



FISH BARRIER MITIGATION OF AN OVERSTEEPENED CULVERT WITHIN SAUGEEN FIRST NATION RESERVE

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ABSTRACT

A deteriorated concrete box culvert conveying a tributary of the Saugeen River under Highway 21 in Ontario had reached the end of its lifespan and was in need of replacement. The tributary supports a diverse range of coldwater fish species such as Rainbow Trout; however, fish passage, particularly upstream migration, has been cut off since the culvert and highway were constructed over seventy-five years ago. Specifically, fish passage has been hindered by shallow sheet flow along the sixty metre flat bottom, excessive velocities associated with the smooth, seven percent gradient, and a perched barrier at the downstream outlet. A key component of the culvert replacement was an effort to improve the overall condition of the tributary's natural environment, including the promotion of fish passage and migration opportunities. The culvert replacement project undertaken by the Ontario Ministry of Transportation (MTO) and MMM Group, coupled resources with the Saugeen Ojibway Nation (SON) Environment office, Parsons biologists, and Aquafor geomorphologists. The most ecologically sensitive replacement methodology of an open bottom structure was not viable for this project as it would have required a full closure of the Highway for approximately four months. A circular steel pipe culvert installed through tunneling was designed to by-pass and replace the existing concrete box culvert. In an effort to mitigate the current barriers to fish with the new pipe culvert, a prefabricated corrugated steel slip liner with engineered baffle arrangement was integrated into the design. The baffle configuration and geometry was designed by Jason Duguay (Université de Sherbrooke) and Ken Hannaford (Gov. NFLD), and the slip liner construction by the Corrugated Steel Pipe Institute. Construction of the new culvert and slip liner was completed in December, 2015, and a two year monitoring program will be undertaken to assess the effectiveness of barrier mitigation and geomorphic stability of the tributary.

Keywords: Fish Passage, Culvert, Baffle, Rainbow Trout

1. INTRODUCTION

Culverts are an essential tool to enable roadway crossings of watercourses; however, one of the primary issues with regards to fish is the impact they can have on migration and passage. Maintaining free passage of fish is a requirement of the Canadian *Fisheries Act* (Government of Canada, 1985), and the Ministry of Transportation (MTO) follows the MTO/DFO/OMNR Protocol for Protecting Fish and Fish Habitat on Provincial Transportation Undertakings (MTO et al. 2013). However, There are many instances of existing culverts where reduced fish passage and habitat connectivity exists as a result of vertical barriers found at the downstream outlet, as well as sheet flows too shallow for fish, increased flow velocities, and lack of refuge within the structures. These issues are often associated with structures constructed before the *Fisheries Act* and joint Protocol were in place, or have developed over time, and can be addressed through maintenance or replacement, with the intent of restoring the natural function and connectivity to pre-disturbed conditions.

2. CRAIG STREET CULVERT REPLACEMENT UNDER ONTARIO HIGHWAY 21

The Craig Street Culvert, located along Highway 21 within the Saugeen First Nation, was deteriorated, at the end of its lifespan, and required replacement. The culvert facilitates the watercourse crossing of a tributary which maintains permanent flow throughout the year, and confluences with the Saugeen River as presented within Figure 1. As the culvert and watercourse are part of the Saugeen River watershed located within Saugeen First Nation, fisheries is of special importance as a valuable natural resource.

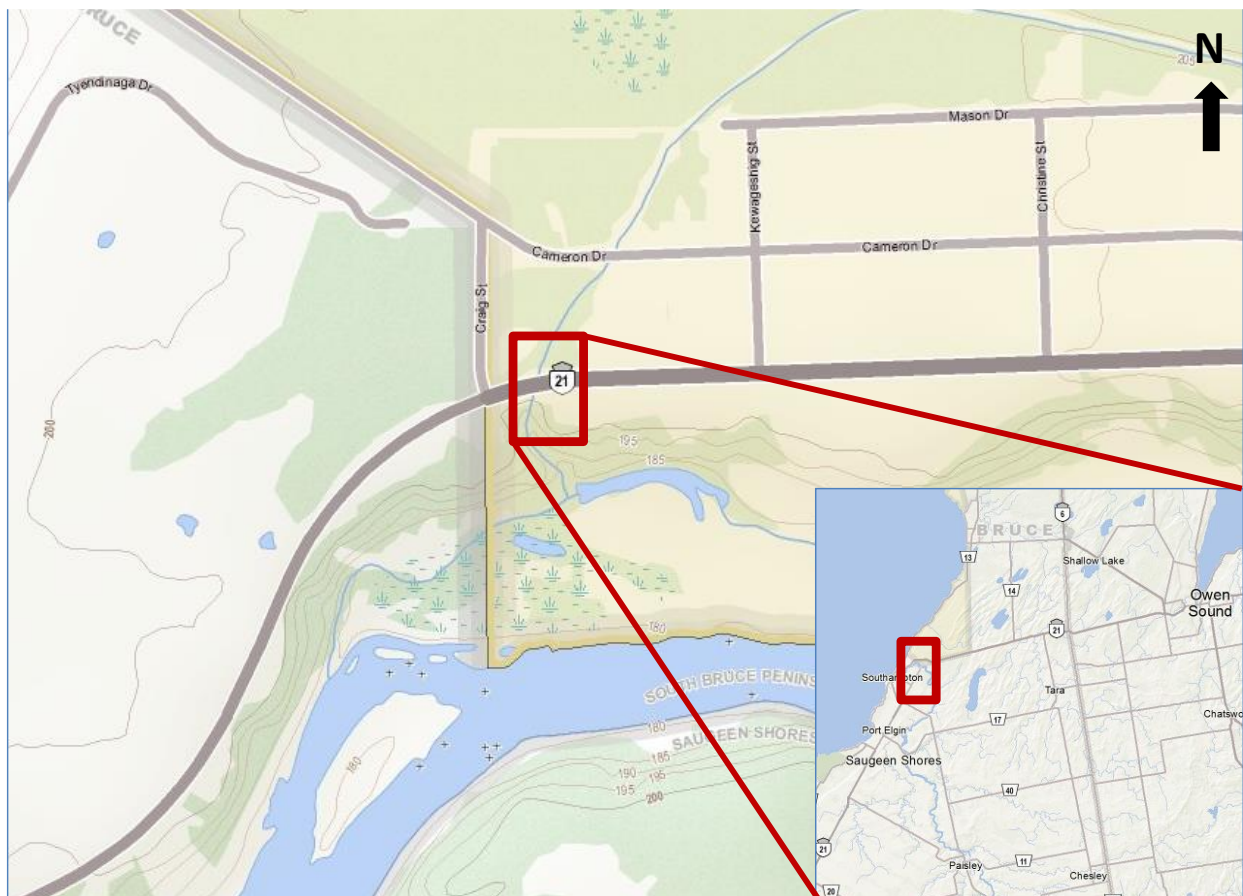


Figure 1: Study Area with respect to Saugeen Tributary and Craig Street Culvert (MTO Station 9+901), Saugeen First Nation #29 Reservation

In order to prepare for the culvert replacement, the MTO, working in consultation with the Saugeen Ojibway Nation Environment Office, retained Parsons to conduct a Fish and Fish Habitat Existing Conditions and Impact Assessment.

Concurrent with the fisheries assessment, MMM Group provided engineering services to develop a culvert design which would tunnel through the existing Highway 21 embankment, with the intent of minimizing disturbance to the adjacent First Nation lands while maintaining roadway traffic.

2.1 Fish and Fish Habitat Considerations for Craig Street Culvert Construction

The aquatic assessment followed the Protocol for Protecting Fish and Fish Habitat on Provincial Transportation Undertakings, including three (3) seasonal field investigations in the spring, summer, and fall of 2013. The intent of the assessment was to determine the existing conditions, as well as potential impacts to fisheries associated with undertaking the replacement of the culvert. During each investigation, fish habitat was assessed both upstream and downstream of the culvert, and fish were collected via electrofishing for identification purposes and released thereafter.

The watercourse downstream of the culvert was defined as highly sensitive, supporting a diverse range of cool and cold water species. Spawning habitat for Rainbow Trout was evidenced by the high number of juvenile and Young of Year Rainbow Trout, as well as a variety of more common species such as Creek Chub, Northern Redbelly Dace, Brook Stickleback, Central Mudminnow, Black Bullhead, Bluntnose minnow, and White Sucker, with the collective inventory presented in Table 1.

Table 1: Fish Collection Inventory Downstream of Craig Street Culvert (2013)

Fish Species	Spring	Summer	Fall
Rainbow Trout (<i>Oncorhynchus mykiss</i>)	1	43	57
Creek Chub (<i>Semotilus atromaculatus</i>)	18	39	58
Northern Redbelly Dace (<i>Chrosomus eos</i>)	23	20	3
Brook Stickleback (<i>Culaea inconstans</i>)	2	1	2
Black Bullhead (<i>Ameiurus melas</i>)	1	1	-
Central Mudminnow (<i>Umbra limi</i>)	2	-	-
Common Shiner (<i>Luxilus cornutus</i>)	-	-	3
Bluntnose Minnow (<i>Pimephales notatus</i>)	-	-	1
White Sucker (<i>Catostomus commersonii</i>)	-	-	7
Total	47	104	131

Upstream of the culvert, fish habitat potential was observed as the watercourse extended through a well defined riparian corridor of White Cedar and mixed hardwood vegetation, however, the fisheries investigations did not identify any fish utilizing the creek upstream of the culvert.

The dramatic contrast between fisheries conditions in the tributary downstream and upstream of Highway 21 (where the downstream habitat supports a diverse community of sensitive native species, and no fish were observed in the upstream reach); suggests that the passage and connectivity between the two stream segments was negatively impacted as a result of the existing culvert structure.

The types of barriers and obstructions the Craig Street Culvert posed were considered threefold, including shallow sheet flow along the sixty metre flat bottom, excessive velocities associated with the smooth, seven percent gradient, and a perched barrier at the downstream outlet.

A comparison of conditions has been presented within Figure 2 to illustrate the existing habitat conditions, as well as aspects of the culvert impacting to fish passage and connectivity.



Figure 2: Representative Photos of Existing Fisheries Habitat Conditions
 (Photo A – Downstream Habitat Supporting Sensitive Species,
 Photo B – Vertical Barrier at Culvert Outlet,
 Photo C – Shallow Sheet Flows with No Refuge,
 Photo D – Upstream Fish Habitat Void of Fish)

With an understanding of the existing fish habitat conditions, opportunities for enhancement when replacing the culvert were made, particularly with regards to mitigating the perched outlet, and providing refuge throughout the structure through measures to reduce flow velocities. In order to address these changes, the study team required a fluvial geomorphic investigation to define channel morphological features and restoration adjustments which will provide stability to the adjacent creek segments.

2.2 Geomorphic Considerations for Craig Street Culvert Construction

The geomorphology of a watercourse defines the interaction between the channel flow and the surrounding landscape. Stable geomorphology of the watercourse, particularly as it relates to the upstream and downstream transitions into a culvert, is required to maintain fish passage connectivity over the lifespan of the structure. In contrast, geomorphic instabilities will often cause a channel to adapt, and are typically the cause of barriers such as perched outlets and excessive erosion or degradation. In addition to inhibiting passage, geomorphic instabilities can also cause risks to the integrity of the structure by undermining foundations and inhibiting embankment failures through toe erosion.

In order to maintain or improve the geomorphic conditions of the watercourse at the transitions of the culvert replacement, Aquafor was retained to complete a detailed geomorphic assessment, and provide input into the design as it relates to channel transitions and fish passage.

The first component of the geomorphic assessment included a detailed topographic survey of the channel conditions, in order to define geomorphic metrics such as longitudinal profile, bankfull channel geometry, floodplain connectivity, and riffle – pool spacing. Other aspects of the geomorphic investigation included assessment of bed and bank composition, modes and rates of channel adjustment, stages of channel evolution, and constraints imposed by the natural landscape on the culvert design.

The topographic survey was compiled to define the existing longitudinal profile of the channel and culvert, as presented within Figure 3.

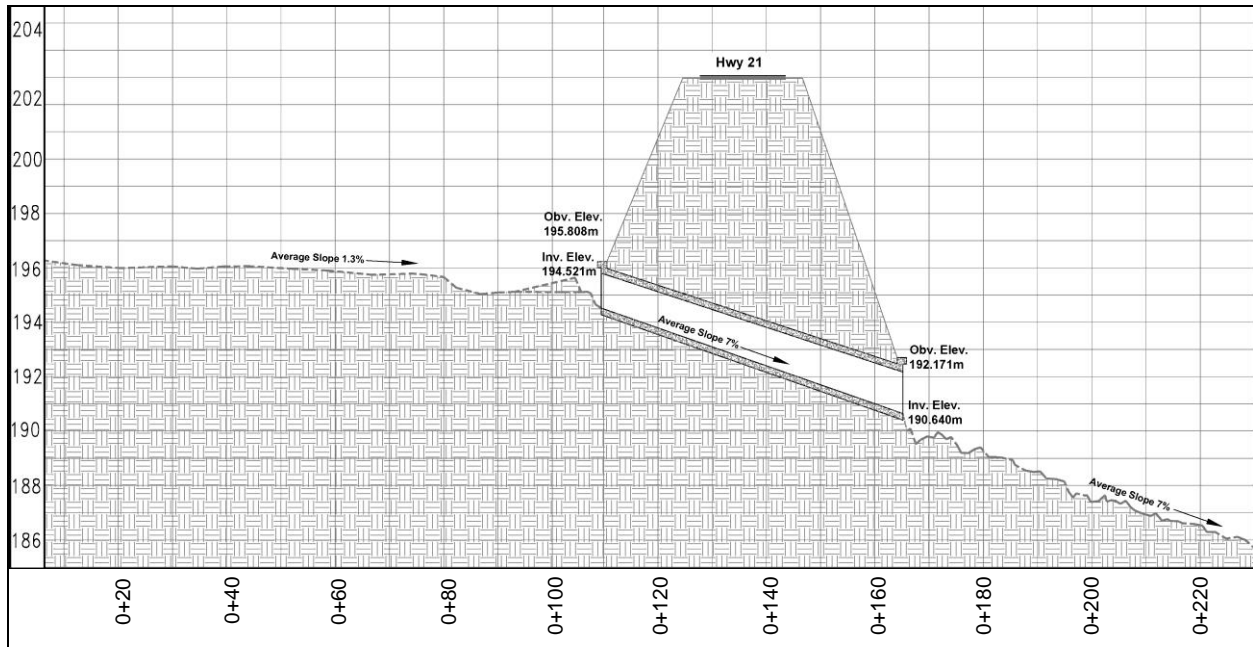


Figure 3: Longitudinal Profile of Channel and Craig St Culvert

The profile of the channel is such that the downstream channel maintains an average gradient of 7%, which is carried through the culvert, and then transitions to a significantly lesser slope of 1% within the upstream segment. The reason for the dynamic profile is the proximity of the culvert and roadway along the top slope of the confined Saugeen River valley, with the upstream segment draining the table lands, and the downstream segment traversing the valley slope.

Although the downstream channel segment maintains a steep gradient, the channel has naturally adjusted over time to a relatively stable channel form, with large cobbles and boulders (median grain size (D_{50}) ranges from 32 - 128 mm) forming short cascade features which prevent the bed from downcutting, and allow for significant pool volumes providing high quality refuge and fish habitat. As this gradient is carried through the culvert however, the culvert does not have the same morphologic features providing natural refuge areas, as the bottom of the culvert is flat and flows increase in velocity to supercritical conditions for the length of the structure.

Comparison of the existing longitudinal profile to Guidelines for the Protection of Fish and Fish Habitat (DFO, 2015), the culvert significantly exceeds the thresholds for passage, which recommend mitigation measures be included for fish passage if the culvert is greater than 25m in length and 0.5% slope, whereas the existing Craig Street Culvert is 60 m in length and 7% slope.

As the profile and gradient of the culvert replacement will be generally constrained in the same manner as the existing culvert, mitigation measures have been evaluated and included in the design to enhance fish passage in order to meet the requirements for fish passage under the Fisheries Act (1985).

2.3 Design Considerations to Enhance Fish Passage

When it comes to designing culverts to allow fish passage, options may include open-bottom culverts, embedded closed-bottom culverts, and baffled or non-baffled closed bottom configurations (MNR et. al, 2012). Open-bottom culverts are generally used in order to minimize impacts of culvert installation on a natural stream channel; however, can be at risk of downcutting when not designed to appropriately convey a stable channel system. Best management practices for implementing open bottom culverts require the culvert span be at a minimum equal to the bankfull width of the downstream channel and possibly as large as the meander belt width (ie. channel width plus width of any confining boundaries). For the case of the Craig Street culvert, the span would need to be a minimum of 4 m to meet bankfull channel widths, or more ideally 10 m which would be consistent with the base of the confined valley setting within the downstream segment.

Construction of an open bottom culvert was not considered practical, as the existing culvert supports an eight metre high embankment and Highway 21 across the top, which would require prolonged road closure to facilitate significant excavation to the base level of the channel. Also, this construction would cause enlarged areas of disturbance, and higher costs in comparison to a closed bottom culvert constructed using tunneling technologies.

With regards to an embedded closed-bottom culvert where natural materials line the bottom, this alternative was also not considered practical as the oversteepened profile and associated stream power would create issues with regards to material stability. It is expected that the steep gradient (~7%) and associated flow velocities (estimated at 4.5 m/s) through the culvert would lead to increased particle mobility size and likely create unstable bed conditions. For example, the median grain size (D_{50}) within the study area that was measured during the geomorphic assessment ranges from 32 - 128 mm, which is quite large and provides stability to the cascade system as the channel extends down the valley. However, empirical relations as shown in Table 2 indicate this size of material will become entrained during velocities ranging from 0.9 to 1.22 m/s.

In turn, a fixed, baffle configuration that can withstand significant stream power and velocities was defined as the preferred solution to enhance fish passage opportunities.

Table 2. Permissible Shear and Velocity for Selected Channel Lining Materials (Adapted from Fischenich, 2001).

Channel Lining Type	Permissible Shear Stress Range (N/m ²)		Permissible Velocity Range (m/s)	
Soils				
Fine Gravels	3.6		0.76	
Stiff Clay	12.4		0.91	1.37
Alluvial Silt	12.4		1.14	
Graded Silt to Cobble	18.2		1.14	
Shales and Hardpan	32.1		1.83	
Non-Uniform Gravel / Cobble				
50 mm	32.1		0.91	1.83
152 mm	95.8		1.22	2.29
304 mm	191.5		1.68	3.66
Long native grasses	57.5	81.4	1.22	1.83
Short native and bunch grass	33.5	45.5	0.91	1.22
Reed plantings	4.8	28.7		
Hardwood tree plantings	19.2	119.7		

3. DETAILED DESIGN OF CULVERT AND BAFFLE CONFIGURATION

Baffles within the culvert are intended to reduce velocities throughout the oversteepened culvert, creating areas for resting and adequate water depth during low flow periods. At the preliminary design stage, an initial orientation and layout following the Guidelines for Protection of Fish and Fish Habitat (DFO, 2015) was applied to the general arrangement of the new culvert as shown in Figure 4.

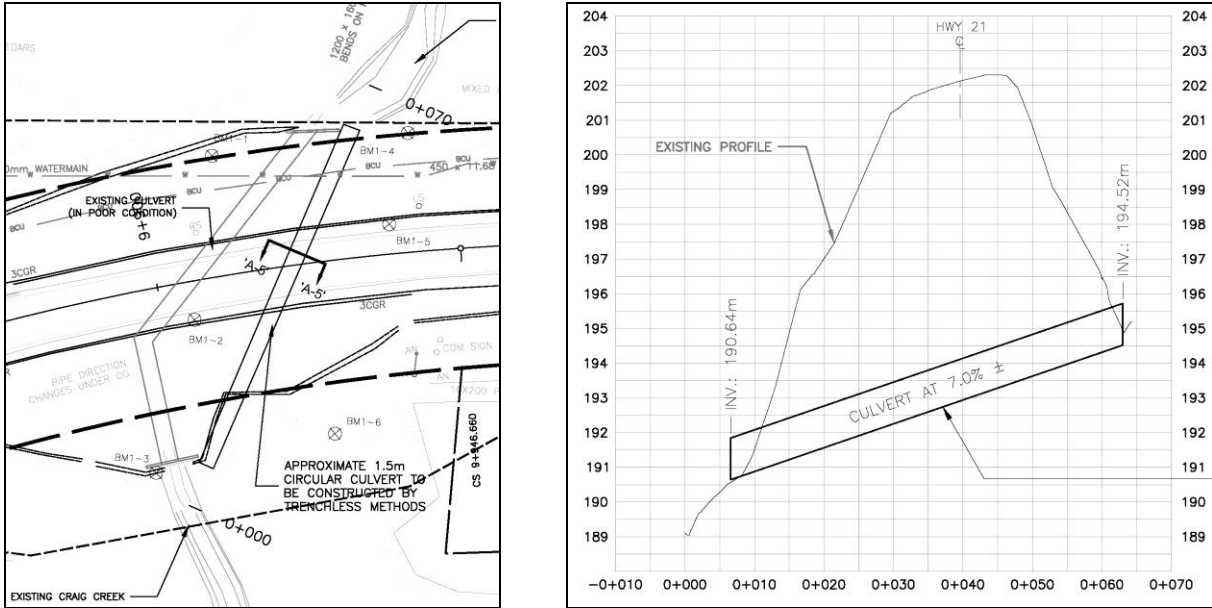


Figure 4: General Arrangement of Proposed 1.5m CSP Culvert (adapted from MMM Group Design Drawing)

In order to span the embankment and tie into the adjacent tributary segments, the culvert requires a significant length of approximately 56 m, and vertical drop of 4.5 m, extending the profile of the steeper downstream channel segment to match the break into the table lands at the upstream end. The recommended or fixed parameters for the culvert are summarized in Table 3, with refinement to the downstream invert shown in Figure 4.

Table 3: Summary of Fixed Culvert Parameters for Baffle Design

Craig St Culvert	
Culvert Length (m)	56
Culvert Diameter (m)	1.5
Downstream Invert (m)	190
Upstream Invert (m)	194.5
Total Drop (m)	4.5
Culvert Slope (%)	8

As defined by DFO (2015), baffles should be configured to control water velocities throughout the culvert, ensuring burst swimming speeds are not exceeded within the high velocity sections (ie. over the baffle), and sustained swimming speeds are provided for resting between baffles.

When designing a baffle configuration for a fixed culvert with a significant slope (ie. > 4%), the spacing of the baffles is generally the first step as this is largely the controlling factor. As defined in Table 3, the Craig Street culvert will have a slope of ~8%, and a length of ~56 m. The number of baffles can be defined applying Equation 1.

$$[1] \text{ \# of baffles} = (H / \Delta h) + 1$$

Where

H (m) is the total drop

Δh (m) is the drop between baffles

As per DFO (2015), the maximum drop between baffles should be 0.2 m, which was chosen as a starting point to minimize the total # of baffles.

When applying formula to the Craig Street culvert and total drop, the result follows:

$$\begin{aligned} \# \text{ of baffles} &= (4.5 / 0.2) + 1 \\ &= 24 \end{aligned}$$

When configuring the spacing and arrangement, the downstream most baffle was placed so that the top of the first baffle is set equal to the downstream control of the scour pool (ie. first downstream riffle / cascade). The profile for the proposed arrangement is presented within Figure 5, presenting the slotted weir baffle concept, as well as the extended restoration works within the channel transition segments upstream and downstream of the culvert.

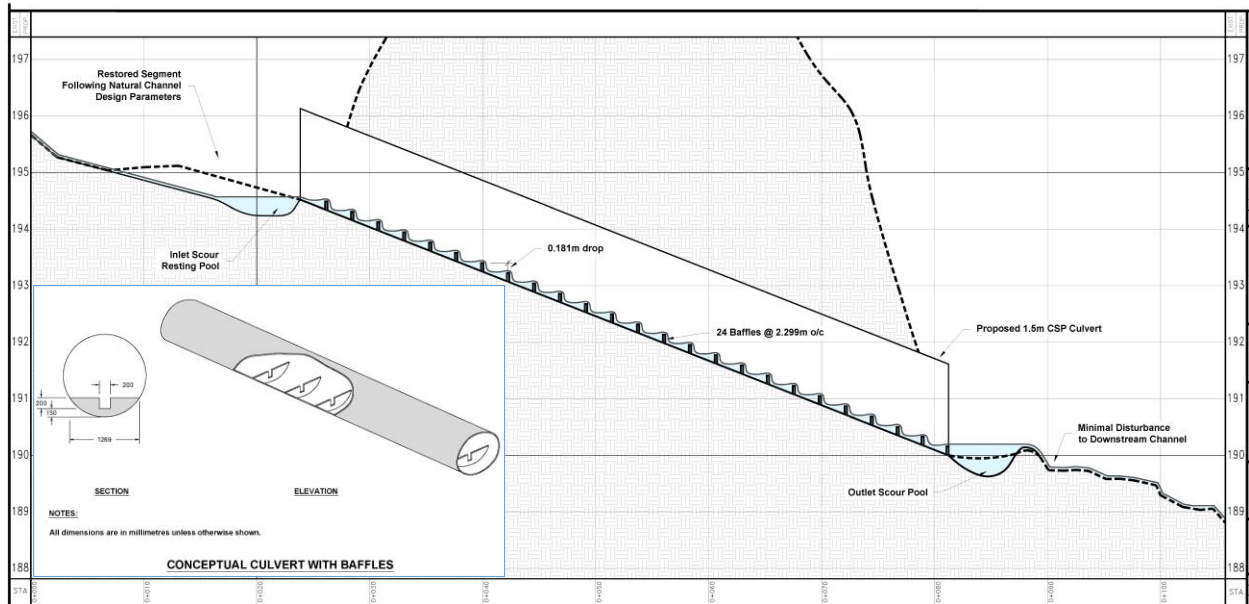


Figure 5: General Arrangement of Preliminary Baffle Configuration

With regards to the type of baffle, the slotted weir baffle as presented within Figure 5 has been noted to cause some issues with regards to turbulent conditions spanning the refuge pools, as well as debris jams blocking the slots causing low flow conditions to crest over the upper weir.

In turn, an alternate arrangement for baffles was presented to the MTO through an initiative of the Corrugated Steel Pipe Institute (CSPI), in which a curved baffle configuration referred to as the Duguay-Hannaford design, as presented within Figure 6, is appended to a corrugated steel slip liner and affixed to the steel culvert following the general layout and spacing as per Equation 1.

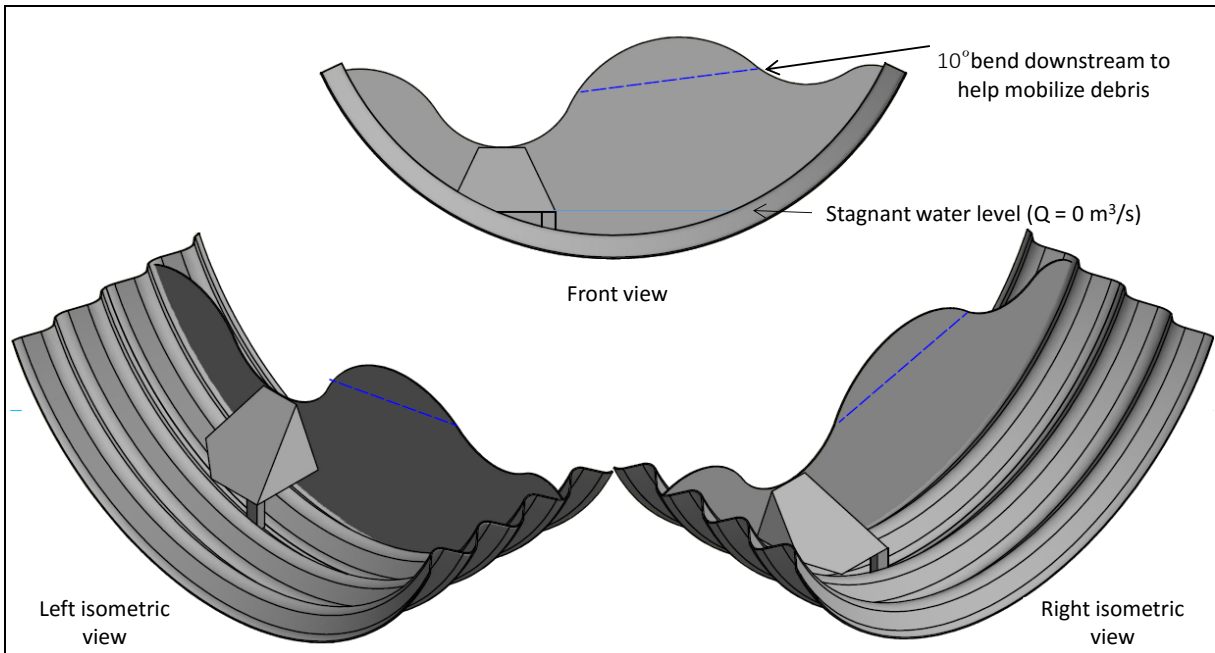


Figure 6: Configuration of Duguay - Lacey (2014) Baffle Design

With regards to confirming the functionality of the Duguay-Hannaford baffle liner, design criteria for culvert velocities was referenced to the swimming capabilities of the target fish species within the study area. Fish swimming performance has been classified into three categories based on speed and duration for a given flow velocity: burst speed (highest speed attainable for less than 15 seconds), prolonged speed (moderate speed for 1800 seconds) and sustained speed (a speed that can be prolonged indefinitely) (Katopodis, 1994). In natural watercourses, migrating fish will mainly use sustained and prolonged speeds reserving burst speeds to overcome high velocity rapids. Through the culvert, burst speed capabilities will typically be used to overcome the baffle, finding refuge within the adjacent pool.

Rainbow Trout between 100 – 400mm in length, the target species within the tributary, belong to the subcarangiform category, and maintain swimming capabilities for 1m bursts between 0.6 m/s to 2.5 m/s (Katopodis, 1994).

Modelling of the baffle configuration was provided by CSPI to provide an understanding of baseflow ($0.2 \text{ m}^3/\text{s}$) velocity through the culvert, and to be used for comparison to swimming capabilities of the target species. The results of the modelling are presented within Figure 7, in which the velocity profile ranges between 0m/s within the lower pool areas for resting, to the upper limit of 2m/s as flows crest over the top of the baffle. As the burst speed swimming capabilities of the target species exceeded the velocities estimated over the baffles, the Duguay-Hannaford baffle configuration appended to a corrugated steel slip liner was chosen as the preferred baffle arrangement. Construction of the culvert was implemented in winter 2015 in anticipation of the spring spawning runs, and a two year monitoring program by the MTO is underway.

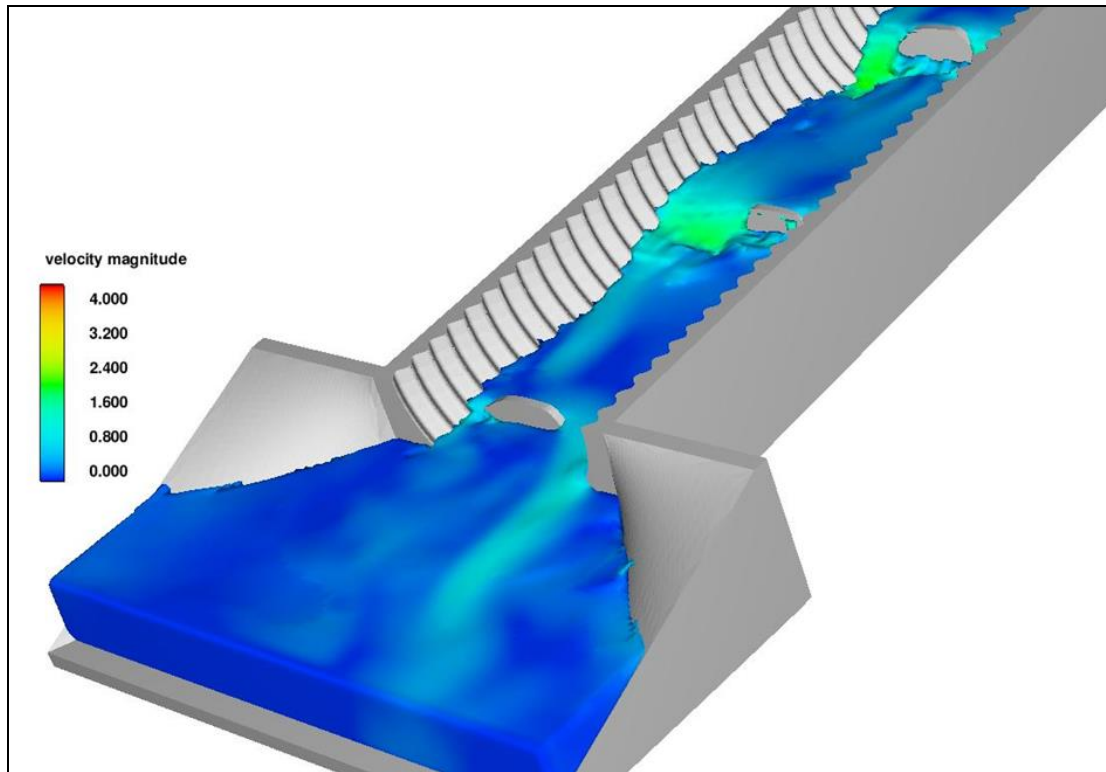


Figure 7: Hydraulic Modelling of the proposed Duguay, Lacey (2014) Baffle Design provided by CSPI

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