methods of calculating velocity produced close correlation (Tables 9-11). The equations used are (1) the composite Manning's n value used in FishXing, (2) geometric conversions for circular channels, and (3) Manning's equation.

FishXing uses a composite Manning's n formula calculated in the following manner.

1) $$n = (n_1 p_1 + n_2 p_2) / (p_1 + p_2)$$

Where:

n_1 is the Manning's n value for surface of fill material within the pipe,

n_2 is the Manning's n value for the sides of the pipe,

p_1 is the wetted perimeter of the sediment layer within the countersunk pipe,

p_2 is the wetted perimeter of the exposed pipe section,

Other forms for calculation a composite Manning's n can be found in hydraulics texts.

The following are equations used in FishXing for calculating wetted perimeter, top width, and cross-sectional area of the flow through a circular culvert. Figure 17 shows symbols used in the following equations.

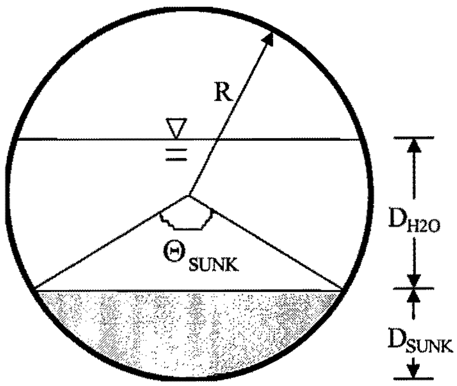


Figure 17: Circular culvert cross-section. From FishXing Help.

2) $\Theta_{sunk} = 2\cos^{-1}[(R - D_{sunk})/R]$

$A_{sunk} = (R^2/2)[\Theta_{sunk} - \sin(\Theta_{sunk})]$

$P_{sunk} = R\,\Theta_{sunk}$

$P_{bottom} = 2R\sin(\Theta_{sunk}/2)$

$\Theta_{H2O} = 2\cos^{-1}\{[R - (D_{sunk} + D_{H2O})]/R\}$

$P_{sides} = R\,\Theta_{H2O} - P_{sunk}$

$W_{TOP} = 2R\sin(\Theta_{H2O}/2)$

$A_{H20} = \{[R^2(\Theta_{H2O} - \sin(\Theta_{H2O}))]/2\} - A_{sunk}$

Where:

D_{Sunk} = Sunken Depth,
A_{Sunk} = Sunken area,
P_{Sunk} = Outside perimeter of sunken area,
P_{Bottom} = Perimeter of water on the bottom (0 for At Grade culvert),
P_{Sides} = Perimeter of pipe from sunken depth to the water level,
W_{Top} = Top width of the water surface,

At this point, Manning's equation can be used to calculate the average velocity through a culvert.

Manning's equation:

3) $V = 1.49 / n * R^{2/3} * S^{1/2}$ (English units)

Where:

V = velocity of fluid,
n = Manning's roughness coefficient,
R = Hydraulic Radius (cross-sectional area / wetted perimeter),
S = Slope of channel or culvert,

To determine the discharge using Manning's equation simply include the cross-sectional area in the above equation as follows:

3) $Q = 1.49 / n * A * R^{2/3} * S^{1/2}$

Where:

Q = Discharge (cfs),
A = Cross-sectional area,

Sample calculations have been performed at water depths of 0.50, 1.00, 1.50, 2.00 and 2.20 feet. Tables 9, 10, and 11 show velocity values generated with FishXing and using Manning's equation and the formulas given in FishXing. The columns labeled FishXing are the values displayed in the uniform flow output table within FishXing. The column labeled "calculated" are values computed using Manning's equation and other formulas given in the FishXing help menu.

FishXing			Calculated	
Discharge	Velocity	Depth	Velocity	Discharge
3.67	1.58	0.50	1.58	3.67
11.44	2.39	1.00	2.39	11.44
21.65	2.98	1.50	2.98	21.65
32.98	3.40	2.00	3.40	32.98
37.53	3.53	2.20	3.53	37.52

Table 9: Velocity and discharge comparisons for culvert # 67. Culvert # 67 is a 60 inch CMP at a 0.50% gradient, embedded 16 inches.

FishXing			Calculated	
Discharge	Velocity	Depth	Velocity	Discharge
3.89	5.02	0.50	5.02	3.89
15.44	7.49	1.00	7.49	15.44
32.2	9.11	1.50	9.11	32.20
50.48	10.08	2.00	10.08	50.48
57.18	10.29	2.20	10.29	57.18

Table 10: Velocity and discharge comparison for culvert # 27. Culvert # 27 is a 36 inch CMP at a 4.00% gradient with no counter sinking measures.

FishXing			Calculated	
Discharge	Velocity	Depth	Velocity	Discharge
6.79	2.74	0.50	2.75	6.80
23.09	4.14	1.00	4.15	23.14
47.70	5.22	1.50	5.23	47.80
79.76	6.12	2.00	6.13	79.94
94.47	6.44	2.20	6.46	94.68

Table 11: Velocity and discharge comparisons for culvert # 49. Culvert # 49 is a 108 inch CMP at a 0.93% gradient, embedded 6 inches.

FishXing Water Surface Profile and Haestad Culvert Master

Another comparison that was made during this evaluation of FishXing was to compare calculations performed with FishXing to those made with Haestad's Culvert Master. Culvert Master is a widely accepted model used in design work with culverts. Calculations were completed using Haestad's Culvert Master on a subset of culverts. Values obtained with Culvert Master were compared to the output generated in the Water Surface Profile section of FishXing. The comparison was done using 14 culverts that were not embedded in the stream substrate nor became overtopped by the 50-year recurrence flow. Of the 14 culverts in this sample, 11 were circular and 3 were pipe arch. The output generated using each program was statistically evaluated for the downstream velocity (p-value 0.399), critical depth (p-value 0.476), normal depth (p-value 0.491), and the headwater depth (p-value 0.488). This evaluation shows there are no statistically significant difference between FishXing and Haestad's Culvert Master.

The values given by the two methods are in Tables 12 and 13. A constant value of 0.027 for Manning's n was used for all culverts. All culverts had a projecting inlet with an entrance loss coefficient (k_e) value of 0.9. The entrance loss coefficient is to account for the local loss of energy at the culvert inlet due to constriction of flow.

In the case of the pipe arch culverts, the size of culvert used varied slightly between FishXing and Haestad's Culvert Master due to the sizes available in each program. All efforts were made to use the same culvert size. The minor differences in culvert sizes used between programs for pipe arch culverts did not affect this comparison.

			FishXing Generated Output				
Culvert Number	Size (in)	Slope(%)	Velocity (fps)	Critical depth (ft)	Normal depth (ft)	HW depth (Outlet control) (ft)	HW depth (Outlet control) (in)
5	72	5.158	9.33	1.47	1.05	2.45	29.40
16	60	1.45	8.21	2.53	2.49	4.43	53.16
20	88 X 66	5.063	12.98	2.65	1.79	4.84	58.08
26	48	2.4	9.39	2.73	2.59	5.05	60.60
27	36	4	8.95	1.77	1.44	3.18	38.16
31	48	5.867	11.46	2.05	1.45	3.60	43.20
33	84	0.575	8.50	3.97	5.64	6.77	81.24
43	72	6.959	15.80	3.47	2.26	6.20	74.40
47	120	3.769	13.57	3.71	2.71	6.31	75.72
50	72	1.512	7.30	2.06	2.00	3.50	42.00
52	43	6.777	9.99	1.47	1.01	2.53	30.36
62	49 X 35	0.6	4.77	1.32	1.66	2.19	26.28
63	71 X 48	0.545	6.64	2.18	3.07	3.77	45.24
68	48	3.3	6.16	0.97	0.80	1.62	19.44

Table 12: FishXing output of values.

			Culvert Master Generated Output				
Culvert Number	Size (in)	Slope (%)	Velocity (fps)	Critical depth (ft)	Normal depth (ft)	HW depth (Outlet control) (ft)	HW depth (Outlet control) (in)
5	72	5.158	9.31	1.47	1.05	2.46	29.52
16	60	1.45	8.01	2.53	2.59	4.38	52.56
20	88 X 66	5.063	13.22	2.64	1.78	4.82	57.84
26	48	2.4	9.37	2.73	2.60	5.05	60.60
27	36	4	8.91	1.77	1.44	3.18	38.16
31	48	5.867	11.51	2.08	1.47	3.64	43.68
33	84	0.575	10.22	3.97	5.65	6.77	81.24
43	72	6.959	15.96	3.48	2.27	6.20	74.40
47	120	3.769	13.63	3.71	2.71	6.31	75.72
50	72	1.512	7.28	2.06	2.00	3.50	42.00
52	43	6.777	9.97	1.47	1.01	2.53	30.36
62	49 X 35	0.6	6.08	1.27	1.87	2.28	27.36
63	71 X 48	0.545	7.49	1.90	2.87	3.43	41.16
68	48	3.3	6.15	0.97	0.80	1.62	19.44

Table 13: Haestad's Culvert Master output values.

Positive Attributes of FishXing

After using FishXing for four simulations runs of fish on 72 culverts, positive and negative aspects of working with FishXing were observed. Table 14 has a list of the positive aspects found while working with FishXing.

Positve Attributes of Using FishXing	
1	Easy to use
2	Rapid output
3	Multiple design comparison
4	Excellent visual display of output
5	Allows for prioritization of culvert replacement
6	Uses established swimming abilities
7	Includes swimming abilities of 40 species
8	Field data sheet is included
9	Support Webpage
10	Provides good links to the WWW

Table 14: Positive attributes of using FishXing.

The following is a further description of the positive aspects found while using FishXing. The first item is that FishXing is easy to use. By using the example projects, information on the web site http://www.stream.fs.fed.us/fishxing/index.html and help menu, one can become very comfortable using the FishXing software to assess fish passage through culverts. The commands are laid out in an intuitive manner. The first input window has fields to enter background information on stream-crossings such as crossing location as road mileage and/or GPS coordinates, available upstream habitat in length, and if there are any downstream obstacles to fish passage. The next window requires entry of fish and culvert parameters. First the desired species, age class, and length of fish are selected, then the size of a culvert, whether a culvert is embedded or bare, the length of the culvert, inlet and outlet elevations or direct slope input, desired flow size, minimum, mid range, and maximum flow, and a method for determining the tailwater elevation. Constant Tailwater, User Defined Rating Curve, or Channel Cross Section methods are available. If one of these fields is not properly filled in, FishXing will not run calculations for the culvert and will direct the user to the field in question.

The second positive attribute found with FishXing is the rapid calculations and notification if an input field was skipped. Display graphs show the user what the strengths and weaknesses of a design are and use using numeric tables. Several culverts can be entered and run through FishXing in a short period of time allowing the user to assess fish passage potential for numerous culvert stream-crossings quickly. Those culverts that do not provide fish passage according to FishXing can be further evaluated and ranked by importance of replacement.

The third positive of using FishXing is that several crossing designs can be compared in a relatively short time. Having the ability to quickly design a culvert, a person faced with a stream-crossing replacement or new installation can try different designs to see what will meet fish passage requirements, flow requirements, and economic constraints. This is accomplished quickly and with relative ease. Countersunk designs and different shapes and sizes of culverts can be compared. The most effective design can be chosen for the given crossing.

The fourth positive found was the use of visual displays. The displays show the discharge when the culvert will be deep enough for a fish to swim through and at what flow the velocity or leap become too high for the desired species to pass.

The fifth positive attribute of FishXing is being able to enter an inventory of existing culverts into FishXing for quick evaluation of their performance for fish passage. By knowing which culverts are expected to provide fish passage and which are not, a replacement strategy for culverts can be developed. By entering in the required information about a culvert, a prioritization can be made for culverts that block the greatest amount of upstream habitat. These culverts can be a first priority to have work done to restore fish passage. This could be done by designing a backwater effect with FishXing or experimenting with a new culvert design that will meet hydrologic and fish requirements.

Downstream culverts on the same stream can be checked to make sure fish can reach a culvert that is planned for replacement. If a downstream culvert is on a different ownership of land and blocks fish passage, the upstream owner may be better off improving fish passage at another location where downstream fish passage is unobstructed.

The sixth positive attribute found while using FishXing is the use of established swim speeds to determine whether or not a culvert hinders fish passage. FishXing uses individual swimming abilities for juvenile and adult fish of 40 species of fish. Not all species have both juvenile and adult default settings for swimming abilities due to the lack of a reliable source to use at the time of FishXing's design. However for any species of fish, the user may input swim speed values based on the knowledge of local fish capabilities or maximum velocities set by governing agencies.

The seventh positive with FishXing is that the equations used to determine fish swimming abilities are included in the help section of FishXing. Some species simply have set, known velocities, while other species' swimming abilities are based on the size of the fish using the following equation.

$V=aL^{b}t^{-c}$ (Hunter and Mayor. 1986)

Where:

V= velocity,

L= length of fish,

t= time to exhaustion,

a,b,c= regression constants,

Values used in the above equation by FishXing are listed in Tables 15 (juvenile) and 16 (adult).

Juvenile Swim Speed Coefficients								
	Prolong							
Burst Coefficients	Coefficients	Minlength	Maxlength					
Species	a	b	c	a	b	c	(mm)	(mm)
Arctic Char	4.3	0	0.49	2.69	0.606	0.08	70	420
Arctic Grayling	-	-	-	1.67	0.193	0.1	60	400
Atlantic Salmon	-	-	-	36.31	1.72	0	30	52
Broad Whitefish	-	-	-	1.46	0.45	0.1	50	400
Brook Trout	-	-	-	1.99	0.43	0.1	40	270
Burbot	-	-	-	2.23	0.07	0.26	100	700
Chum	-	-	-	93.59	1.89	0	38	48
Coho	-	-	-	3.02	0.52	0.1	40	178
Flathead Chub	-	-	-	2.66	0.67	0.1	150	350
Goldfish	5.37	0.66	0.22	-	-	-	67	213
Humpback Whitefish	-	-	-	1.73	0.35	0.1	60	600
Inconnu	-	-	-	1.29	0.175	0.1	70	800
Longnose Sucker	-	-	-	2.39	0.529	0.1	30	700
Northern Pike	-	-	-	1.17	0.55	0.1	100	800
Rainbow Trout	15.98	0.81	0.5	3.28	0.37	0.1	30	200
Sea Lamprey	-	-	-	2.57	0.36	0.26	145	508
Sockeye	-	-	-	4.42	0.5	0.1	77	200
Steelhead	15.98	0.81	0.5	3.28	0.37	0.1	30	200
Striped Bass	-	-	-	22.11	0.58	0.3	29	115
Walleye	-	-	-	2.6	0.51	0.1	70	400
White Sucker	-	-	-	2.48	0.552	0.1	105	400

Table 15: Juvenile fish swimming ability (Hunter and Mayor. 1986).

Adult Swim Speed Coefficients								
Burst Coefficients	Prolong Coeff	Minlength	Maxlength					
Species	a	b	c	a	b	c	(mm)	(mm)
Arctic Char	4.3	0	0.49	2.69	0.606	0.08	70	420
Arctic Grayling	-	-	-	1.67	0.193	0.1	60	400
Atlantic Salmon	11.34	0.88	0.5	0.173	0.68	0.5	52	500
Broad Whitefish	-	-	-	1.46	0.45	0.1	50	400
Brook Trout	-	-	-	1.99	0.43	0.1	40	270
Burbot	-	-	-	2.23	0.07	0.26	100	700
Chinook	11.49	0.32	0.5	-	-	-	508	965
Coho	13.3	0.52	0.65	-	-	-	256	610
Dace	12.37	0.65	0.5	-	-	-	30	250
Flathead Chub	-	-	-	2.66	0.67	0.1	150	350
Goldfish	5.37	0.66	0.22	-	-	-	67	213
Humpback Whitefish	-	-	-	1.73	0.35	0.1	60	600
Inconnu	-	-	-	1.29	0.175	0.1	70	800
Longnose Sucker	-	-	-	2.39	0.529	0.1	30	700
Northern Pike	-	-	-	1.17	0.55	0.1	100	800
Pink Salmon	-	-	-	4.08	0.55	0.08	494	607
Rainbow Trout	12.8	1.07	0.48	-	-	-	103	813
Sea Lamprey	-	-	-	2.57	0.36	0.26	145	508
Sockeye	-	-	-	5.47	0.89	0.07	126	611
Steelhead	12.81	1.07	0.48	-	-	-	103	813
Walleye				2.6	0.51	0.1	70	400
White Sucker				2.48	0.552	0.1	105	400

Table 16: Adult fish swimming ability (Hunter and Mayor. 1986).

The eighth positive attribute with FishXing is the setup of the culvert inventory data sheet, Figures 3 and 4. The sheet has spaces to enter values for all the information required to operate FishXing. The data sheet provides places for notes about a culvert and a place to make a sketch of a culvert. This sheet helps a survey or inventory crew record all necessary information to successfully use FishXing to assess fish passage at a given culvert. Currently a user must access the FishXing web page to download the data sheet.

The ninth positive attribute found while using FishXing is that there are links provided on the FishXing web page to other fish passage websites. From the web page http://www.stream.fs.fed.us/fishxing/index.html there are many links to web pages pertaining to fish passage issues. Some of the links are to government stream-crossing guidelines, while others show examples of work that has been done: "The Good, The Bad, and The Ugly." From these links there are other fish passage links available.

NEGATIVE ATTRIBUTES OF FISHXING

Negative aspects of using FishXing were also observed and are listed in Table 17.

Negative Attributes of Using FishXing	
1	Inconsistant use of units
2	No baffles option
3	Requires equal embedded depth for inlet and outlet
4	Doesn't compare channel width to culvert size
5	Swimming speeds rather than comparison to change in stream velocity
6	Must use predetermined culvert sizes
7	Can only run one age class of fish at a time
8	Difficult to move files
9	Culvert inventory sheet is located on website
10	No account for upstream or downstream slope
11	Flat culvert installation do not pass more than a few cfs
12	Inadequate depth while meeting or exceeding values set

Table 17. Negative aspects found while using FishXing.

The first negative attribute found while using FishXing is an inconsistent use of units. The user is asked to input the fish length in mm, required water depth in $1/10^{th}$ of feet, culvert diameter or span in inches, sunken depth in feet, and culvert length in feet. It would be useful for the user to have the option to determine whether SI or English units are preferred for input of culvert parameters. There have been numerous errors while entering a of sunken depth of 3 or 4 inches that result in 3 or 4 feet because of the difference in dimension size used. This is caught either by FishXing because the fill is greater than the pipe size, or by the user reviewing the output and noticing that the culvert is sunken too deep, if it is caught.

The second negative attribute is that FishXing does not evaluate culverts with baffles. There are efficiency adjustments available within the program, but there is no option for baffles which are beginning to be used more as a means of providing fish passage on steeper stream-crossings. It is acknowledged that baffles create complex flow patterns within culverts, and only a few baffle types have been studied, thus currently making it difficult to include baffle simulation in computer models (Love. 2002).

The third negative found with the use of FishXing is the inability to have the inlet and outlet of a culvert sunk to different depths. New designs are calling for many different approaches to culvert installation. Some of these new designs call for one end of a culvert to be sunk deeper than the other end. To analyze these culverts with FishXing, one of the sunken elevations must be chosen by the user. This either causes too much or too little of the crossing to use greater roughness associated with countersinking especially for round culverts. This affects the values for water depth and velocity associated with culverts with uneven inlet and outlet countersinking.

The fourth negative attribute of FishXing is that there is no account of upstream channel cross-section. If a wide stream section is limited to the width of a much narrower culvert, an increase in water velocity can occur at the inlet of the culvert. A fish could have successfully swum through a culvert to be blocked by high velocity while only a few feet from the upstream end of a culvert (Robison. 1997).

The fifth negative, while also mentioned as a positive, attribute of FishXing is that passage is determined by comparing fish swimming ability to water velocity within a culvert limiting fish passage evaluation to experimental data on fish swimming capabilities. Another approach to evaluating culverts that are installed is to take water velocity samples upstream, through, and downstream of a culvert to determine if the culvert is causing a change in the water velocity. Using this alternate method, one can determine if the stream reach and culvert have similar characteristics. If the characteristics of the stream and culvert are similar, and fish inhabit the stream, then it is believed that fish should be able to pass through a culvert with similar depth and velocity as the stream.

The sixth negative of FishXing is a limited number and size of culverts to choose from. Pipe arches are beginning to be made in different designs and shapes than those available to choose from in the pipe arch selection window. There are some culverts that are smaller than the available choices, so FishXing doesn't have the ability to accurately evaluate these culverts. Now that more attention is focused on fish passage issues, these smaller pipe arch culverts may begin to be used more in small headwater streams to allow for fish passage throughout the entire stream reach. The new focus on providing fish passage is opening new and creative ways to conduct transportation needs, as well as provide connectivity within the stream reach. Allowing the user to select a wider range of pipes used for a crossing would more accurately model a larger spectrum of fish passage installations. The smallest size pipe arch one can evaluate with FishXing measures 60 in. X 46 in. The smallest pipe arch installation in the ODF data set was 46 in. X 36 in.

The seventh negative attribute of FishXing is the inability to simultaneously evaluate a culvert for each species and age class of fish. Each species and age class must be evaluated separately in version 2.2 of FishXing. In the current version of FishXing evaluation of different age classes or species of fish requires a copy of the culvert parameters to be made. Then the user must change the fish parameters (species or age class) on the input sheet and run FishXing again.

The eight negative found while using FishXing is the inability to change the location where a file for a specific culvert was saved. If culvert parameters were entered into the wrong project folder, they had to be deleted and reentered into the proper project folder.

The ninth negative attribute of FishXing is that the culvert inventory data sheet associated with FishXing is only available on the associated web site. This is an inconvenience, especially if the user has limited access to the Internet. The culvert inventory data sheet should be stored somewhere in the program so that users can simply print it out from the program.

The tenth negative aspect found with FishXing is that there is no account for stream profile. The inability to see if the culvert installation is at a gradient similar to the stream it is designed for may result in inappropriate culvert installation on steep streams. Including stream profile may provide a means for another tailwater calculation. A long profile may be able to help model a water surface slope at various discharges and improve the function of the model. Including a long profile would hopefully reduce the number of culverts installed at flat gradients on streams with gradients up to 8% as has been reported, and encouraged by some Forest Practices Foresters (Commentary from and ODF culvert workshop. Summer 2000).

Including a stream profile option can help a designer validate a culvert is set at the proper gradient to endure high flows and changes in the channel. If a culvert is being replaced, a long profile can be used to determine if the existing culvert has been a sediment trap. If this is the case, when a new, larger culvert is installed a large amount of sediment may be released, resulting in the new culvert functioning differently than it was designed to. An example of a culvert appearing to be properly installed and degrading over time can be seen in Figure 6.

The eleventh negative attribute of FishXing is with flat culvert installations only a few cfs will pass using any tailwater method. The inclusion of a stream profile may be able to use stream energy to account for changes in flow characteristics with increased discharge.

The twelfth negative attribute of FishXing is the message of inadequate pool depth that appears in the Uniform Flow table and Project Summary table when using the Constant Tailwater Method. These culverts require no leap by fish to enter the culvert and meet the minimum requirements set by the user for pool depth. This occurs using the Constant Tailwater Method to evaluate culverts on some of the culverts set at less than approximately 0.20% slope. Based on the inadequate pool depth message, culverts falling into this category completely block fish passage at all flows when using the Constant Tailwater Method. In this situation, the user would have to use his or her own judgment as to take the FishXing assessment of the stream crossing, or to choose another means to assess fish passage at culverts which fall under this category.

SUGGESTIONS FOR FUTURE VERSIONS OF FISHXING

Table 18 is a list of suggestions of items to include or change in future versions of FishXing.

Suggestions for Future Versions of FishXing	
1	Include a flow predicition method
2	Develop a display range of fish passage flows on the summary table
3	Create an all inclusive display of culvert performance
4	Consistent units
5	Culvert Installation design
6	Nomagraph or other means to create a rating curve

Table 18: Suggestions for future versions of FishXing.

One of several suggestions for inclusion in a future version of FishXing would be a flow prediction method. A general rough database of high and low flow contribution by area, cubic feet per second per square mile (csm), values for places where FishXing is expected to be used could help designers check the values they have calculated for the 50 year return flow or low flow passage values. This could also be used to help determine the high flow passage values so a designer can confirm calculations, or use these values in preliminary rough assessment of culvert performance, or installation/replacement.

The second suggestion for improvement in future versions of FishXing would be to display the range of flows for a culvert that allow for fish passage on the project summary sheet. Rather than having to check the uniform flow table, or go through a trial and error approach with the water surface profile analysis, the user could quickly check under what conditions a culvert can or does provide fish passage according to the FishXing analysis by glancing at the project summary table. For an inventory of culverts, this would give a user a quick reference to the status of culverts. This is currently only listed for high flows.

The third suggestion for a future version of FishXing would be to have a graph that displays the flow levels that are passable, meaning that there is not a depth constraint, leap constraint or velocity constraint for fish passage. This would be a graphical display of the information contained in the summary table as mentioned in the second suggestion for improvements with FishXing. It seems most of the problem culverts have low enough velocity at inadequate depths, but too high a velocity at depths required for the fish to pass through a culvert. This would give a visual display of the range of fish passage FishXing calculates for a given culvert in one display.

The fourth suggestion for a future version of FishXing is to maintain consistency of units on the input page, or let the user select which units they would like to use in each field. With the current layout of the input page, errors can occur with data input if the user is not using a data sheet with the same units used in FishXing.

The fifth suggestion is to allow the user to enter the type of culvert design to be evaluated with FishXing. If the design is a baffle or streambed simulation type culvert, a window can come up asking the user for more information about the culverts performance. Possible questions could be:

1) Does the culvert retain sediment?
2) Does the sediment pattern simulate local stream conditions?
3) Are there resting pools through the culvert?
4) Is there adequate depth linked through the length of the culvert?
5) Notes about a culvert installation that the user can describe fish passage criteria as to whether or not the culvert appears to provide favorable conditions for fish passage.

Using these questions, and the velocity calculations performed in FishXing, a user may be able to get a more accurate prediction as to how the culvert will perform for fish passage.

The final suggestion is to include a method for creating a rating curve for discharge through countersunk culverts. This would allow users to avoid using the Constant Tailwater method, thus avoiding the problems associated with that method.

CONCLUSIONS

Results obtained from FishXing and the ODF fish passage study have a 67% agreement for all culvert-crossing options, as well as the juvenile Cutthroat trout set to the state of Oregon's target velocity. When culvert crossings set to nearly flat slopes are compared (ODF options 1 and 9) the agreement between FishXing and the ODF fish passage study is 78%. These culvert options are flat/backwatered and "other" installations. The other installations category did not provide enough information for ODF to determine the crossing option used. However, the majority of the other crossings were flat or backwatered designs. Of the culvert crossings using ODF option 1 and 9, the majority that did not meet both FishXing and ODF criteria did not maintain backwater through the culvert to the specified depth of 0.8 feet, or had inadequate pool depth for adult fish when the depth met or exceeded the minimum set by the user.

Culverts with a gradient of 0.30% or greater did not provide passage for juvenile Coho salmon, the weakest swimming fish used for this research because the average water velocities at all flows in these culverts was greater than that which the juvenile Coho are capable of swimming against. Juvenile Cutthroat trout swimming ability set at the state of Oregon maximum average velocity of 2 feet per second were capable of passing some culverts with slope of up to 2.18% according to FishXing analysis. The majority of the differences in the analytical results were that culverts did not meet depth requirements for backwatered designs when visited in the field for evaluation by the ODF staff or that within FishXing, the pool depth was inadequate to pass fish while meeting the minimal requirements set by the user.

Results for the streambed simulation and baffle crossing strategies would better correlate if the Constant Tailwater Method had not been the only analytical option available. Further studies with FishXing should include either the User Defined Rating Curve or Downstream Cross Section methods. These other two methods increase the depth of the downstream water within the culvert as discharge increases. This would provide a more accurate analysis of the hydraulics within the culvert. These methods do not produce the inadequate pool depth message in the uniform flow and summary tables, as was observed in this research using the Constant Tailwater Method.

For culvert design using FishXing, the user should make sure that output generated with FishXing meets requirements of the governing agency regarding fish passage. If maximum water velocity targets are set, the designer can select the user-defined swim speed option to ensure that velocities are kept below the target value through a culvert. For culvert design using FishXing, the designer should take into account the existing stream width and not force a wide stream into a narrow culvert. This can result in high velocities at the inlet of the culvert, making it difficult for fish to exit a culvert after having swum the length of a culvert.

Research results indicate the output of the Constant Tailwater Method in FishXing is not as accurate as the two other tailwater methods. The Constant Tailwater Method must either backwater the culvert to preclude a steep draw-down curve as the water exits the culvert, or meet the observed stream level and apply that to all conditions. The Constant Tailwater Method is best suited to culverts that have inlet control and a perched outlet, or to culverts that experience backwater from another stream or backwater structure. Culverts with outlet drops are already known to block fish passage in most cases. In FishXing a culvert with a perched outlet can be analyzed with the outlet drop removed. This can determine whether or not the culvert can provide fish passage by alleviating the outlet drop by raising the downstream elevation with weirs, boulders, logs, and other means, or if the entire crossing needs to be redesigned.

With proper field data collection, FishXing is a powerful tool for assessing current culvert installation requirements for fish passage despite the shortcomings discussed in this paper. This information, along with field observations, can be used to develop a culvert replacement and retrofitting plan throughout the Pacific Northwest.

FishXing can be a useful tool in assessing current culvert installations likelihood to provide fish passage. It can also aid in characterizing which culvert installation methods pose the greatest threat to fish passage. Once an inventory of culverts has been evaluated with FishXing, prioritization of culvert replacement can be developed. Prioritization of culvert replacement can be determined by the user based on economic constraints and stream habitat to be returned to fish use.

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