APPENDIX A - HYDRAULIC & HYDROLOGIC TECHNICAL MEMOS

Issue Date:	April 12, 2020	**File:**	
Previous Issue Date	September 5, 2018		
To:	Amber Leal, Town of Innisfil		
From:	Angela Peck, Civil Designer		
Client:	Town of Innisfil		
Project Name	Cross St. Culvert		
Project No.	2018-5229		
Subject:	Hydrology and Hydraulics Memo		

TECHNICAL MEMORANDUM

1 INTRODUCTION

The Town of Innisfil (TOI) retained Associated Engineering (AE) to carry out preliminary and detailed design for the Cross Street Culvert Replacement. The culvert is undersized which causes localized flooding during frequent storm events. This technical memo summarizes existing culvert characteristics, hydrologic analysis, hydraulic assessment, design alternatives and recommended solution.

2 PROJECT LOCATION

The culvert is identified as Culvert RC RC2506 and conveys flows of Banks Creek. It is located on Cross Street between 7th Line and Kennedy Road, approximately 80 m south of 7th Line in the Town of Innisfil (Figure 1-1). Flows ultimately discharge 40 m downstream of the existing structure location into Lake Simcoe. The existing culvert is a single cell cast-in-place concrete box culvert. It has a total deck length of 4.9 m and an overall length of 11.2 m with approximately 400 mm fill on top of the culvert and a skew of 15 degrees.

Figure 1-1: Site Location (Google Maps)

3 WATERSHED CHARACTERIZATION

The Cross St. culvert watershed is part of the Great Lakes – St. Lawrence primary watershed and part of the Black River – Lake Simcoe tertiary watershed. The watershed is approximately 912 ha with a mean watershed slope of approximately 3%. Primary land uses in the watershed include: agriculture and rural (56%), urban community (19%), and treed/forested (14%). Lake Simcoe is a regulated waterbody part of the Trent-Severn Waterway. Water levels in the lake are managed to strike a balance flood prevention, recreational use, and fish and wildlife habitats. Typically, Lake Simcoe water levels vary by about 0.4-0.5 metres during any given year. The highest levels usually occur between April and June and the lowest levels typically occur in late fall and winter. These outlet conditions influence the hydraulic performance, and subsequently the hydraulic design at Cross Street Culvert.

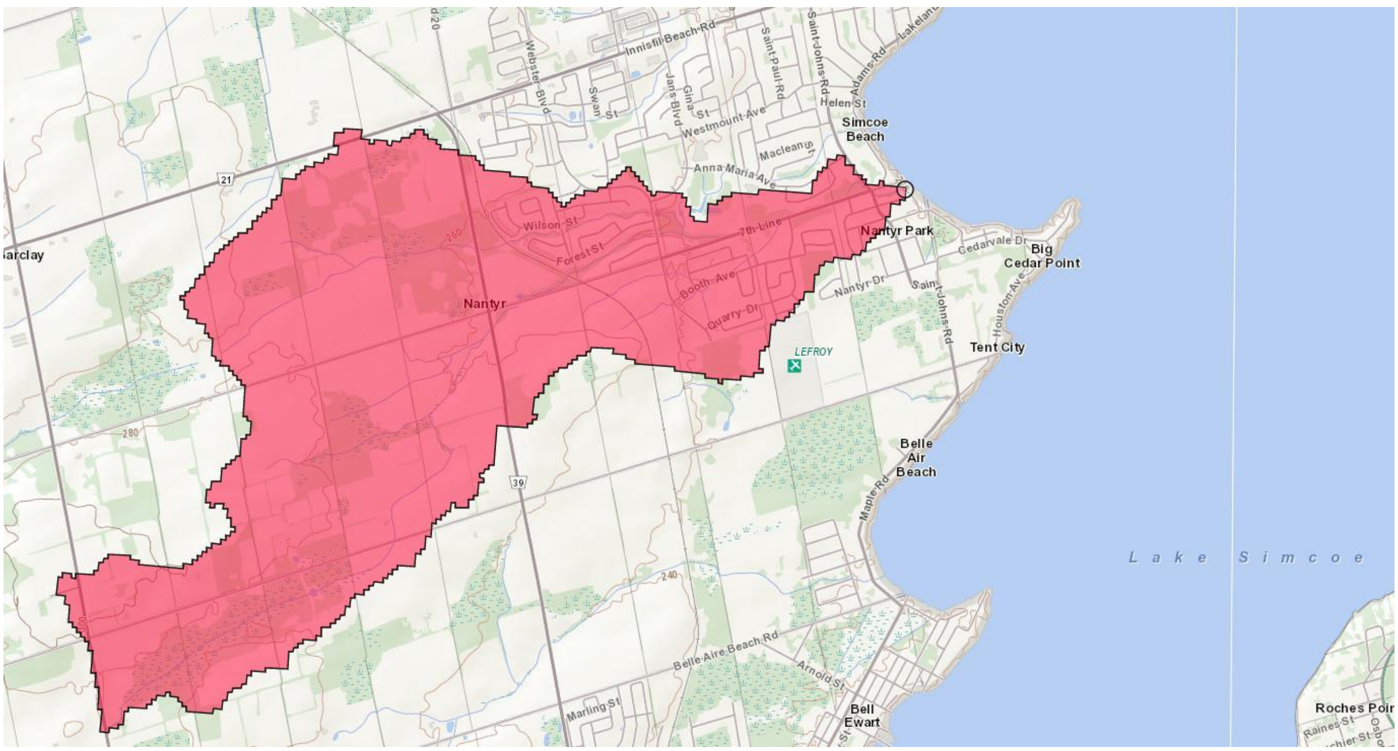


Figure 3-1: Cross Street culvert watershed

4 DESIGN CRITERIA

The following design criteria were derived using the following standards, guidelines, and documents:

- MTO Drainage Design Standards (2008);
- Transportation Association of Canada (TAC) Geometric Design Guide for Canadian Roads;
- Town of Innisfil Engineering Design Standards; and
- Lake Simcoe Region Conservation Authority (LSRCA).

Design requirements vary depending on the type of structure (ex. open-footing culvert; closed culvert; or bridge). Based on the findings of the geotechnical investigations, it is assumed that the proposed replacement structure will be a closed culvert. Therefore, the following design criteria are based on the assumption that the replacement structure will be a closed culvert.

4.1 Road Classification

Based on OSIM Bridge Inspection Report and the above standards, Cross Street was classified as a **local road**.

4.2 Design Storm

In accordance with WC-1, the following is required for design:

- Design Flow for a local road with a total span less than or equal to 6.0 m is the **10-Year storm**;
- Scour check flow is **100% of the 100-Year flow** (i.e. the 100-Year flow); and
- The Regulatory storm is **Zone 1: Hurricane Hazel or the 100-Year storm**, whichever is greater.

4.3 Freeboard and Clearance

In accordance with WC-7, the freeboard and clearance requirements for closed footing culvert alternatives are as follows:

- Freeboard **shall be ≥ 0.3 m**; and
- There are **no clearance requirements** for closed-footing culverts.

4.4 Relief Flow

If the proposed culvert were designed to satisfy the 10-Year event, there will likely be flows conveyed over the roadway (relief flow) during larger events. In this instance, the Regulatory Storm is considered in defining the relief flow. In accordance with WC-13, where relief flow is provided the following design criteria applies:

- Relief flow depth **must be ≤ 0.3 m**; and
- Relief flow product of velocity and depth **must be ≤ 0.8 m^2/s**.

4.5 Fish Passage

In accordance with WC-12, requirements to facilitate fish passage through culverts includes: minimum culvert widths, culvert embedment depths, characterization of appropriate culvert substrate materials, and shape of the low flow channel. Where fish passage is required, the following design criteria applied:

- Typically, the **2-Year event** is considered to be representative of bankfull flow conditions, and therefore is used as the return period for calculating fish passage flow requirements; and

- The invert of closed-bottom culverts on migratory fish routes shall be embedded a **minimum of 0.3 m** below the natural streambed to promote fish passage and accommodate culvert substrate materials.

4.6 Icing

Since winter ice conditions have been identified as a problem, the requirements for accommodating ice build up at closed bottom culverts in accordance with WC-11 is as follows:

- Culvert soffit clearance shall be ≥ 0.3 m above the maximum observed ice build up plus winter flow
- Culvert width shall be the observed channel's static ice width + 10% to prevent property damage.

4.7 Temporary Flow Passage

The contributing factors affecting the choice of return period for temporary flow passage depends on the length of the construction period and includes potential consequences in terms of public safety, traffic delays, property damage due to flooding, and environmental impacts. In accordance with TW-1:

- The temporary drainage design storm is **2-Years** for all construction less than two (2) months in duration.

4.8 Other: Structural Considerations

Structurally, culverts will require a minimum depth of cover. This requirement varies depending on the type, shape, and material of the culvert.

5 HYDROLOGY

Three (3) non-hydrographic statistical hydrological estimation methods were used to estimate flow rates for the two (2) culvert locations:

1) Northern Ontario Hydrology Method (NOHM);
2) Modified Index Flood Method (MIFM); and,
3) Primary Multiple Regression Model (Moin & Shaw 1985 method as calculated in OFAT tool).

These analyses are well-documented and widely accepted methods of flow estimation in the hydrologic community. The use of three (3) methods helps provide confidence in the results and offers a comparative, conservative flow estimation for design purposes. The results of these analyses are shown in the table below and are compared with the flows provided in the previous hydrology report, as well as the flows already in the existing LSRCA HEC-RAS model. The most conservative flow estimates were used in hydraulic analysis.

	Flow Estimations (m^3/s)					
	Hydrological Estimation Methods			Other Existing Hydrological Estimates		
Return Period	NOHM	MIFM	Moin & Shaw PMR	Previous Hydrology Report	LSRCA HEC-RAS model	Conservative Estimate (m^3/s)
2-Year	2.4	6.9	2.8	n/a	n/a	6.9

10-Year	3.9	11.5	6.3	n/a	11.2	11.5
100-Year	5.6	17.2	12.0	16.0	16.6	17.2
Regional	n/a	n/a	n/a	n/a	68.3	68.3

5.1 Climate Change Considerations

Extreme weather events across Canada and around the world have demonstrated that Earth's climate is changing; the magnitude and frequency of extreme events is increasing, having a formidable impact on our infrastructure, environment, and our communities. Therefore, as part of this work, a climate change sensitivity analysis was completed using the MTO IDF Curve Tool. This analysis revealed that rainfall intensities may increase 6% (based on the 10-Year, 2-hour rainfall intensity) by 2070 (50-Years from an assumed completion date of 2020) to approximate the design service period. If we were to conservatively extrapolate that a 6% increase in intensity reflects an 6% increase in runoff volumes, then the conservative 10-Year climate change influenced design flow estimate would be 12.2 m^3/s. These climate change influenced flow estimates were used in the subsequent hydraulic analyses.

6 HYDRAULICS

Using the conservative, flow estimates from the hydrologic analysis, hydraulic estimation was completed with:

1) HY-8 culvert analysis software; and
2) HEC-RAS.

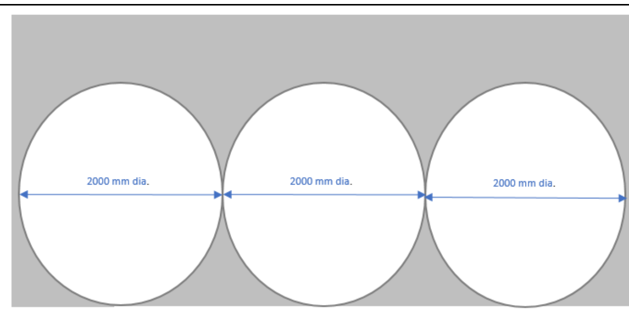
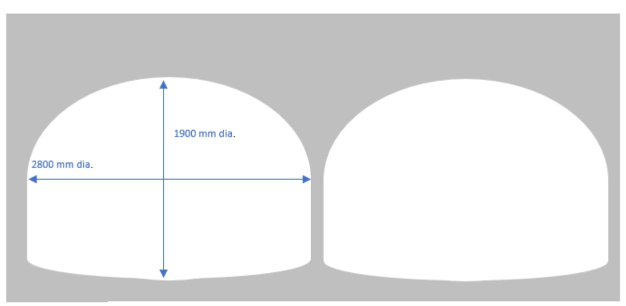
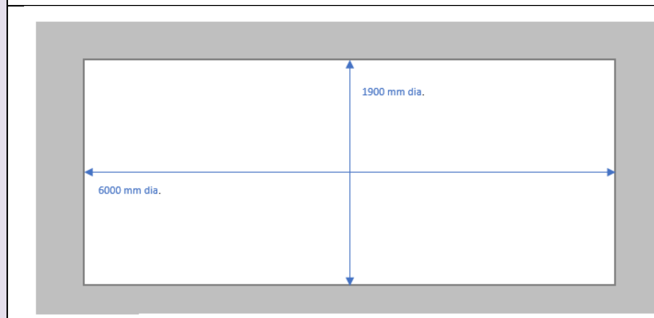
Hydraulic analysis was completed for the existing culvert and three (3) proposed design alternatives. The analysis considered both inlet and outlet-controlled conditions. The results of the hydraulic analysis for the existing and proposed structures are provided in the table, below. Note that none of the proposed alternatives would be able to meet Relief Flow criteria considering the Hazel storm and designing to this level of service is not beneficial from a cost-benefit perspective. Therefore, the table below refers to satisfying relief flow as it pertains to the 100-Year storm.

It is important to note that the hydraulic performance of this culvert is highly dependent upon the water levels in Lake Simcoe. Since Lake Simcoe is managed as part of the Trent-Severn Waterway, there are periods during the spring where lake levels will be high, and the culvert will be under outlet control. During these times, the benefit provided by the increased capacity that any of the proposed design alternatives will be limited.

6.1 Ice Considerations

Probably the most common form of ice blockage in culverts is caused by the complete freezing, from surface to bottom, of the shallow flow at the bottom of the culvert. Circular and pipe-arch metal culverts and box-type concrete carry such small depths of flow in the winter that often the entire depth of flow is frozen. If flow continues from upstream, it must pass over the ice already formed, and it is liable to become frozen solid in the same way. In this way the ice builds upward, layer by layer, and restricts the size of the culvert cross-section. Given the historic ice-related flooding issues in this area, ice impacts and hydraulic restrictions due to ice formation should be considered. External energy dissipaters maybe used to control the formation of ice at the culvert.

Table 6-1: Hydraulic properties for the existing culvert and three (3) proposed design alternatives

	Photo / Conceptual Schematic (not to scale)	Description	Total Area of Hydraulic Opening[1] (m²)		Meets Design Criteria?				
				Design Flow	Freeboard and Clearance	Relief Flow[2]	Fish Passage	Icing[3]	Temporary Flow Passage
Existing Culvert		Existing 4500 x 1100 concrete box culvert with headwall and downstream wingwalls	4.95	No	No	No	Unknown	No	N/A
Proposed Alternatives		Three (2000) circular CSP culverts with headwall and downstream wingwalls	9.4	Yes	Possible	Yes	Possible, with fish baffles and constructed pools	?	TBD
		Twin (2800 x 1900) CSP pipe arch culvert with headwall and downstream wingwalls	9.0	Yes	Possible	Yes	Possible, with embedment	?	TBD
		Closed bottom (6000 x 1900) concrete box culvert with headwall and downstream wingwalls	11.4	Yes	Yes	Yes	Possible, with embedment	? Possible, with energy dissipater. Preferred alternative for ice passage	TBD

[1] Not including embedment depths
[2] Considering the 100-Year storm

7 PREFERRED ALTERNATIVE

The 6000 x 1900 mm closed bottom concrete box culvert alternative would provide the largest hydraulic opening, providing improved flow capacity and offering the best alternative for debris, ice, and fish passage. However, a cost-benefit analysis could help provide additional insight as to whether the benefits of constructing a new concrete box culvert would outweigh the costs of its construction. In addition, further investigation should be made as to whether the construction of the new culvert would fulfil the environmental assessment (EA) problem statement. It is therefore recommended that a cost-benefit analysis be completed before continuing with the detailed design of the preferred alternative. The EA should also be re-opened to ensure that the solution being provided is aligned with the Town's goals.

Prepared by:	Reviewed by:
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AP	**SB**

Associated Engineering GLOBAL PERSPECTIVE. LOCAL FOCUS.

Issue Date:	April 14, 2020	**File:**	
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To:	Amber Leal, C.E.T.		
From:	Angela Peck, Civil Designer		
Client:	Town of Innisfil		
Project Name	Cross St. Culvert		
Project No.	2018-5229		
Subject:	TCM#2 Cost-Benefit Analysis		

TECHNICAL MEMORANDUM #2

1 INTRODUCTION

The Town of Innisfil (TOI) undertook an EA in 2007 (completed by others) which identified the replacement of Cross Street culvert (with a larger structure) as the preferred alternative to alleviate flooding. Based on the findings of this EA, the Town retained Associated Engineering (AE) to carry out preliminary and detailed design for the replacement of Cross Street Culvert. As part of preliminary design, AE completed preliminary hydrologic and hydraulic analysis (documented as part of *Technical Memo #1*) which confirmed that the existing culvert is undersized for the design event. However, it was suspected that the increase in conveyance capacity offered by the new structure may not translate to significant reductions in floodplain extent or depths. In order to better quantify the potential benefits, a cost benefits analysis was completed as part of this work.

This technical memo (*Technical Memo #2*) characterizes the existing culvert; summarizes previous hydrologic and hydraulic analysis from *Technical Memo #1*; summarizes the findings from the Town's 2019 ice monitoring program; and provides an assessment of the ability for the replacement structure to alleviate localized flooding issues, supported by a cost-benefit analysis.

2 PROJECT LOCATION

The culvert is identified as Culvert RC RC2506 and conveys flows of Banks Creek. It is located on Cross Street between 7th Line and Kennedy Road, approximately 80 m south of 7th Line in the Town of Innisfil (Figure 1-1). Flows ultimately discharge 40 m downstream of the existing structure location into Lake Simcoe. The existing culvert is a single cell cast-in-place concrete box culvert with a hydraulic opening of approximately 4.5 x 1.5 m (6.75 m^2) with approximately 400 mm cover.

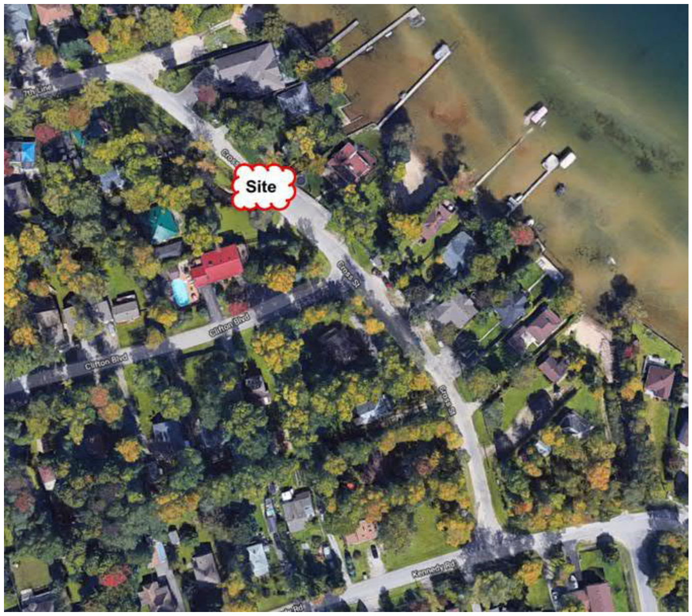


Figure 2-1: Site Location (Google Maps)

3 WATERSHED CHARACTERIZATION

The Cross St. culvert watershed is part of the Great Lakes – St. Lawrence primary watershed and part of the Black River – Lake Simcoe tertiary watershed. The watershed is approximately 912 ha with a mean watershed slope of approximately 3%. Land uses in the watershed include: agriculture and rural (56%), urban community (19%), treed/forested (14%), and other (11%).

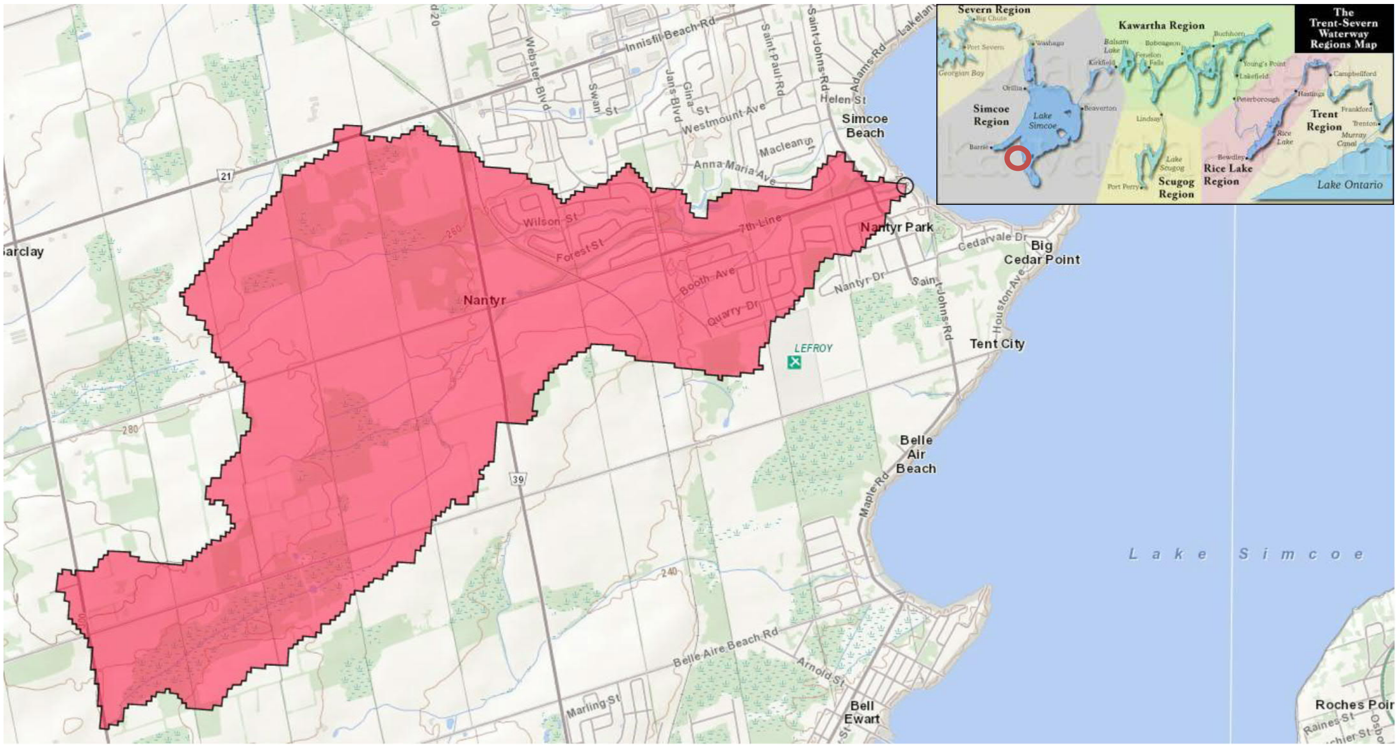


Figure 3-1: Cross Street culvert watershed
(image generated using OFAT; inset image from theTrentSevernWaterway.com)

4 LAKE SIMCOE

Cross Street culvert outlets to Lake Simcoe, which is part of the Trent-Severn Waterway. Lake Simcoe is a regulated waterbody part of the Trent-Severn Waterway. Water levels in the lake are managed to strike a balance between flood prevention, recreational use, and fish and wildlife habitats. Typically, Lake Simcoe water levels vary by about 0.4 to 0.5 metres during any given year. The highest levels usually occur between April and June and the lowest levels typically occur in late fall and winter. These outlet conditions influence the hydraulic performance, and subsequently the hydraulic design at Cross Street Culvert. The Waterway and its tributary lakes and rivers are controlled by Parks Canada in collaboration with Ontario Ministry of Natural Resources (OMNR), local conservation authorities (CAs), and hydro producers.

Lake Simcoe is the largest lake in the Trent-Severn system. A series of dams control water levels throughout the year to ensure adequate water supply for recreational and hydro-power production and to mitigate against flooding and optimize public safety throughout the interconnected system, the water levels are lowered (drawdown) mid-summer to make room for anticipated high spring-time flows. Water levels are monitored using a system of water level gauges. Furthermore, Parks Canada uses a "rule curve," to manage the lowering of water levels in Lake Simcoe to provide storage for future precipitation. Figure 4-1 shows data from the Lake Simcoe water level gauge and operating rule curve.

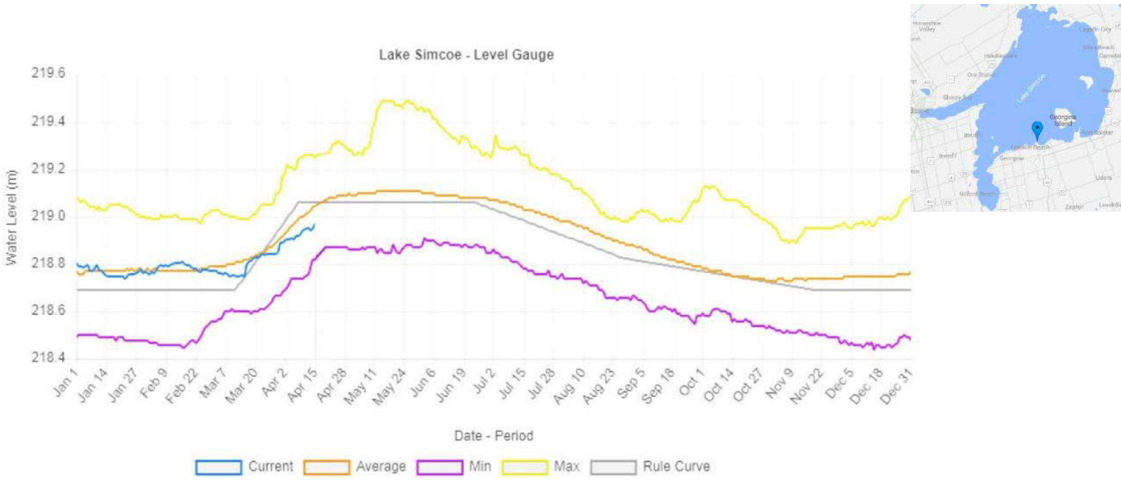


Figure 4-1: Lake Simcoe (water level gauge
(data provided by Parks Canada, current as of April 18, 2019;
inset figure of gauge location from Parks Canada)

5 EXISTING REGULATORY FLOODPLAIN LIMIT

Figure 5-1 indicates that approximately ten (10) houses are within the existing LSRCA regulatory floodplain. The four (4) houses in the immediate vicinity of the culvert (1779, 1784, 1787, and 1790 Cross St.) are of particular interest in this study since they are most affected by the constriction at the culvert location during smaller events. This floodplain was used for informational purposes only, as it was unclear as to the modeling assumptions made and boundary conditions used to generate this map.

Figure 5-1: Existing Regulatory Floodplain Limits as per LSRCA (2018)

6 PREVIOUS ENVIRONMENTAL ASSESSMENT (EA)

An EA was completed in 2008 (by others) which evaluated various options for improving the flooding at Cross Street. The results of the EA indicated the preferred alternative for addressing flooding issues at this location was to increase the conveyance capacity of the existing structure. The EA recommended replacing the existing culvert with a larger concrete box culvert structure to accommodate higher flows. Therefore, a hydrology and hydraulics analysis was completed for three (3) options that would increase the culvert conveyance capacity of the existing culvert, without significant changes to the road grade.

7 DESIGN CRITERIA

The design criteria and hydraulics evaluation of three (3) different structures was completed as part of a separate deliverable: *Technical Memo #1: Drainage and Hydrology*. Table 9-1 summarizes the findings of Technical Memo #1. From the preliminary analysis it was determined that a 6000 x 1900 closed bottom concrete box culvert was the preferred (of three (3)) alternatives and was therefore carried forward to form the analysis in this memo. Furthermore, it was determined that the 10-Year is the design storm, which forms the basis for the benefits analysis as presented in this memo. Please see Technical Memo #1 for additional details.

8 HYDROLOGY

Three (3) non-hydrographic statistical hydrological estimation methods (Northern Ontario Hydrology Method; Modified Index Flood Method; and Primary Multiple Regression Model) were used to estimate flow rates for the culvert location and compared with results of three (3) previous hydrological studies (Previous hydrology report (as part of the previous EA completed in 2007); flows as per LSRCA HEC-RAS model; and flows as per Alcona South Master Drainage Plan (C.C. Tatham & Associates, 2018).

The statistical analysis methods are well-documented and widely accepted methods of flow estimation in the hydrologic community. The use of three (3) methods helps provide confidence in the results and offers a comparative, conservative flow estimation for design purposes. The results of these analyses are shown in the table below and are compared with the flows provided in the previous hydrology report (as part of the previous EA), flows as estimated in the Alcona South Master Drainage Plan, as well as the flows already in the existing LSRCA HEC-RAS model. The most conservative 10-Year flow estimate was selected.

8.1 Climate Change Considerations

The magnitude and frequency of extreme events is increasing across Canada, and around the world, having a formidable impact on our infrastructure, environment, and our communities. Therefore, as part of this work, a climate change sensitivity analysis was completed using the MTO IDF Curve Tool. This analysis revealed that rainfall intensities may increase 6% (based on the 10-Year, 2-hour rainfall intensity) by 2070 (50-Years from an assumed completion date of 2020) to approximate the design service period. If we were to conservatively extrapolate that a 6% increase in intensity reflects an 6% increase in runoff volumes, then the conservative 10-Year climate change influenced design flow estimate would be 12.2 m^3/s. This is the climate change influenced flow estimate used in the subsequent hydraulic and cost-benefit analysis.

8.2 Ice Considerations

Cross Street culvert outlets to Lake Simcoe, which is a large waterbody that freezes during the winter. Ice can be a major contributor to flooding conditions, particularly at waterway constrictions such as bridges and culverts. There is the potential for ice to develop in and around the culvert during ice formation processes and the culvert may also be affected by ice floes and jams during springtime ice breakup. Icing conditions and the impact of ice was not considered as part of the original EA for the replacement of this culvert, so the Town undertook their own ice monitoring study in the winter of 2018-2019. Appendix A describes a few basic ice characterizations and summarizes the findings of the Town's 2019 (visual) ice inspections. Based on these observations, the Town decided that design for ice conditions was not required. However, it should be noted that a single year of observational data does not mean that Cross Street culvert does not experience some degree of ice jams or ice-induced flooding. Due to the culvert's proximity to Lake Simcoe, it is recommended that regular winter ice observations and/or monitoring are conducted.

9 HYDRAULICS

Using the conservative flow estimates from the hydrologic analysis, hydraulic analysis was completed using both:

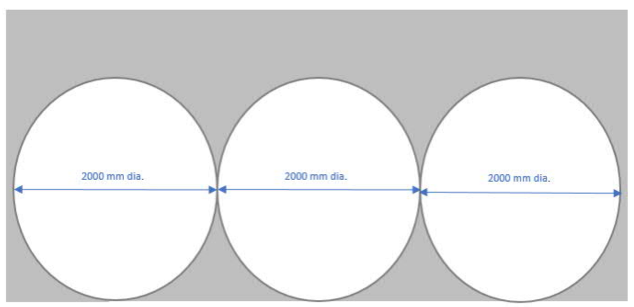
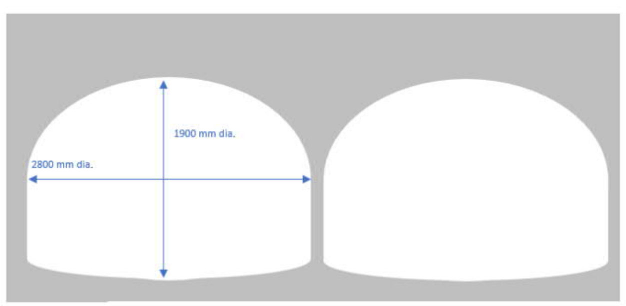
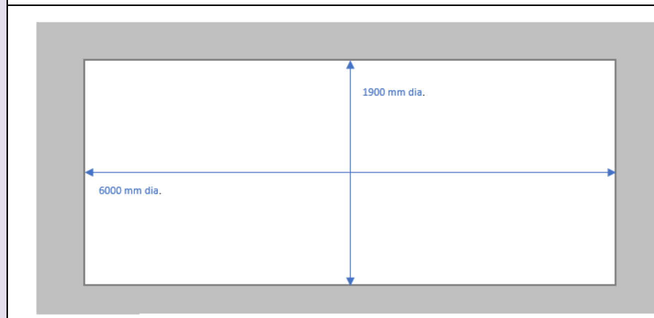
1) HY-8 culvert analysis software (preliminary); and
2) HEC-RAS.

Hydraulic analysis was completed for the existing culvert and three (3) proposed design alternatives using HY-8 hydraulic modeling software. The three (3) alternatives were as follows:

- Three (3) 2000 diameter circular CSP culverts with headwall and wingwalls;
- Twin (2) 2800 x 1900 CSP pipe arch culverts with headwall and wingwalls; and
- Single (1) 6000 x 1900 closed bottom concrete box culvert with headwall and wingwalls.

The analysis was run considering both inlet and outlet-controlled conditions. The results of the hydraulic analysis is provided in Table 9-1, below. Note that none of the proposed alternatives would be able to meet Relief Flow criteria considering the Hazel storm. Designing to this level of service would not be practical and therefore, Table 9-1 refers to satisfying relief flow as it pertains to only the 100-Year storm. From the HY-8 hydraulics analysis, it was determined that a **closed bottom concrete box culvert** was the preferred alternative due to enhanced hydraulics, debris, fish, and ice passage. This alternative was then compared to the performance of the existing culvert using a HEC-RAS model.

Table 9-1: Hydraulic properties for the existing culvert and three (3) proposed design alternatives

	Photo / Conceptual Schematic (not to scale)	Description	Total Area of Hydraulic Opening[1] (m^2)	Design Flow	Meets Design Criteria? Freeboard and Clearance	Relief Flow[2]	Fish Passage	Icing	Temporary Flow Passage
Existing Culvert		Existing 4500 x 1500 concrete box culvert with headwall and downstream wingwalls	6.75	No	No	No	Unknown	No	N/A
Proposed Alternatives		Three (2000) circular CSP culverts with headwall and downstream wingwalls	9.4	Yes	Possible	Yes	Possible, with fish baffles and constructed pools	Less favourable	TBD
		Twin (2800 x 1900) CSP pipe arch culvert with headwall and downstream wingwalls	9.0	Yes	Possible	Yes	Possible, with embedment	Less favourable	TBD
		Closed bottom (6000 x 1900) concrete box culvert with headwall and downstream wingwalls	11.4	Yes	Yes	Yes	Possible, with embedment	Possibly with energy dissipater. Preferred alternative for ice design.	TBD

[1] Not including embedment depths
[2] Considering the 100-Year storm

A 1-D model of the riverine system was created in HEC-RAS, which is described in more detail in the following sections.

9.1 HEC-RAS Model

The HEC-RAS RAS Mapper tool was used for spatial and visual representation and preparation of the hydraulic modeling data. The HEC-RAS model was georeferenced to the projection NAD 83 UTM 17. Geometries (cross sections) were derived from AE bathymetric and topographic survey, supplemented by South Central Ontario Orthophotography Project (SCOOP) 2013 terrain data (produced by MNRF in-house Mapping and Geomatics Services Section from the Classified LAS product; retrieved from Land Information Ontario, 2019). River centreline and banks were approximated considering AE's bathymetric survey. A visualization of the hydraulic model in RAS Mapper is provided in Figure 9-1. Ineffective flow areas were specified upstream and downstream of the existing culvert structure.

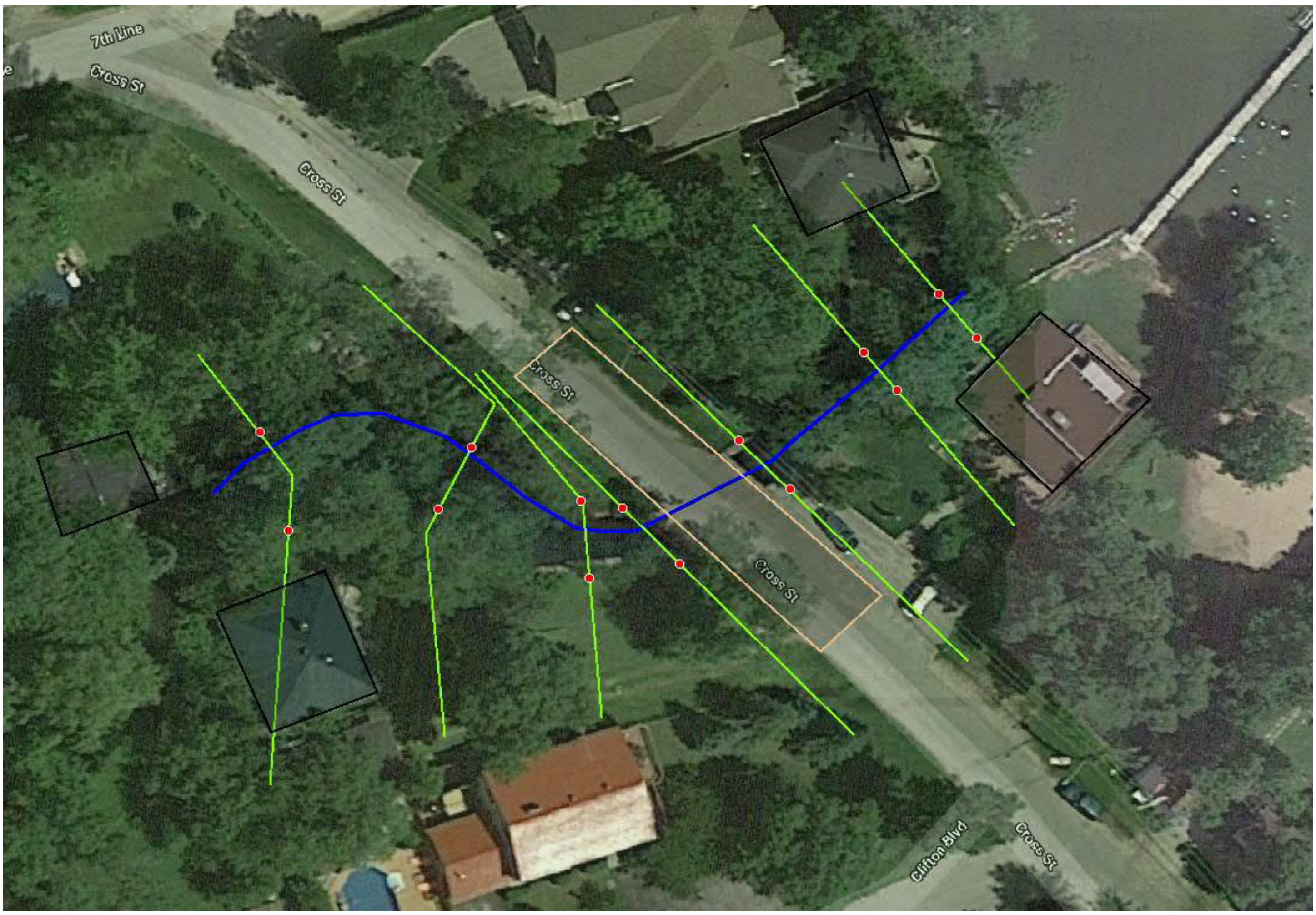


Figure 9-1: plan view of Cross St. culvert crossing and geometry (river centreline, flow paths, banks, and cross sections) in HEC-RAS RAS Mapper

9.2 Model Development

Model parameters include:

Manning's n: which is used by the program to evaluate friction losses and depends on multiple factors such as surface roughness; vegetation; suspended materials; and the shape and size of the channel. The following Manning's numbers (originally from Chow's *Open Channel Hydraulics*, 1959) were used in the model:

Overbanks; parks and lawns (0.040)
Upstream main channel; clean, straight, full stage, no rifts or deep pools with some stones and weeds (0.035)

Contraction and expansion coefficients: which are used by the program to evaluate transition (contraction and expansion) losses between cross sections. When changes in the cross section happens abruptly, such as at a culvert, these transition losses are typically greater than the losses between typical cross sections. As such, the following coefficients were used in the model:

Typical cross section: contraction (0.1); expansion (0.3)
Culvert cross section: contraction (0.3); expansion (0.5)

Ineffective flow areas: which are used by the program to indicate areas of flow which are not actively being conveyed (for example, to define areas of ponding). There were two (2) ineffective flow areas defined in the model; one (1) in the cross section immediately upstream of the culvert, and one immediately downstream of the culvert. These two (2) ineffective sections were set to the low roadway crown elevation in both upstream and downstream sections.

9.3 Model Flows

Model flows were simulated in steady state as per the results of the hydrologic analysis, summarized in Table 9-2, below.

Table 9-2: Flows profiles

Return	Description	Flow (m^3/s)
2-Year	Fish Passage Design	6.9
10-Year	Design Flow	11.5
10-Year + CC	Design Flow + CC	12.2
100-Year	Check Flow	17.2

9.4 Boundary Conditions Sensitivity Analysis

It is important to note that the hydraulic performance of any culvert at this location is highly dependent upon the water levels in Lake Simcoe. Since Lake Simcoe is managed as part of the Trent-Severn Waterway, there are periods – particularly during the spring and summer – where lake levels will be high, and the culvert will be under outlet control. Therefore, in order to help determine the potential levels of protection provided by the proposed culvert alternative, a sensitivity analysis was performed in HEC-RAS to estimate water levels under four (4) different boundary conditions. Boundary conditions were based on data from the Parks Canada Lake Simcoe level gauge (Figure 4-1) as follows:

A. **Low water level:** this scenario represents low water levels in the lake during the winter, and a subsequent springtime rain event. In this case, the model boundary conditions reflect the Minimum water level during the wintertime of 218.4 m.
B. **Average water level:** this scenario represents average water levels in the lake during the winter, and a subsequent springtime rain event. In this case, the model boundary conditions reflect the Average water level during the wintertime of 218.8 m. This scenario aligns closely to the Lake Simcoe rule curve.
C. **High water level:** this scenario represents a case where water levels in the lake were high, and a subsequent springtime rain event. In this case, the model boundary conditions reflect the Maximum water level during the springtime of 219.1 m.
D. **Extreme water level:** this scenario represents a "worst case" where water levels in the lake are at a maximum during the spring, with a subsequent rainfall event. In this case, the model boundary conditions downstream reflect the Maximum Max water level of 219.5 m.

The results of the sensitivity analysis revealed that the downstream boundary condition (lake level) does not greatly influence flood extents upstream of the structure until the lake level elevations approach the culvert soffit elevation. Under most of the design flow scenarios, the culvert is governed by inlet flow. This was confirmed with HY-8 modeling, the results of which are provided in Appendix C.

Scenario C (high water level) was used for the purposes of floodplain mapping and cost-benefit analysis.

9.5 Floodplain Analysis

Inundation mapping was completed using HEC-RAS's built in RAS Mapper tool. The map was used to determine which building(s) would be flooded under each of the design storms. Furthermore, building elevations, floodplain depths, and stage-damage curves were then used to estimate flood damages under existing conditions (baseline) to compare with estimated damages averted with the proposed structure which formed part of the benefits analysis. The existing and proposed floodplains for the design scenario (Scenario C; 10-Yr+CC) can be seen in Figure 9-2, below. Table 9-3 provides a comparison of the elevations between the existing and proposed scenarios near the culvert.

Table 9-3: Existing vs. proposed elevations at select model cross sections

Cross Section	Existing (m) (10-Year + CC)	Proposed (m) (10-Year + CC)	Difference (m)
89 (d/s of culvert)	219.29	219.24	0.05
110 (culvert)	219.86	219.24	0.62
134 (u/s of culvert)	219.91	219.44	0.47
273	219.92	219.77	0.14

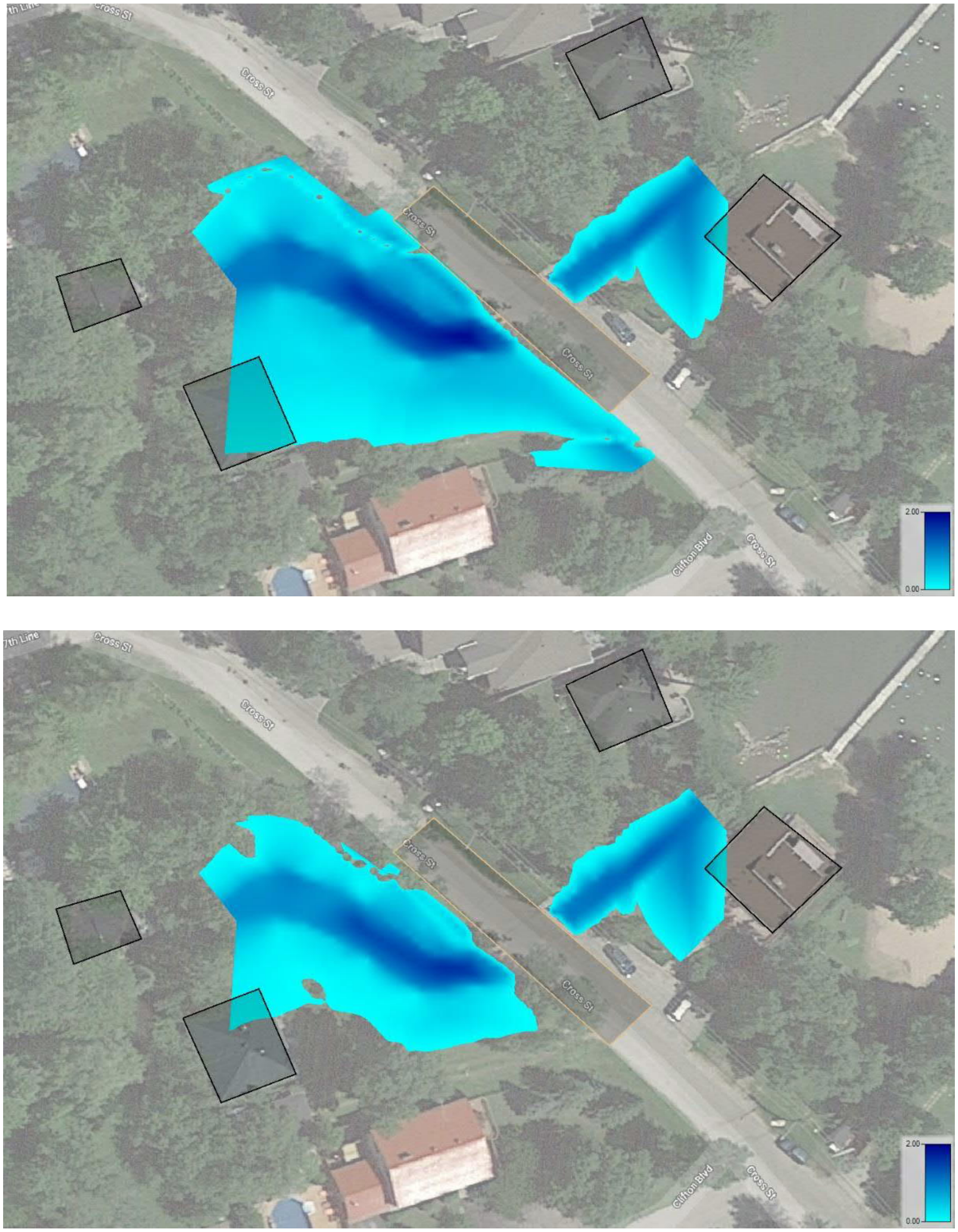


Figure 9-2: approximate floodplain for (a) existing; and (b) proposed conditions (not to be used for regulatory or other purposes)

9.6 Benefits Analysis

A high-level benefits analysis was performed to estimate the value which could be provided by replacing the existing structure. Benefit was assessed as the amount of *direct damages averted* (difference between existing damages and proposed damages) to properties immediately upstream and downstream of the structure. Inundation maps were generated per the results of the HEC-RAS simulations; building elevations for the parcels immediately upstream and downstream of the culvert were per the findings of AE's survey; and since no local stage-damage curves were available, curves were obtained from the flooding module of the HAZUS (Federal Emergency Management Agency (FEMA)) model shown in Appendix B. For the benefits analysis, the following assumptions were made:

- Buildings at 1790 Cross St. (u/s) and 1787 Cross St. (d/s) were assumed to have functional, finished basements and buildings 1784 Cross St. (u/s) and 1779 Cross St. (d/s) were assumed not to have basements; and thus, two (2) buildings used stage-damage curves for residential buildings *with* basements (HAZUS curve for residential SL w/bsmt) and two (2) buildings used stage-damage curves for residential buildings *without* basements (HAZUS curve for residential 1 FL no bsmt) – these curves can be found in Appendix B;
- Houses were assumed to be slab on grade;
- Replacement value of the existing structures was based on MPAC assessment values (note: this data is confidential and values cannot be explicitly published in this report);
- MPAC assessment date is unknown and therefore assessment values may be outdated;
- Content damages were estimated as per the content depth-damage curves provided in Appendix B;
- Values of all house contents were assumed to be 60% of the structure replacement value;
- Two (2) homes were surveyed for elevation and for the other two (2) homes elevation was assumed;
- The lowest surveyed elevation for each building was assumed to be representative of the 1st floor elevation;
- Highest depth of water intersecting the building footprint was used as the stage value to estimate damages;
- No flood warning was provided to residents;
- Damage due to scour of the channel was not estimated, though the meandering of this creek suggests that stream migration may be possible which would have additional consequences in addition to the migration of the floodplain;
- This analysis considers only *direct structural and contents damages averted* and does not account for any other loss types. A non-exhaustive list of additional types of damage may include indirect damages, social, environmental, consequential losses, economic, road damage, or third-party utilities.

These assumptions may lead to the potential over-estimation of direct structural (and contents) damages, but due to the shape of the stage-damage curves, suggest this assumption would capture the maximum possible structural benefits provided by the proposed structure.

A summary of the results of the benefits analysis is provided in Table 9-4.

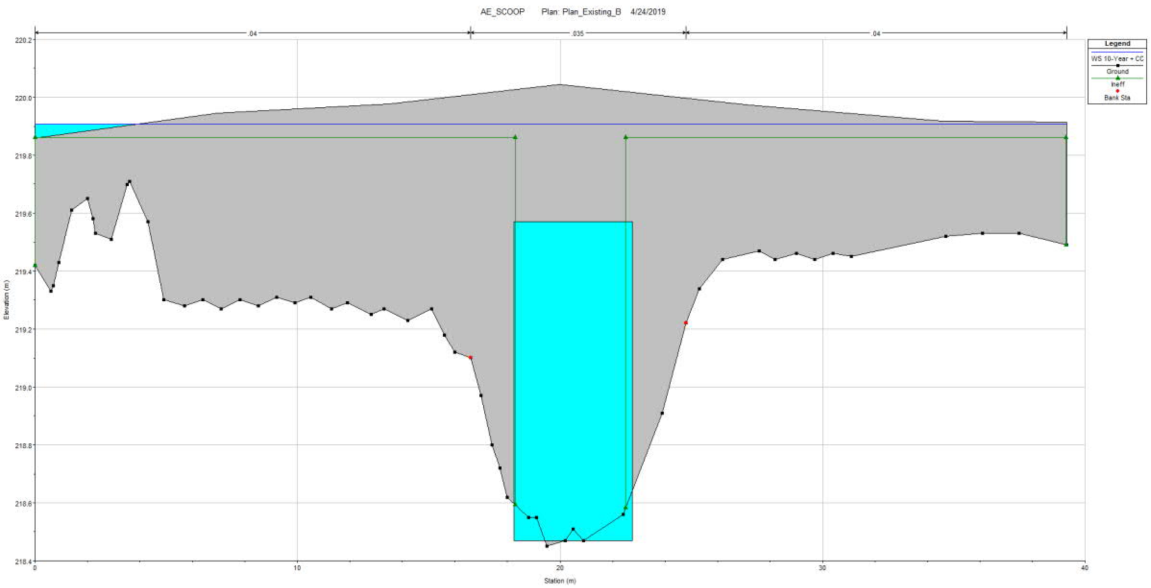


Figure 9-3: Existing 10Yr+CC (average lake water levels)

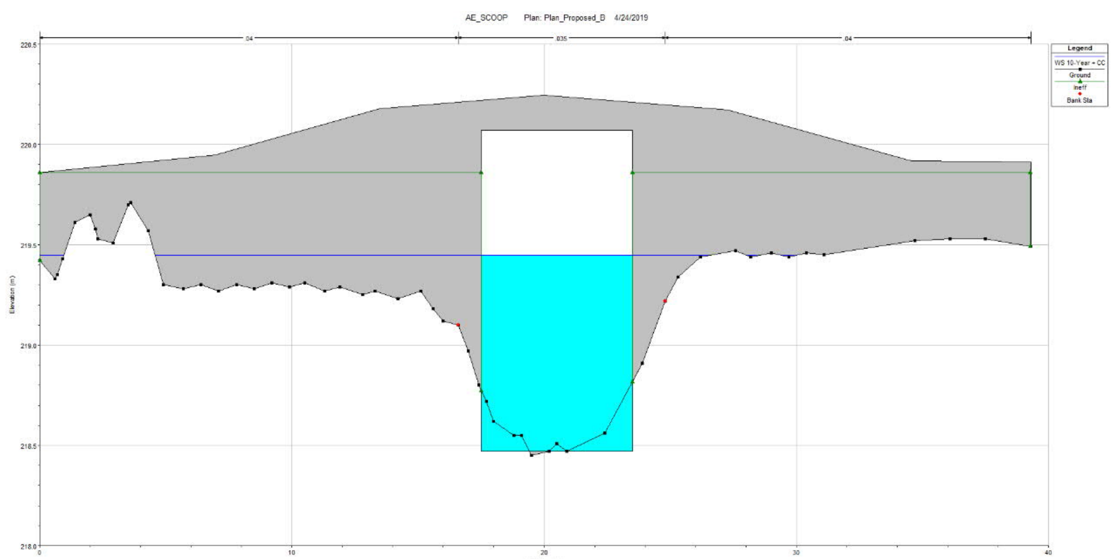
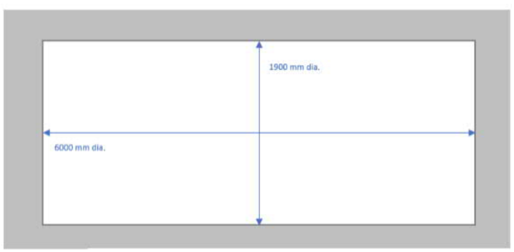


Figure 9-4: Proposed 10Yr+CC (average lake water levels)

Table 9-4: Hydraulic modeling scenarios, results, and summary of benefits analysis for design storm (10-Year + CC)

			Scenario C (High lake levels)
		Design Flow	10-Yr+CC
		Downstream Boundary Condition: Water Surface Elevation (m)	219.1
Existing	 4500 x 1100 concrete box culvert with headwall and downstream wingwalls	Water surface elevation at culvert (u/s)	219.9
		Depth at four (4) selected locations:	
		1784 Cross St. (u/s)	3 cm
		1790 Cross St. (u/s)	28 cm
		1779 Cross St. (d/s)	3 cm
		1787 Cross St. (d/s)	0 cm
		Estimated damages to all structures ($) (structure + contents)	$491,000
Proposed Alternative	 Closed bottom (6000 x 1900) concrete box culvert with headwall and downstream wingwalls	Water surface elevation at culvert (u/s):	219.5
		Depth at four (4) selected locations:	
		1784 Cross St. (u/s)	0 cm
		1790 Cross St. (u/s)	14 cm
		1779 Cross St. (d/s)	2 cm
		1787 Cross St. (d/s)	0 cm
		Estimated damages to all structures ($) (structure + contents)	$487,000
		Estimated Damages Averted (damages existing – damages proposed)	$4,000

10 RESULTS & DISCUSSION

A larger culvert at Cross Street would provide additional conveyance capacity, would provide improved hydraulics for the passage of debris and ice, and could help this crossing meet design criteria. However, based on the above information, during high and extreme water levels in Lake Simcoe, the floodplain benefits provided by the increased capacity of the proposed design alternative would be minimal. The damages averted were estimated to be approximately $4,000 for the design storm. The preliminary Class C cost estimate for replacing the structure (not including required property acquisitions or easements) is estimated to be about $802,500. Therefore, the benefit-cost ratio is low (a ratio of approximately 1:200) indicating that the new culvert would not likely provide a high cost-benefit for reduction of flood damages. Important to note, however, is that the current benefits estimate is event-based and not based on design life (or remaining design life) and does not factor in other considerations such as: inconveniences, indirect losses, expected level of service, or other impacts including those listed in section 9.6. Due to low cost-benefit ratio, if the Town decides to proceed with this design alternative, it is recommended to wait until the lifespan of the culvert has been reached and re-evaluate the culvert replacement option at that time.

11 WAY FORWARD

Based on the above analyses, the following is recommended:

- The Town implement a winter ice monitoring program to continue to monitor winter freeze and break-up patterns at the Cross Street culvert location to confirm whether flooding results from ice impacts;
- The Town maintain a detailed record of localized flooding complaints which may include, but is not limited to: complainant name, address, date of flood event, depth of water, damages (if available);
- The analysis reveals that the replacement of Cross Street culvert with a larger (6000 x 1900) structure would not provide high cost-benefit to the Town and would only provide minimal improvements to reduce flooding impacts to houses immediately upstream and downstream of the structure for the design storm. This analysis, however, did not consider indirect damages (such as emergency response or traffic disruptions) or intangible impacts (such as inconvenience to homeowners or issues associated with accessibility). With this in mind, the Town may wish to reopen the EA to consider additional alternatives which may offer a higher cost-benefit ratio to alleviate flooding of the nearby properties.

Furthermore, the current regulatory floodplain limits extend to cover a large area; it may be prudent to enforce minimum building elevations for habitable living areas.

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AP	**SM**	**AW**

APPENDIX A – TOWN OF INNISFIL ICE MONITORING WINTER 2018-2019

Introduction

Typically, ice-related problems occur during ice break-up, rather than by ice freeze-up. Studies and experience have shown that flowing ice forces may vary due to site conditions, flow rates, ice thickness, and weather conditions prior to breakup (including temperature, sunlight, and precipitation).

According to Canadian Standard Association Manual, CAN3-S6-M78, Ice Forces, and the Ontario Highway Bridge Design Code, break-up ice conditions in a stream may be categorized as one of the following:

1. Break-up occurs at melting temperatures and ice flows in small cakes and its structure is substantially disintegrated.
2. Break-up occurs at melting temperatures, however, ice moves in large pieces and is internally sound.
3. Break-up and ice movement occurs in a single sheet or large sheets of ice.
4. Break-up occurs with ice temperature significantly below the melting point and the movement of ice is predominantly in the form of single or very large ice sheets

These types of break-up conditions lead to the formation and movement of various types of ice, which may include the following:

Frazil Ice

Frazil ice forms throughout the flow depth of supercooled turbulent water. This type of ice is very adhesive and frazil ice flocs stick together to form frazil ice slush. Oftentimes frazil ice formations are most evident in waterway constrictions such as bridges and culverts. When frazil ice particles freeze together on the gravel of the river bed, it can result in anchor ice, further constricting flow and preventing fish passage.

Extreme nighttime cold temperatures can increase the likelihood of frazil ice formation which can compound flooding issues. The formation of the slushie-like ice can increase the risk of ice jams, increasing the risk of more severe flooding when a snowmelt event occurs.

Surface (Border) Ice

This type of ice is typically the first to form along the banks of a river where velocities are low. The ice forms vertically and horizontally towards the middle of the stream.

Aufeis Ice

Aufeis ice forms when ice forms on top of ice, such as when a waterway's stream flow freezes layer upon layer over the course of the winter. This is one of the most common icing issues in culverts, and hence this ice formation is also often referred to as "culvert ice". Circular and pipe-arch metal culverts and box-type concrete carry small depths of flow in the winter that often the entire depth of flow is frozen. If flow continues from upstream, it must pass over the ice already formed, and it is liable to become frozen solid in the same way. In this way, the ice builds upward, layer by layer, and restricts the size of the culvert cross-section. This type of ice formation can lead to reductions in culvert capacity and ultimately lead to culvert washouts.

Spring 2019 Town of Innisfil Ice Monitoring

Given the historic ice-related flooding issues in the Cross Street culvert area, ice impacts and hydraulic restrictions due to ice formation were monitored in the spring of 2019 by Town of Innisfil Public Works Department. During this time, the Town took photos and visually monitored the formation and breakup of ice. To supplement the qualitative analysis completed by the Town, a compilation of maximum and minimum temperatures (recorded at nearby Environment Canada Shanty Bay station) and corresponding field data (photos) collected during this period is provided in Figure A-1 to help characterize ice break up characteristics.

Based on the available information, it appears that Lake Simcoe freezes back up to the Cross Street culvert, which remains frozen for most of the winter season. During the springtime, the surface ice broke up and thawed within the span of a couple of days. During this time, visual inspections were completed, and photos were collected. No flow data was recorded during the monitoring period, and no measurements were made. During the monitoring period border and frazil ice were observed, but no ice jams occurred during breakup. However, even though an ice jam was not observed during the Town's spring 2019 ice observations, doesn't mean that ice jams do not happen, and does not mean they will not occur in the future. Estimating the effects of such jams on a flood of a given magnitude is not a simple problem. Significant field reconnaissance is required as guidelines (such as the O*MNR's Technical Guide to Flood Hazard Limit*; the *MTO Drainage Management Manual*; and *New Brunswick's River Ice Manual*) recommend estimates should be based on field data and the history of jams at a specific site, considering local factors. As such, one (1) year's worth of qualitative data is not sufficient to make a definitive assessment as to whether ice is a significant contributor to the flooding at Cross Street culvert, however at this time it was agreed upon by AE and the Town that icing conditions would not be further considered in the hydraulic analysis.

However, if at a future date additional information is available that indicates ice is a major contributor to flooding conditions at Cross Street culvert, it's suggested that (1) a winter ice monitoring program be implemented; and (2) external energy dissipaters be investigated as a potential solution to control the formation and break up of ice at the culvert. Bubbler de-icing systems have had success in preventing ice formation on dock piers and have applications in de-icing water intakes in the Great Lakes.

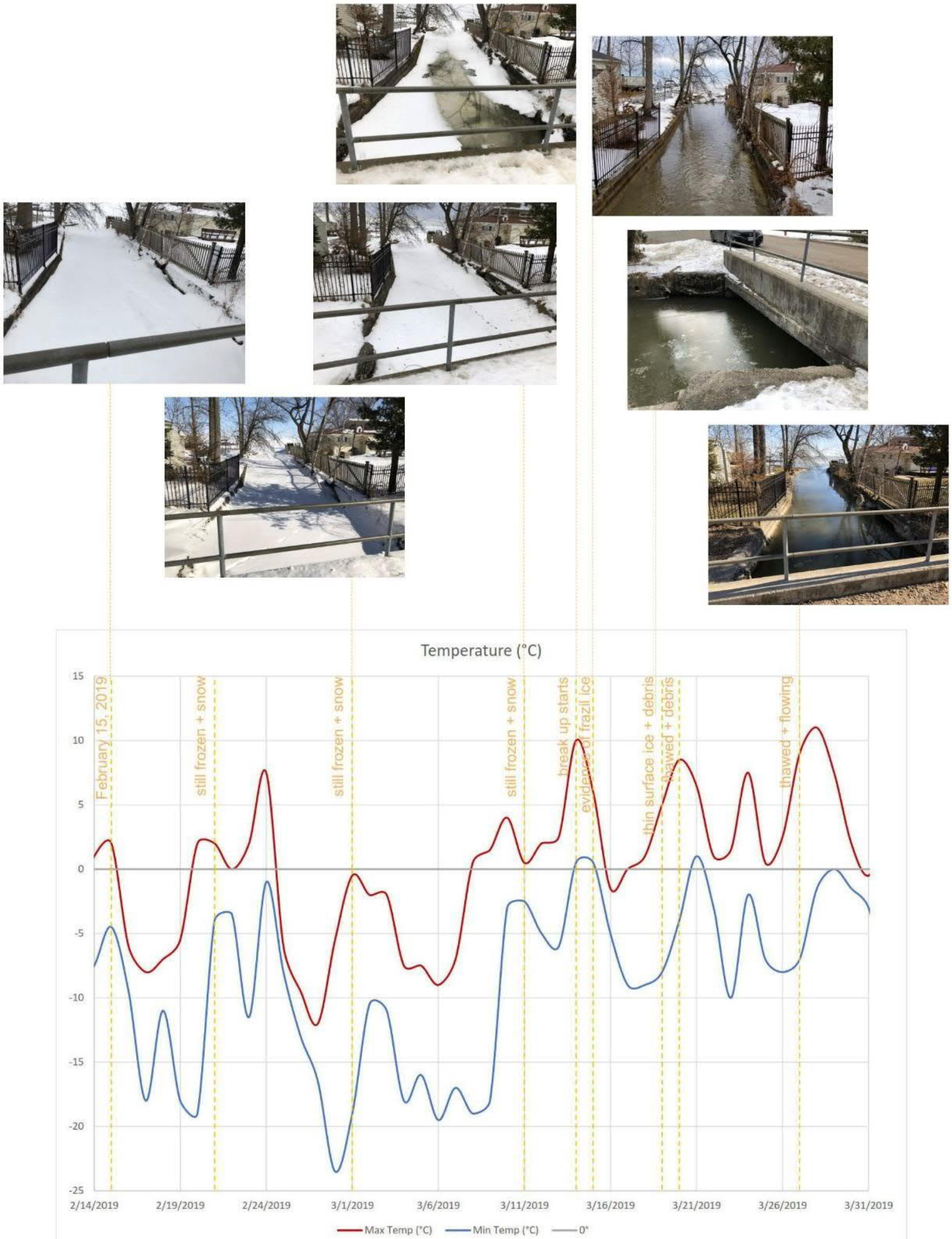


Figure A-1: Ice break up in Spring 2019
(temperature data from Environment Canada Shanty Bay station; photos from Town of Innisfil)

APPENDIX B – STAGE DAMAGE CURVES

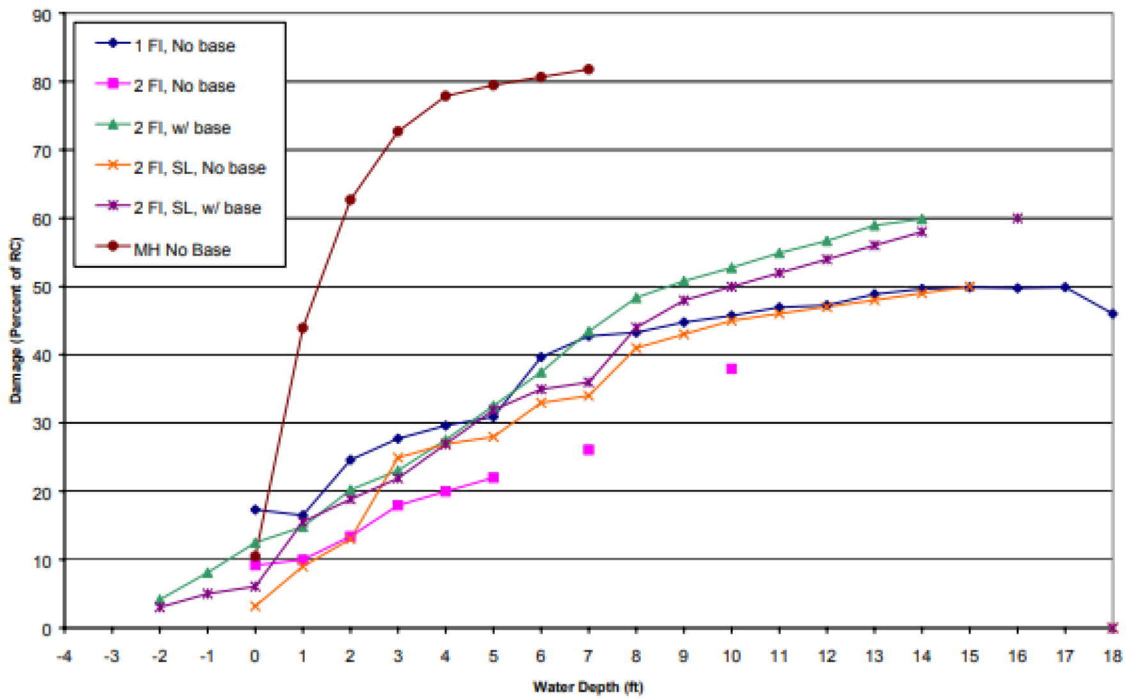


Figure 5.2 FIA Credibility-Weighted Building Depth-Damage Curves as of 12/31/1998

Figure B-1: Building depth-damage curves, HAZUS

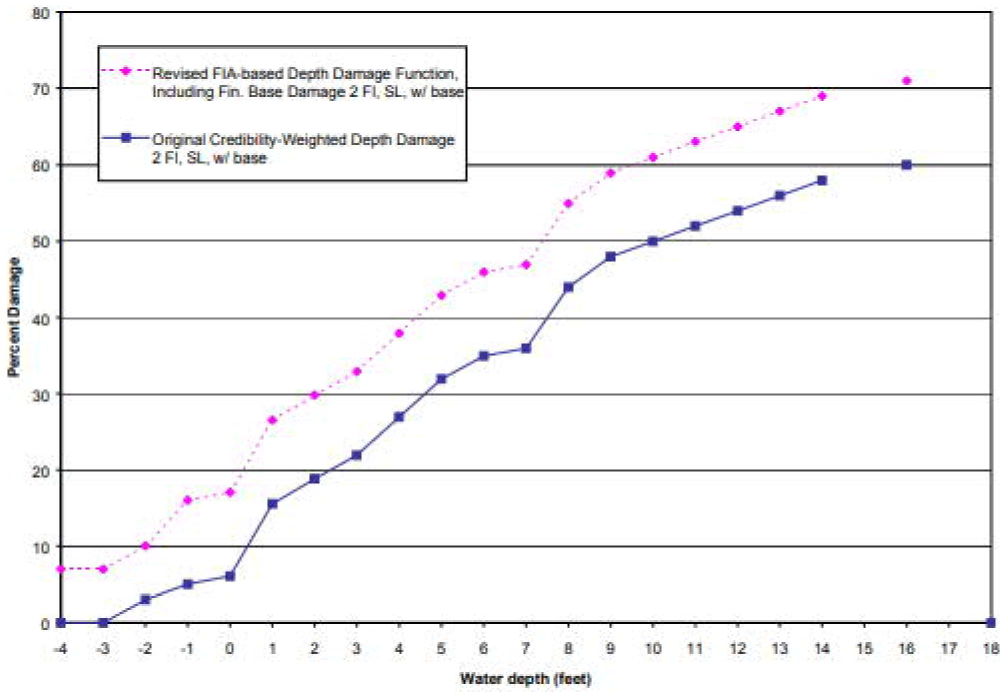


Figure 5.4 FIA-Based Structure Depth-Damage Curve Split Level, Basement-Modified

Figure B-2: Residential depth-damage curve, HAZUS

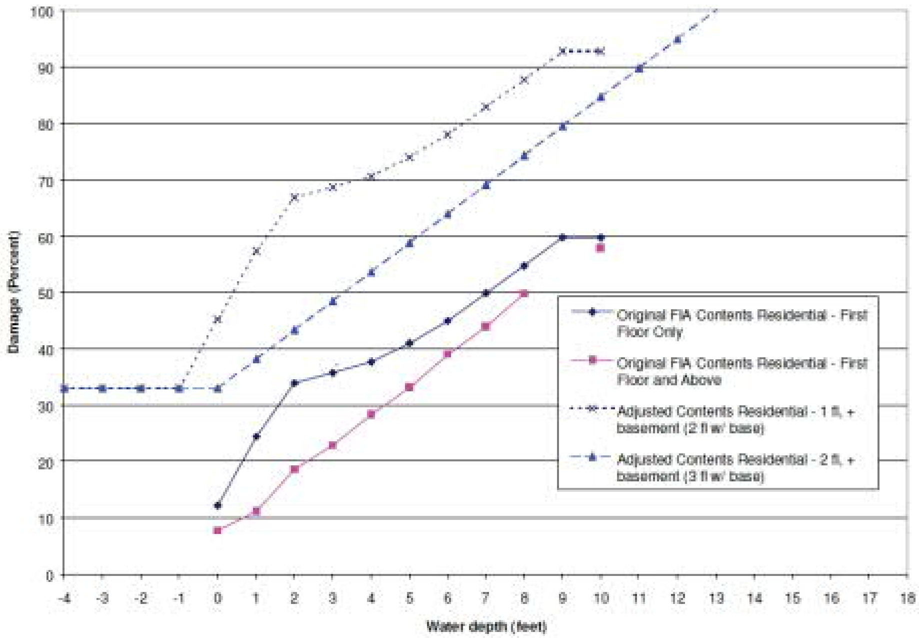
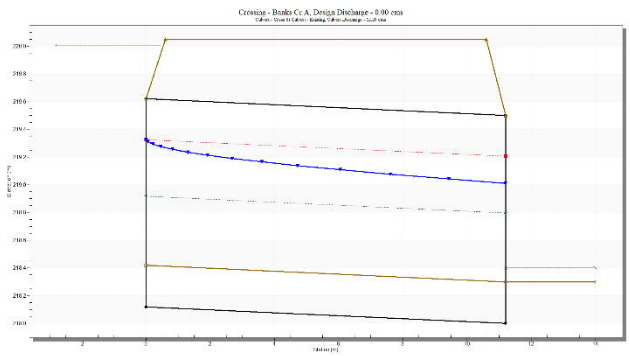


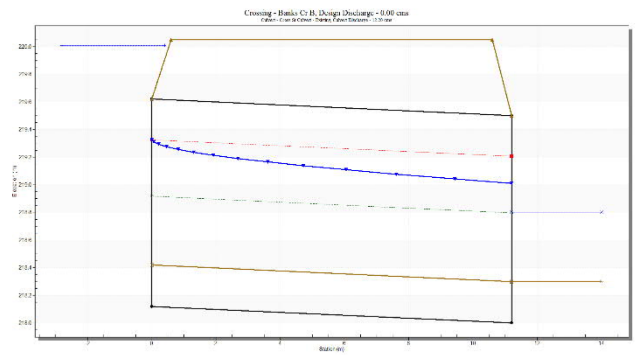
Figure B-3: Depth-damage curves for residential building contents, HAZUS

APPENDIX C – HY-8 HYDRAULIC MODELLING RESULTS

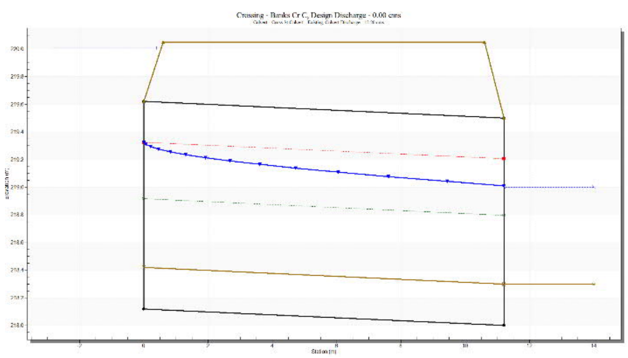
(a)



(b)



(c)



(d)

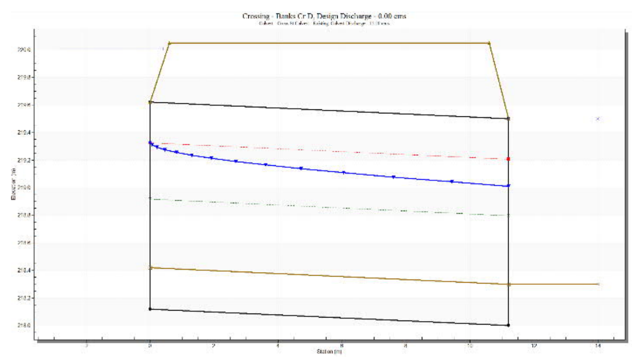
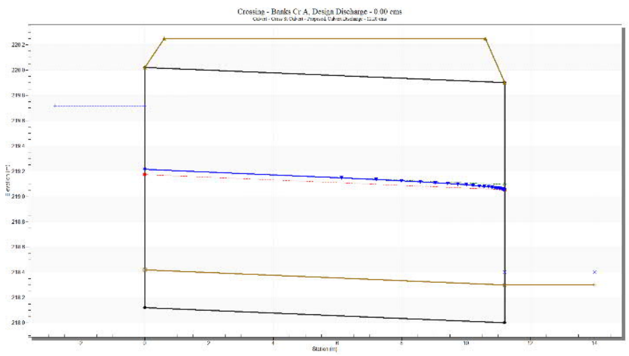


Figure C-1: Existing culvert sensitivity analysis for various lake levels in HY-8 for the design storm (10Yr+CC)
(a) Scenario A (low); (b) Scenario B (average);
(c) Scenario C (high); (d) Scenario D (extreme)

(a)



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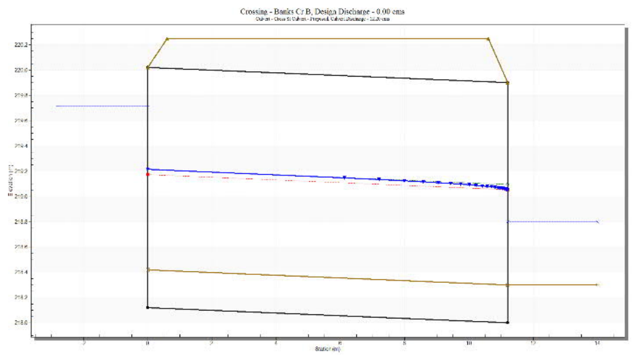
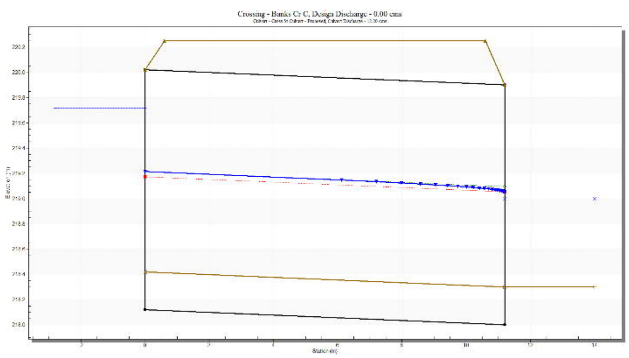


(c)



(d)

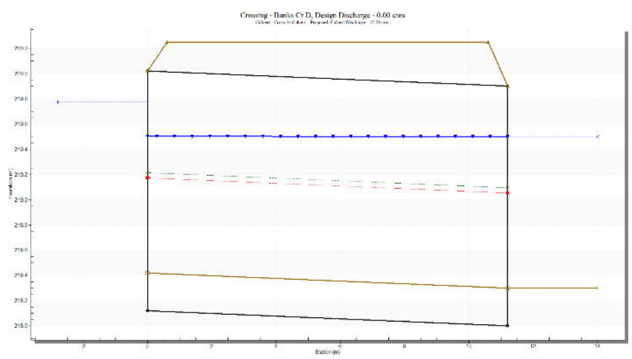


Figure C-2: Proposed culvert sensitivity analysis for various lake levels in HY-8 for the design storm (10Yr+CC)
(a) Scenario A (low); (b) Scenario B (average);
(c) Scenario C (high); (d) Scenario D (extreme)