Assessing Fish Passage at Culverts – the method, its metrics and preliminary findings from over 4,000 assessments.

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ABSTRACT

There has been a long history of concern regarding road stream crossings as partial or full barriers to fish movement. The past decade has seen the need for a reliable, repeatable method to assess closed bottom structures for their ability to pass fish. BC has adopted a methodology that builds on fish passage assessments developed for the BC Watershed Restoration Program and those used in Washington and Oregon States. The current fish passage assessment methodology uses a series of stream channel and crossing structure measurements to assess the likelihood that a fish will be able to pass through the structure.

The paper addresses

1. The assessment methodology, the metrics and scoring model
2. Some of the common problems encountered during application of the assessment methodology.
3. Key findings on why culverts fail to pass fish? A preliminary look at the data from over 8,000 fish passage assessments conducted in BC.

As more data is collected we continue to develop a better picture of the size, scope and reasons for fish passage failures in B.C. The data is now spatially available and can be found on iMap BC.

Background

British Columbia is a large province rich in natural resources. In order to gain access to those resources over 550,000 kilometers of road has been developed.   Provincially there are over 440,000 road stream crossings or roughly 0.8 crossings per kilometer. Each of these crossings has the potential to impact the riparian and aquatic environment. Stream crossings can result in

1. Direct loss of instream and riparian habitat
2. Changes in aquatic and riparian connectivity such as the movement of fish, amphibians, and small mammals
3. Changes in channel processes such as movement of woody debris, bedload , and sediment
4. Direct entry of pollutants such as sediment and hydrocarbons
5. Changes to downstream habitat and channel through increased velocity or blocking of bedload and woody debris.
6. Reductions in species distribution and productive capacity.

The focus of the Fish Passage Technical Working group (FPTWG) has been on restoring aquatic connectivity, or more specifically, fish passage at road stream crossings. The desired outcome is a crossing structure which allows aquatic organisms to move upstream and downstream as they would in the natural channel. The best way to achieve this outcome is to maintain channel continuity through the crossing by ensuring the streambed is maintained or emulates the natural channel bed and that the stream channel is not constricted (BC Ministry of Forests Lands and Natural Resource Operations et. al. , 2012) by the crossing structure or erosion protection measures (e.g. Rip rap).

With the large number of crossings in the province the task of assessment presents significant challenges. In order to allocate scarce resources efficiently the FPTWG has implemented a strategic approach to assessment and remediation which sets priority watersheds based on fish values (BC Ministry of Environment, 2009).   The assessment of structures within those priority watersheds is carried out in a systematic way at road crossings within our modeled fish distribution (Mount et. al, 2011).

How are culverts assessed for fish passage?

The literature presents a number of potential methods to evaluate fish passage at culverts (Robison et al 1999, Washington Department of Fish and Wildlife 2009, US Forest Service 2005, FishXing 2012).

- Observation, Mark recapture experiments
- Velocity Measurement,
- Hydraulic Calculations,
- Hydraulic Surrogates

Each of these methods has Pros and Cons. Direct observation (mark recapture experiments) is difficult and time consuming making them impossible to apply across large numbers of structures. Sampling for fish above a suspect structure, while less time consuming than mark recapture, requires specialized

equipment, training and time and may not result in the determination of fish movement. Fish found upstream may be part of a resident population or have dispersed downstream from a lake.   Directly measuring stream velocity, which can be compared to fish swimming ability, is technically challenging and dependent on location of measurements in the stream profile (Kehler, 2009) and the stream flow stage (spring melt vs. summer low flow).   Hydraulic calculations require specific expertise and knowledge of watershed conditions. Government and industry staff needed a methodology that would be simple to implement, repeatable and supported in the literature. In order to achieve these requirements the current methodology which relies on hydraulic surrogates was developed.

Current Method

The method employed by the FPTWG measures a number of stream channel and structure indicators that allow inference of the hydraulic conditions within the culvert.

Key Indicators:

1. Embeddedness
2. Outlet Drop
3. Stream Width Ratio
4. Culvert Slope
5. Culvert Length.

These indicators are simple to measure, repeatable (they can be done at most stream stages) and can be done in fifteen to twenty minutes at any given site.

What is Embeddedness? This indicator is a measure of the stream bed material within a culvert (Figure 1). Assessors are asked to determine if a natural stream bed continuously covers the bottom of the culvert and the depth of cover.   A culvert with a natural stream bed is assumed to have similar roughness and velocity shadows to allow fish to pass through the culvert as if they were in an undisturbed segment of the stream. The depth of material is an important measure as it relates to the probability of the stream bed being scoured from the culvert exposing the bare culvert which results in velocity increases.

Figure 1: Properly embedded culvert. Streambed is continuous and 40% of culvert diameter.

What is outlet drop?   Outlet drop is the distance from the invert (bottom) of the culvert to the top of the residual pool (Figure 2). The residual pool is the pool that would remain at the point that water just stops flowing out of the pool. The measurement is made to the residual pool to ensure that the measurement is consistent regardless of the current flow in the stream. Outlet drop is an important consideration as fish have limited ability to jump.
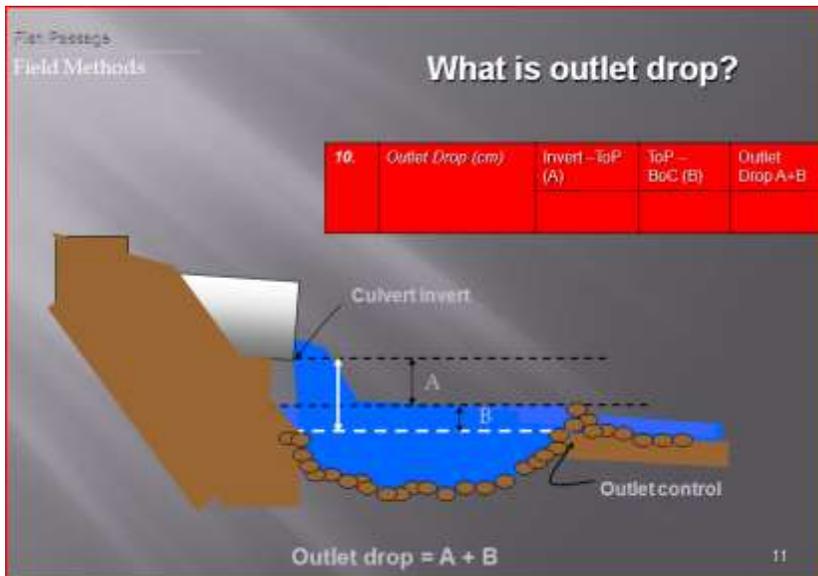

Figure 2. Outlet drop measured from the culvert invert to the top of the residual pool.

What is stream width ratio? The Stream Width Ratio is simply the ratio determined by stream channel width divided by the culvert width. This ratio is an indication of channel constriction (Figure 3) which results in increased velocities within the culvert.
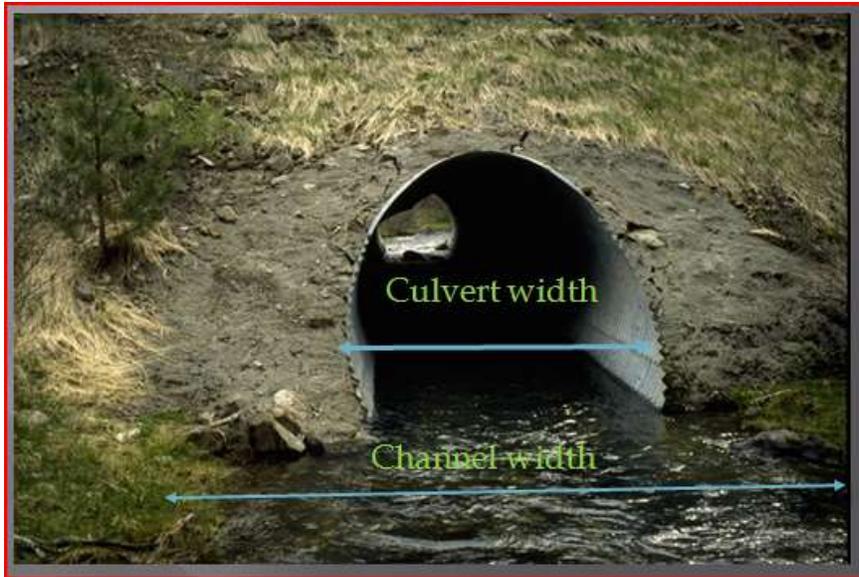
Figure 3.   Stream width ratio.

What is culvert slope? This is a measure of the angle of the culvert and is calculated by measuring the difference in elevation from the outlet to the inlet divided by the horizontal distance between the outlet and inlet of the culvert (Figure 4). Flume studies done in Washington State and Manitoba (Powers, 1997.; Kehler 2009) have shown that bare culverts at slopes greater than 1.0 % can be a barrier to juvenile salmonid movement. Because such a small difference in slope can be problematic for fish the current methodology calls for the use of an engineering level to more accurately measure the slope of the culvert where the slope as measured with a clinometers is less than 4%. A common error often made by assessors is to assign too high a level of accuracy to clinometers. Clinometers are typically accurate to plus or minus 2%.

What is culvert length? This is a simple measurement of the length of the culvert from the inlet to the outlet. Fish have limited ability to maintain their highest speed (burst velocity typically 1 to 6 seconds also known as darting speed) This metric is not independent of culvert slope and stream width ratio but recognizes that a longer high slope culvert will be more difficult for a fish to pass than a shorter culvert.
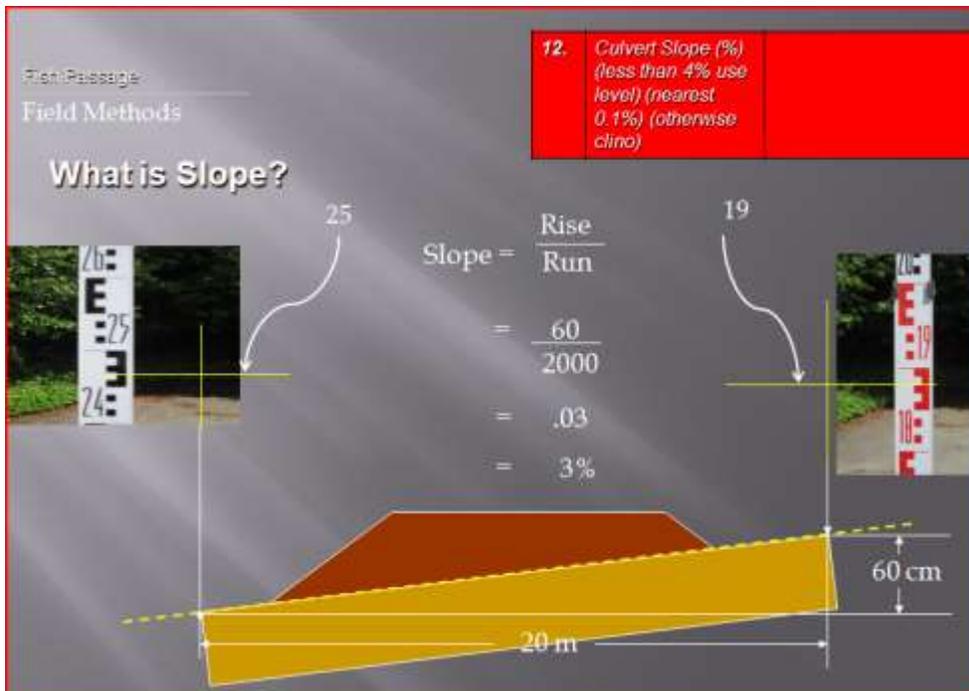
Figure 4: Culvert Slope and length.

Barrier Determination Model

The measurements made in the field are used to calculate a Barrier determination score. For example a culvert with no streambed (bare pipe), outlet drop of 20 cm, stream width ratio of 1.2, slope of 2%, and length of 14 meters would have a Barrier score of 23. This number is arrived at by summing the individual values for each of the indicators (Table 1.). Not embedded = 10, Outlet drop 20 cm = 5, Stream width ratio of 1.2 = 3, Slope of 2% = 5, Length of 14 meter = 0.

Risk	Embedded[2]	value	Outlet drop	value	Slope	value	SWR	value	Length	value
low	> 30 cm. or > 20% of Diameter and continuous	0	< 15	0	< 1	0	< 1.0	0	< 15	0
mod	< 30 cm. or 20% of Diameter but continuous	5	15 - 30	5	1 - 3	5	1.0 - 1.3	3	15 – 30	3
high	No embeddment or discontinuous	10	> 30	10	> 3	10	> 1.3	6	> 30	6

Table 1. Barrier determination value for each indicator in Fish Passage model.

Once the assessor has determined the score for an individual culvert that score is put in to one of three categories. Scores of 20 or greater are considered a barrier (Table 2). A structure with a score of 15 to 19 is classified as a potential barrier and should undergo further detailed analysis if it is to be considered for restoration.

Cumulative Score	Result
0 - 14	passable
15 - 19	potential barrier
20 or greater	barrier

Table 2. Barrier Determination Score outcome.

The values associated with each of the indicators in the barrier determination model were developed based on information available on fish swimming ability which is a function of species and size (Figure 5). A juvenile Coho does not have the same swimming ability as an adult Coho similarly an adult Grayling is a weaker swimmer than an adult Steelhead. The indicator scores reflect the best estimation for the passage of a juvenile salmon or small resident rainbow trout.
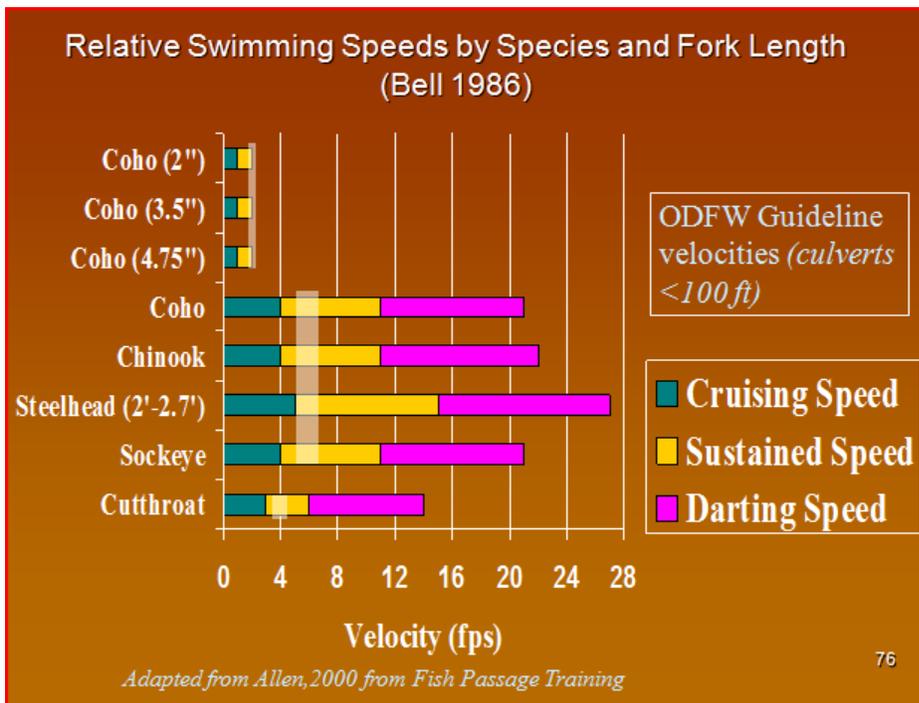

Figure 5 – Fish Swimming Ability.

Preliminary Findings

The Provincial Stream Crossing Inventory System (PSCIS 2011) as of November 1, 2012 had data for 4870 culvert assessments. The number of structures in the database is growing as legacy data is loaded and as new assessment projects are completed.   All of the data is available publically and can be accessed through IMAP BC (IMAP 2012). To access data in IMAP add layers and then click on the physical infrastructure layer to find the PSCIS data.

 For the purpose of the Columbia Mountains Institute Road workshop we summarized the current data for two spatial areas, the Province and the Kootenay Natural Resource Region (Table 3). The total failure rate for the culverts assessed is seventy one percent or 3458 structures that fail to meet our fish passage criteria. The database contains crossing assessments from all regions of the province. The data shows some variability in the failure rate from watershed to watershed, and region to region but consistently in every watershed that assessments projects have been conducted a proportion of the fish stream crossings with culverts installed fail to meet the criteria for fish passage. In the Kootenay region sixty one percent or 844 of the 1384 assessed culverts are problematic. If the average cost to restore a failed crossing structure is $50,000 then identifying the top 10% of the currently known failed structures in the Kootenay region would cost over 4 million dollars.

Why do they fail? Over 40 % of the structures both provincially and in the Kootenays have significant outlet drops (greater than 30 cm). Probably more importantly over 70% of the crossing structures constrict the channel resulting in increased velocities through the culvert which often results in downstream channel changes. The scour and restriction of bedload movement can in time result in the development of an outlet drop.

	Province	Kootenay
Number	4870	1384
% Fail	71	61
% Outlet Drop >30 cm	43	47
% Stream Width Ratio > 1	74	78
% Slope >1%	77	81

Table 3 Culvert Assessment Summary

Fish regularly move through natural channels with average slopes of up to 10% (Hoffman 2007). The Forest Practices Code of British Columbia specified that streams with no fish information would default to be a fish stream if the gradient was less than 20%. In natural channels fish are able to use natural velocity shadows associated with boulders, woody debris and other channel complexity to rest and then

dart through areas of higher velocity(higher slope). Close to 80% of the culverts assessed provincially and in the Kootenays have slopes greater than 1% and over 50% have slopes greater than 3%. Bare culverts at these slopes present significant challenges for juvenile or small resident fish to pass.

The most significant finding from assessments done to date is the high proportion of structures that constrict the channel. Channel constriction and its associated increase in velocities often lead to other issues such as outlet drop and loss of embedment material.

Common Problems or challenges in applying the assessment methodology.

The Fish Passage Assessment methodology (BC Ministry of Environment, 2011) is updated periodically to clarify issues assessors have identified.

One of the most helpful items used to review assessments is the photos; unfortunately it remains one of the items assessors often forget. Submission of field data to the PSCIS requires five photos, inlet, outlet, upstream, downstream and the barrel of the culvert.

When can I do assessments? The assessment method was designed to be done at any time, any flow however safety and visibility are a concern. High flows can make many streams too dangerous for assessment.   High flows and snow can visually obscure stream banks and bed making it difficult to complete assessments.

How do I deal with multiple pipes? For the barrier determination use the metrics from the pipe lowest in elevation at the outlet. For pipes installed at the same elevation at the outlet, add diameters for stream width ratio criteria and use the highest slope, and length measurement.

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