Interesting Solutions for a Culvert Rehabilitation Project in a Sensitive Urban Watershed

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Abstract

Bovaird Drive is a key east-west arterial in the Region of Peel, with traffic volumes of approximately 5500 AADT. Just west of Heritage Road, a tributary to the Credit River crosses Bovaird Drive through a 14m deep culvert with three distinct segments, including a 20m long 75 year +/- old masonry structure, and two newer sections – a 20m long cast-in-place concrete box culvert, and a larger 60m long cast-in-place concrete box culvert. Both the first and second segments were structurally deficient and required removal and replacement. A 2m vertical internal drop between the first and second culvert sections impeded fish passage.

Extensive consultation was undertaken with the Department of Fisheries and Oceans Canada (DFO), Ministry of Natural Resources and Forestry (MNRF), and Credit Valley Conservation (CVC) to develop a design that would meet the requirements for hydraulic passage and environmental permitting. The approved designed, tendered and constructed culvert involved 20,000 m3 of earth excavation to expose the deficient portion of the culvert, removal of 40m of the existing deficient culvert and replacement with a 20m long x 1.2m wide by 2.8m high precast concrete box structure, installation of wooden fish baffles within the culvert to improve passage for large-bodied fish, reconstruction of the upstream portion of the tributary for approximately 65m using a pool-step configuration, temporary realignment of Bovaird Drive (reduced to one lane in each direction and with lanes shifted to the south), roadside protection, construction of temporary access roads into the valley to facilitate construction equipment movement, and reforestation of the disturbed area with 400+ trees and 450+ shrubs.

The culvert was over 14m deep which required movement of a large volume of earth by heavy excavation equipment. Careful consideration was required for protection of the natural environment. As required by agencies, the final construction must improve the ability for fish to travel upstream. The new 20m long precast culvert created a 4m difference between the existing tributary and the new culvert invert. Fish passage was achieved through an innovative approach which utilized a fish baffle system within the existing culvert, followed by a pool-step channel, connecting the existing channel to the new culvert in the shortest distance possible, while allowing the fish to jump from pool to pool. Finally, and most importantly, the structurally deficient sections of the existing culvert were removed and replaced. This not only ensures continued operation of a key arterial roadway, but also has improved the ability of the Credit River Tributary to function as a healthy and vibrant natural system.

Background

In 2009, the Region of Peel initiated a Class Environmental Assessment (Class EA) for Bovaird Drive from 1.45km west of Heritage Road to Worthington Avenue, in the City of Brampton. Bovaird Drive (Regional Road 107) is an important roadway link and a major east-west arterial roadway, with traffic volumes of approximately 5500 AADT (Average Annual Daily Traffic). The section of Bovaird Drive from Mississauga Road to the western limit of the Region of Peel is rural and the roadway currently has two core lanes, with an additional eastbound truck climbing lane leaving Norval, a small community on the Credit River, west of the study limits.

The Class EA examined the need and feasibility for widening and improvements on Bovaird Drive to address short term and long term issues related to planned future growth, operational, geometric, capacity and storm drainage deficiencies. Various design options were prepared and assessed by the Class EA study team. Based on input provided by stakeholders including representatives of the new developments, technical agencies, and public participants, as well as based on a formal assessment by the study team, a preliminary design was prepared to address the preferred planning alternative.

At the crossing of the Credit River Tributary of Bovaird Drive (see Figure 1), roadway improvements were not required to address the identified planning alternatives. However, the culvert was identified as a barrier to fish passage, a constraint to fluvial geomorphological variables, and insufficiently sized for the Regional Storm event. A portion of the culvert was also identified to be structurally deficient. The Class EA recommended that detailed design and subsequent construction of improvements to the culvert be completed by the Region of Peel.

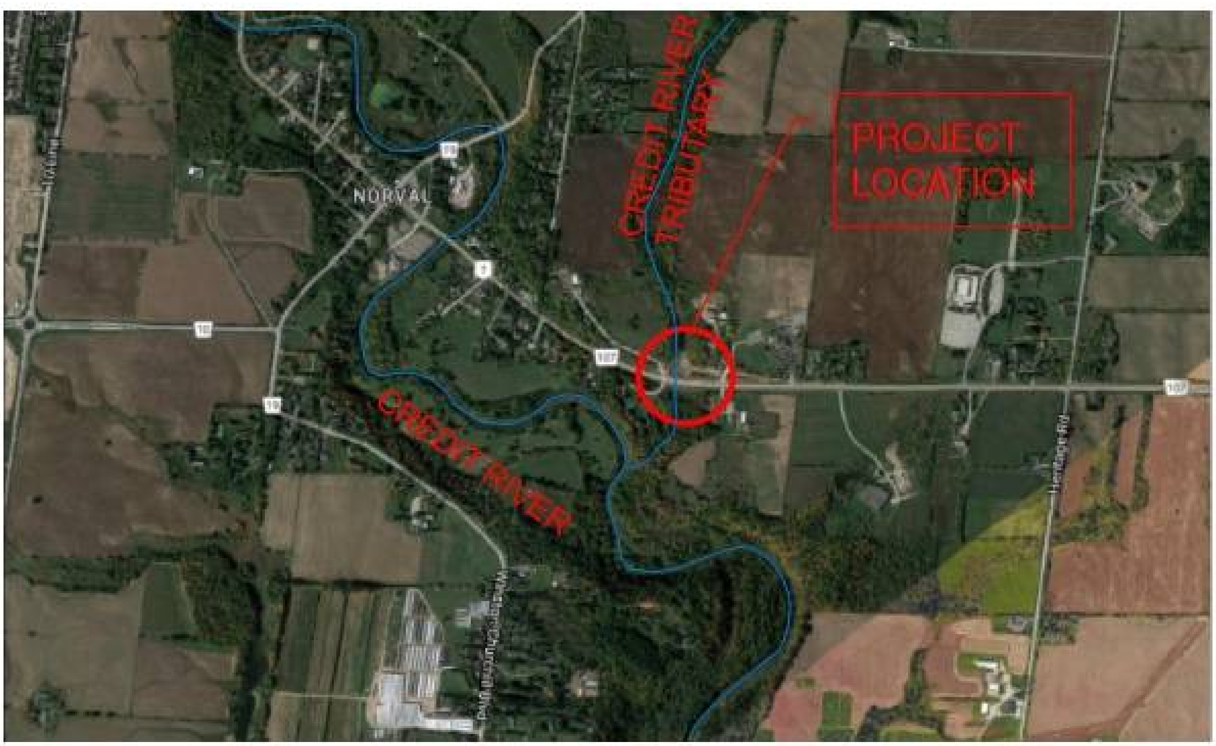

Figure 1 - Project Location

The separate project identified by the Class EA commenced in October 2013, with a focus on repair and remediation of the existing culvert, while also improving fish passage through the creek reach.

The existing culvert consists of a 14m +/- deep structure with three distinct segments. The first segment (length = 20m) consisted of a 75 year +/- old masonry structure which crosses under an old road platform just north of Bovaird Drive (known as old Highway 7). The second segment (length = 20m) consisted of a cast-in-place concrete box culvert. Finally, the third segment (length = 60m) is a larger cast-in-place concrete box culvert. Both the first and second segments were found to be structurally deficient and required removal and replacement. In addition, a 2m drop within the culvert between the segments was impeding fish passage.

Figure 2 - Creek valley pre-construction

Figure 3 - Culvert inlet pre-construction

The gradient of the existing culvert varied along its length. The downstream section of culvert had an average grade of 2.1% and the upstream section of culvert had an average gradient of 7.3%. To extend the 2.1% gradient of the downstream section of culvert up through the new culvert section to provide improved fish passage, a 4m grade transition would be required in the upstream section of channel. To create this grade transition would require significant channel realignment, associated grading and riparian vegetation removal. Access to private property would be required for the duration of construction.

<u>Technical Evaluations</u>

To further define the parameters of the design, a series of site investigations were completed which are summarized below:

Fish and Fish Habitat

From anecdotal reports from local landowners and from video footage, large-bodied fish were observed within the pool immediately downstream of the culvert. MNRF (Ontario Ministry of Natural Resources and Forestry) has electrofished downstream of the culvert, and has confirmed the presence of Rainbow Trout, Coho Salmon, and other salmon species within the tributary. Approximately 50 m downstream of the culvert, a remnant concrete structure is present within the watercourse which prevents passage by small bodied fish. Large bodied fish were able to enter the culvert outlet, but not successfully pass through the culvert. Small bodied fish are likely present at the culvert outlet pool, however, a 0.6m drop at the culvert outlet prevents small bodied fish passage.

Fluvial Geomorphology

From a geomorphic perspective, it is evident that the existing culvert is inadequately sized to permit efficient sediment transport, leading to issues related to excessive scour (as evident by localized scouring upstream) and fish passage. Ideally, the proposed structure should be wider to enable natural channel function. The ideal width of the structure would be at least 3x the bankfull channel width, which has been shown to reduce any long-term implications to creek and structure integrity. Based on the geomorphic assessment of the watercourse, an ultimate crossing structure span of 12m is recommended. This ideal structure span would provide adequate width for natural channel processes, accommodating minor channel adjustments and improved fish passage resulting from the potential open-footing structure. However, the 12m span is only feasible if the culvert is fully reconstructed under Bovaird Drive, a significant capital expense for which funding was not available.

Geotechnical Engineering

The removal of the culvert was proposed to be completed by open-cut excavation, along with the removal of the old Highway 7 embankment. Slope stability calculations using GeoStudio SLOPE/W (Version 7.17) were completed to analyze and determine the factors of safety considering deep-seated slip surfaces. Based on in-situ soil conditions, a channel cut through the existing embankment within the length of the existing culvert to be removed would be stable at slopes of 2:1.

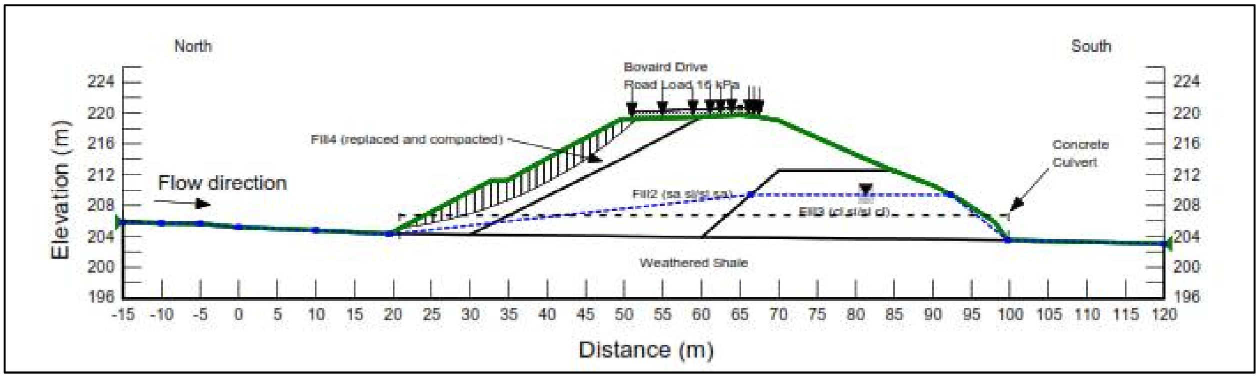

Figure 4 - Output from slope stability analysis

Based on the soil profile observed at the borehole locations and the rehabilitation works being considered, the founding strata for the headwalls/retaining walls/wingwalls would be hard silty clay/ clayey silt till and/or very dense weathered shale. Based on the soil encountered in the boreholes, geotechnical reaction at Serviceability Limit States (SLS) and geotechnical resistance at Ultimate Limit States (ULS) for the weathered shale was found to be 400 kPa and 600 kPa respectively. For foundation design the SLS soil bearing values provided corresponded to total and differential settlements of up to 25 mm and 20 mm, respectively.

To reinstate the roadway embankment removed for construction of the culvert, a slope of 2H:1V on the north side of Bovaird Drive was proposed. The excavated soil would be replaced and compacted to 98% SPMDD during the construction of the slope, and a minimum 2 m wide bench provided.

Hydrogeological Study

The hydrogeological investigation for the site consisted of a desktop study of available information from government records and geotechnical reports completed in the study area. Information was also gathered from drilling boreholes at 4 locations and installing monitors at two of these locations. Single well response tests were completed to estimate the hydraulic conductivity of the saturated materials in the immediate vicinity of the culvert. The data was incorporated into a generic conceptual model and analyzed using Visual Modflow. Using this conceptual model, it is predicted that the maximum rate of dewatering of groundwater that may be expected will be less than 50 m^3/d. Consequently, a Permit to Take Water (PTTW) was deemed to be unnecessary, and any dewatering of the excavation could be completed by the contractor using common pumping equipment.

Hydraulic Analysis

The hydraulic assessment was completed using the hydraulic modelling platform HEC-RAS Version 4.01, as prepared for the ongoing Heritage Heights Subwatershed Study (a major urban expansion planning study). The Heritage Heights Subwatershed Study hydraulic modelling used the City of Brampton's 2010 0.5 m topographic mapping base updated with 2014 and 2015 geodetic topographic survey of the Bovaird Drive crossing and the valley floor upstream of the crossing. The boundary conditions for the hydraulic modelling include peak flows and downstream flood elevations for the 2 to 100 year storm events and Regional Storm Hurricane Hazel. Based on direction from CVC (Credit Valley Conservation), peak flows were revised to represent the uncontrolled future land use condition determined as part of the Heritage Heights Subwatershed Study Phase 2 Impact Assessment.

For the hydraulic model, the barrel size of 1.2m span x 2.8m high to match the dimensions of the third segment was assumed to replace the first and second segments of the existing culvert. Based on the results the following was noted:

i) The existing hydraulic structure provides a conveyance capacity of less than 10.82 m^3/s prior to spill occurring. Under existing conditions, the capacity of the hydraulic structure would be exceeded and spill would be anticipated to occur during events above the 2 year frequency flow.
ii) The results further indicate that the spill flow across the existing structure would be as much as 45.85 m^3/s during the Regional Storm event, accounting for approximately 75 % of the total flow at the crossing during the Regional Storm event.
iii) Under proposed conditions, the hydraulic structure would provide a conveyance capacity slightly below 25.5 m^3/s before spill would occur. This represents a more than doubling of the conveyance capacity of the existing hydraulic structure (i.e. below 10.82 m^3/s) prior to spill occurring. The results also indicate that spill would occur during events above the 20 year frequency, hence the increased conveyance capacity of the hydraulic structure under proposed conditions would reduce the frequency and potential for spill compared to existing conditions.
iv) The proposed works would also reduce the quantity of spilled flow and upstream water surface elevations compared to existing conditions, thus providing further flood protection for upstream properties proximate to the structure, as well as any properties west of the crossing and along the spill zone.

Structural Engineering

The Structural Inspection Report identified the following:

i) The north return wall and northwest retaining wall were found to be in poor condition (see Figure 5);
ii) Loose stones at the northeast end of the culvert wall were observed, but no loss had occurred;
iii) The surrounding conditions included the collapse of the north embankment slope protection and the erosion of the fill on top, and
iv) Stones within the culvert barrel were not held together by mortar, and some stones at the base of the barrel had either shifted or were missing (see Figure 6).

The structural engineering focused on the culvert replacement based on the third segment of the existing culvert. The existing portion of the culvert to remain was a cast-in-place 1.2m span x 2.8m rise, which was completed by the Ministry of Transportation Ontario (MTO) when Bovaird Drive was classified as Highway 7. This non-standard cross section is not typically available by precast manufacturers in Ontario, which led to a cast-in-place culvert design. The culvert was designed to the Canadian Highway Bridge Design Code, CAN/CSA S06-14, with the design live load being CL-625-ONT. The design required that the specified compressive strength of the concrete at 28 days be 30 MPa, with exposure Class F-1. Reinforcing steel was Grade 400W, and the clear cover to the reinforcing steel was at minimum 50mm +/- 10mm for the bottom of the top slab, and 70mm +/- 20mm for the remainder of the culvert.

Figure 5 – North return wall and northwest retaining wall

Figure 6 - Culvert Barrel

Alternative Assessment

Based on the findings of the site investigations described above, several alternatives were considered by the project team. The alternatives considered included:

1. Do Nothing;
2. Remove a portion of the existing culvert and partially replace with a cast-in-place structure with the same cross-section as the remaining portion of the culvert;
3. Implement 2), with a maximum 4% slope from the culvert extension to the existing creek; and
4. Remove the deficient portion of the culvert and install a permanent retaining wall.

Each alternative was assessed against several categories as follows:

Natural Environment

The 'Do Nothing' alternative had the least impact on vegetation, wildlife habitat and fisheries. However, the issues with hydraulic capacity and fluvial geomorphology could not be addressed with this alternative.

Generally, the removal of the deficient portion of the culvert and installation of a permanent retaining wall had benefits for the natural environment, as it would minimize the footprint of the construction to the valley, maximize the length of natural stream channel, and increase light penetration to the channel which would improve the fish feeding area.

Social, Cultural, and Economic Environment

This category covered archeology and cultural heritage resources, access considerations, utilities, construction disruption, safety, and travel delay/traffic capacity. Generally, the 'Do Nothing' alternative would not address the safety concerns and travel delay/traffic capacity criteria, as failure of the culvert would affect the integrity of Bovaird Drive.

There was no difference in the other three alternatives as they relate to the various criteria under this heading. Other factors would need to be considered to determine the best alternative to address the issues identified.

Planning and Cost

Planning criteria involved both incremental capital cost and compatibility with Regional and City plans and policies. Other than the 'Do Nothing' alternative, it was found that the 'Remove a portion of the existing culvert and partially replace with a cast-in-place structure with the same cross-section as the remaining portion of the culvert' alternative was the least costly.

Alternative 4, 'Remove the deficient portion of the culvert and install a permanent retaining wall' was found to be the least preferred for the compatibility criteria, as it would conflict with the Heritage Heights Subwatershed Study, which has identified this crossing to be replaced in 20+ years to service the proposed development.

Preferred Alternative

Based on the review of the various criteria considered, Alternative 4, 'Remove a portion of the existing culvert and partially replace with a cast-in-place structure with the same cross-section as the remaining portion of the culvert' was selected as the preferred alternative. The alternative was found to balance both the need to complete the repairs to the existing culvert with the need to minimize impacts to the natural environment. In addition, this alternative would provide the opportunity to improve hydraulics, fluvial geomorphology, and fish passage.

Environmental Constraints

There were several environmental constraints for the proposed work that needed to be addressed. First, the work zone is within a tributary for the Credit River. This tributary has a total drainage area of a 466 ha, and connects to the main Credit River branch 320m downstream of Bovaird Drive. The surrounding area consists primarily of low lying agricultural land with a small urban area, Norval, located to the west of the culvert. The channel flows through a 14m deep valley surrounded by mixed forest and agricultural lands, and has low lying banks with erosion occurring along the outside meander bends and at valley wall contacts. The channel substrate consists mainly of gravel, sand, and clay with inclusions of cobbles. Construction would need to be carefully staged to ensure that the integrity of the valley was protected.

As previously noted, the work identified to remediate the existing culvert created a 4m difference between the existing tributary and the new culvert invert. To address this issue, a pool-step transition was designed and constructed which allowed the upstream channel to connect to the new culvert in the shortest distance possible. By minimizing the distance, the team reduced the construction footprint, thus minimizing environmental impacts to the surrounding valley. In addition, the reduced footprint allowed the limits of the erosion and sediment controls during construction to be minimized.

Figure 7 – Completed pool-step transition

Secondly, the downstream watercourse provided habitat for many fish species. There were no species-at-risk identified, however, CVC and MNRF expressed a need to improve fish passage through the culvert and into the upstream reaches. As noted above, most of the fish present downstream were large-bodied fish. The design team, in consultation with MNRF concluded that fish movement upstream would be improved by constructing fish baffles within the existing culvert. The fish baffles, constructed out of marine grade timber, would provide 'rest points' at regular intervals (see Figure 8). In addition, the pool - channel transition upstream of the culvert was designed to accommodate fish passage by constructing pools with a depth equivalent to or greater than the height of the step. This has been found to allow the fish to develop sufficient momentum in the pool to clear the step. During low flow periods, the pool depth and equivalent step was designed to be 0.4m +/-. During more significant flow periods, the pool depth increases and the step height decreases, improving the ability for fish movement to be successful.

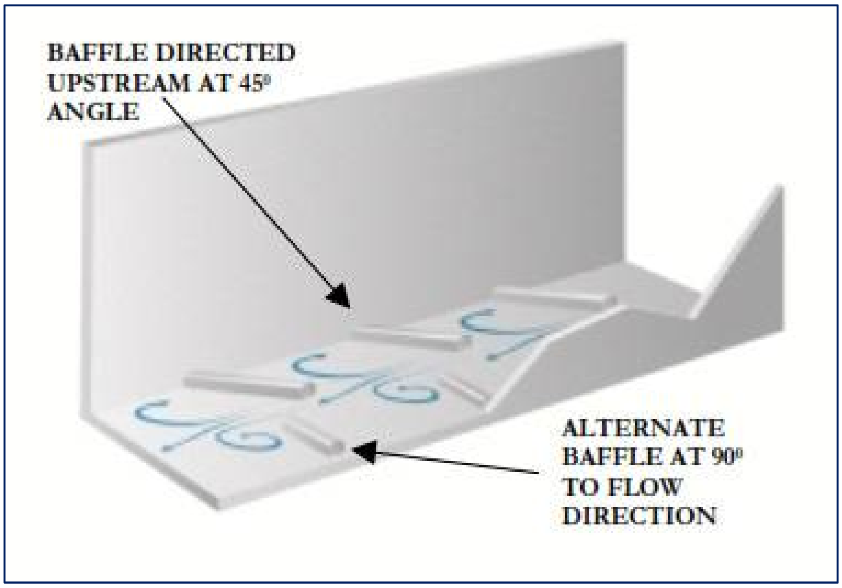

Figure 8 – Graphical depiction of fish baffle configuration (Source: http://www.ontariostreams.on.ca/PDF/OSRM/Chapter%206%20Fishways.pdf)

Figure 9 - Fish baffles after installation

Finally, the work zone was within a mixed forest, and although the size of the work area was minimized to the degree possible, some clearing was necessary to facilitate access and construction. To compensate for the loss of the trees, over 400 trees and 450 shrubs were planted. In addition, over 5,000 m^2 of disturbed area needed to be reseeded. All vegetation and seed materials were native species to the surrounding area.

Agency Approvals

During design, an iteration of the new creek configuration was advanced that would have required 300m of creek construction upstream. Both MNRF and CVC challenged the team to present a better solution which would minimize the footprint of construction. This led to a revised design which reduced the impact to the valley to 65m of creek construction. This design was further refined to the pool-step configuration described above.

Further discussion with the agencies focused on ensuring both the upstream and downstream flood elevations did not increase due to the planned work. The team was able to confirm through detailed modelling that both hydraulic capacity and upstream water elevations would not be adversely affected by the new culvert. In addition, over 10,000 m^3 of flood storage was added to the upstream valley system, improving the capacity of the valley to control major storm events.

Construction

Construction commenced in early 2016 after the competitive bidding process was completed. Construction extended throughout the year, with the core of construction occurring in summer and fall 2016. The project was completed by late October 2016.

Excavation of over 20,000 m^3 of earth was completed to expose the deficient portion of the existing culvert. Access to the culvert and creek reconstruction area was challenging given the 14m +/- deep valley system that the culvert was contained within. To access the valley floor with the necessary equipment, an access with an approximate 20% slope was constructed. Articulating dump trucks and track equipped excavators were used to haul the excavated material up the access to a nearby stockpile. Once the culvert was in place, the required fill material was hauled from the stockpile, placed and compacted. Some surplus material was reused on site for construction of small landscaping berms, with the remainder of the material hauled off-site.

Figure 10 – Construction of roadway shoring with access to valley completed

Figure 11 - Construction of pool-step transition

During construction, the contractor identified that the culvert replacement could be completed using 8 precast concrete culvert units, with each unit being 2425mm long. The units would be delivered from the manufacturing plant and lifted into place using a large overhead crane, with a cast-in-place connection between the existing culvert and the connecting precast unit. This provided a substantial time savings to the project, as a cast-in-place extension would require curing time before backfilling. Also, the cost difference between the precast and cast-in-place options was negligible.

Extensive erosion and sediment control measures were implemented, which included (but was not limited to) Silt Soxx™, single row silt fence, double row silt fence (with straw bales in between), sediment filter bags, temporary rip-rap channels, paige wire tree protection fencing, and temporary culverts. The erosion and sediment control measures were reviewed daily, and adjustments were made by the contractor quickly if deficiencies were identified.

In-water works were limited to the period between July 1st 2016 to March 31st 2017. Careful planning was implemented to ensure the majority of the excavation was outside the defined limits of in-water works.

Community Relations

Given the close proximity of the deep excavation to the existing roadway, roadside protection was required. To minimize the height of roadside protection (to 6m +/-), while maintaining traffic, a staging plan was proposed which closed one lane eastbound (the truck climbing lane), and shifted traffic away from the excavation partly onto the gravel shoulder, which was paved to facilitate the lane shift. Two lanes of traffic (one in each direction) were maintained for the duration of construction.

Figure 12 - Bovaird Drive with staging implemented

Conclusion

The Credit River Tributary Culvert Rehabilitation project was much more complex than a typical culvert rehabilitation project. The culvert was over 14m deep, which required excavation of a large volume of earth by heavy excavation equipment. In addition, access was very constrained, and consideration for the appropriate construction equipment was critical.

Due to the sensitive nature of the watercourse, careful consideration was required with regards to environmental features, in particular fish passage. As required by the agencies, the project must improve the ability for the relevant fish species to travel upstream. This was achieved through an innovative approach which utilized a fish baffle system within the existing culvert, followed by a pool-step channel designed to allow the fish to jump from pool to pool.

In April 2017, the efforts by the team proved successful. A number of large-bodied rainbow trout were found spawning in the pools recently reconstructed, and some distance upstream of the culvert. The habitat constructed and the reaches upstream likely have not had fish present for over 100 years, and monitoring will continue to observe the habits of these new residents to the watercourse.

Figure 13 - Fish observed in newly constructed pools in April 2017