Overview of Alberta Transportation's approach to Fish Passage Design for Culverts

Hydrotechnical Design Overview

Hydrotechnical design of stream crossings (as further described in the Bridge Conceptual Design Guidelines) requires estimation of design flow depth (Y), mean channel velocity (V), and flow (Q). Key principles in determining these parameters are that they are representative of the physical capacity of the channel to deliver flow to the site and consistent with historic highwater observations. Basic hydrotechnical influences on design involve sizing the structure opening and rock protection with the Y, V, and Q values forming the boundary conditions for hydraulic calculations. For culverts, calculations involving gradually varied flow (such as backwater curves) and rapidly varied flow (rapid flow adjustments with abrupt energy losses over a short distance) are necessary to determine hydraulic impacts of the structure. These calculations can be done by relatively simple models using prismatic channels and one dimensional (section averaged) techniques, as is used in the Flow Profile tool. Approaches such as flood frequency analysis and rainfall runoff modeling have proven to be incapable of meeting these principles at most sites, as documented in Context of Extreme Floods in Alberta.

The 'Flow Profile' tool facilitates hydrotechnical analysis as described in its associated documentation. Advanced techniques, such as multi-section (e.g. HEC-RAS), two-dimensional, and unsteady flow calculations offer little value for design. Some reasons to avoid using more complex models include:

- *Boundary conditions are one dimensional, not two dimensional*
- *Natural rivers have mobile boundaries that change with time (scour, bedforms, lateral erosion)*
- *Many natural factors cannot be modeled accurately – drift, ice, sediment transport, vegetation*
- *Data-sets don't exist to support true calibration of complex hydraulic models (oftentimes have only one or two data sets, to which extrapolation occurs for different hydraulic scenarios)*
- *Complicated outputs can be difficult to interpret and assess*
- Numerical models have inherent inaccuracies (+/- 10%, although often are precisely reported)
- *These models are expensive, time consuming, and require significant resources*
- *Most of the output, accurate or not, is not needed to for design (bridge opening and protection design are not highly sensitive; V,Y,Q within ~20% will oftentimes result in the same recommendations)*

Fish Passage Overview

For culverts on fish bearing streams (typically as determined by a QAES Report and/or query of Alberta Environment and Park's Fisheries and Wildlife Management Information System), the potential for fish passage needs to be assessed and designed for. The flow value (Q_{FPD}) is used for this assessment. The main principle for assessment of fish passage is that the mean velocity throughout the culvert should be less than or equal to the mean velocity in the channel at Q_{FPD}. Burial depth will create a backwater curve within the culvert, starting at the outlet, which will result in lower mean velocities. This backwater impact reduces with distance from the outlet, and normal flow conditions can be reached if the culvert is sufficiently long or steep. When comparing mean velocities, the precision of the mean velocities should be extended to 0.01m/s due to the relatively low magnitude.

The reasoning behind the velocity comparison principle is that if the fish can handle certain velocities in the stream to get to the culvert, the culvert should not be a velocity barrier to them. Velocity has traditionally been the main criteria used in evaluating fish passage at culverts. It has been suggested that point velocities will be higher in culverts due to the uniform section. The Velocity Distributions Impacts on Fish Passage at Culverts document shows that there is still significant variance in point velocities within culverts, with typically significant areas of low velocities. It has also been suggested that natural channels provide more opportunities for rest than culverts. However, many of the channels crossed by culverts have relatively uniform cross sections over the length of a typical culvert. Therefore, the mean velocity comparison approach still appears to be the most practical and site specific method for evaluating fish passage. This approach does not involve the use of fish swimming performance curves. These curves are based on empirical studies and have often resulted in mean velocities that are a small fraction of the mean velocity in the channel.

Fish Passage Assessment

A fish passage design flow, Q_{FPD}, is required for assessment of fish passage at culverts on fish bearing streams. The process is as follows:

1. Calculate $Y_{FPD} = 0.8 – 34.3*Slope$; minimum $Y_{FPD} = 0.2$
2. Calculate Q_{FPD} at Y_{FPD}

This method of estimating Q_{FPD} is based on analysis of observed flow values at all Water Survey of Canada gauges with significant records on streams with streambed widths in the range of suitability for culvert crossings. The Y_{FPD} is an envelope curve of all observed values correlating to flow values that are exceeded only 5% of days in a year during the period that migration would occur. The migration period, selected by DFO staff for evaluation, was March 1 to May 15 (76 days; i.e. the typical freshet expectations). Given that not all fish move at the same time, the probability of each species encountering the delay discharge is quite low. For example, the probability of fish encountering the 3Q10 is 4/76 for the given year, multiplied by the frequency of 1/10 years. This results in a probability of 1/190 (0.5%). The Y_{FPD} method, with a probability of 5%, is a more conservative approach which should ensure that fish passage is evaluated at a relatively high flow, while providing more consistent and site specific results than statistical estimates such as the 1 in 10 year 3 day delay flow. Refer to the Discussion on the Selection of the Recommended Fish Passage Design Discharge for more details.

The application of 3Q10 discharge assumes that the same delay period should be applied at all locations for all fish species; there have been no additional studies completed to suggest that this is the case. Anecdotal reports from staff at AEP's Fisheries Management Branch have suggested that some species of fish may wait longer to move upstream. No studies have been completed in Alberta to suggest what length of delay would be appropriate. The second drawback of the use of the 3Q10 discharge is the lack of data for smaller streams. Use of statistical analysis on a site by site basis does not yield accurate results for fish passage evaluation due to the limited data available. In order to obtain enough data for a site on an ungauged stream, basin data transfer techniques would be required. However these methods are a numerical method only with no physical meaning (no consideration to topography, land use, soil types, drainage area or channel slope, etc.) and have yielded poor results in the past.

If the fish passage condition is not met (i.e. velocities within the structure exceed the natural channel) slight changes to the culvert configuration can be considered. In general, increasing pipe diameter is a very cost-ineffective method of reducing mean velocities at Q_{FPD}, as most of the extra area will be above the flow depth. Increasing the burial depth is also problematic, as it can lead to construction difficulties due to increased excavation depth and will result in a more difficult upstream transition (steeper slopes, increased foot print) from the culvert to the channel. If a structure solution cannot be found, installation of substrate and holders should be considered, as per the **Design Guidelines for Bridge Size Culverts** document. Substrate holders assist in retaining bed substrate material and increase the effective roughness of the culvert. The result is decreased velocities and increased flow depth. Consideration may also be given to installing localized rock clusters in areas of localized high velocities (such as inlet transition zones), to provide resting areas and flow variation.