Appendix ‘I’ – Hydraulic Assessment

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PROFESSIONAL ENGINEERS

Memorandum

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To:	Jack Turner, GM BluePlan Simon Green, GM BluePlan	**Date:**	May 11, 2021
From:	Chris Moon, ERI (Reviewer) Robert Chlumsky, ERI (Original) Brad Dickieson, ERI (Revisions)	**ERI Project No.:**	2012
Project:	City of Brantford Three Grand River Crossings EA		
Re:	Hydraulic Modelling Methodology and Results		

1. Introduction

The City of Brantford has retained GM BluePlan to complete a Schedule B' Municipal Class Environmental Assessment (EA) for three bridges over the Grand River. These three crossings are the Lorne Bridge, Brant's Crossing Bridge also referred to as the CN Railway bridge , and the TH&B Crossing Bridge, all located in series over the Grand River in Brantford, ON. Ecosystem Recovery Inc (ERI) has been retained to undertake the hydraulic assessment of these structures in support of the EA.

Following the flooding and ice jam event of February 2018, the crossings have each been identified as requiring some degree of structural repairs. Brant's Crossing Bridge was closed in 2018 following the ice jam event and subsequent inspection. This Environmental Assessment is intended to identify long and short term plans for the three crossings, including the potential to remove the current winter load limit on the Lorne Bridge, and the need for the other two crossings, which both serve as pedestrian crossings.

The hydraulic assessment will be used to confirm flood elevations and evaluate the structures against the Ministry of Transportation Ontario (MTO) and City standards. Opportunities to enhance the hydraulic function of each crossing are discussed.

The location of the three bridge crossings within the proposed study area are provided in **Figure 1**.

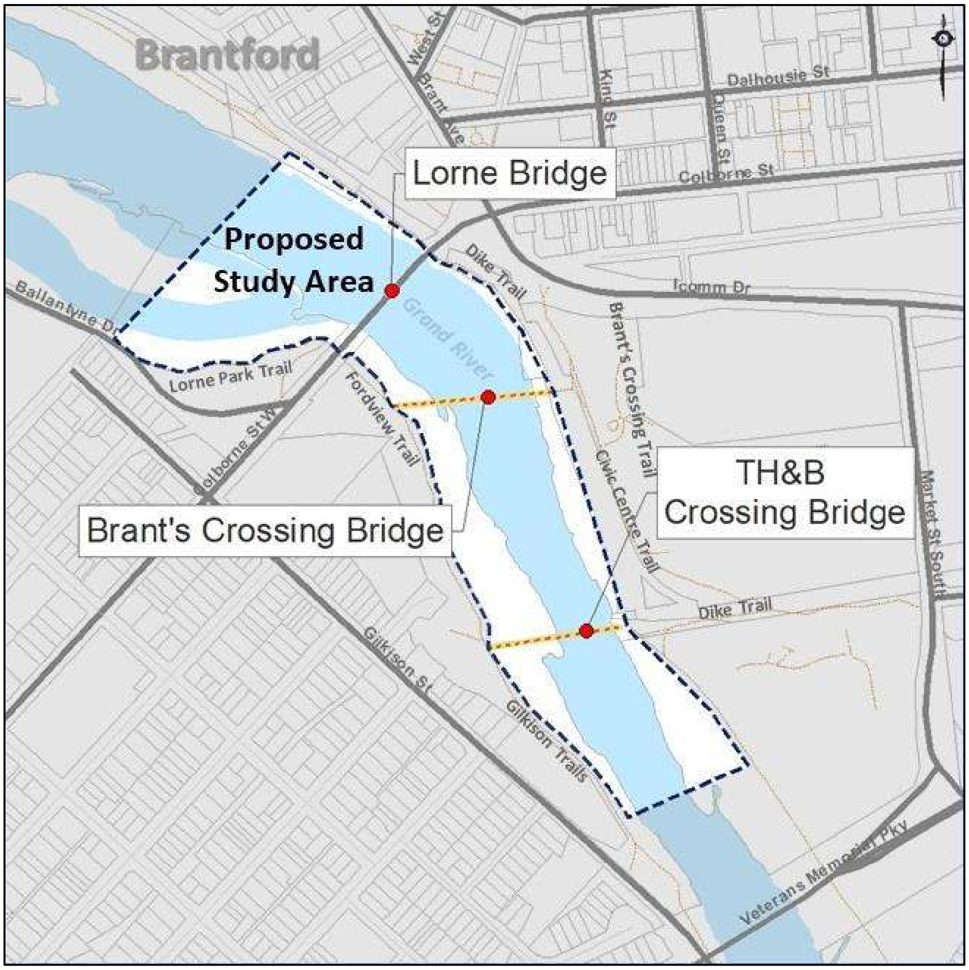


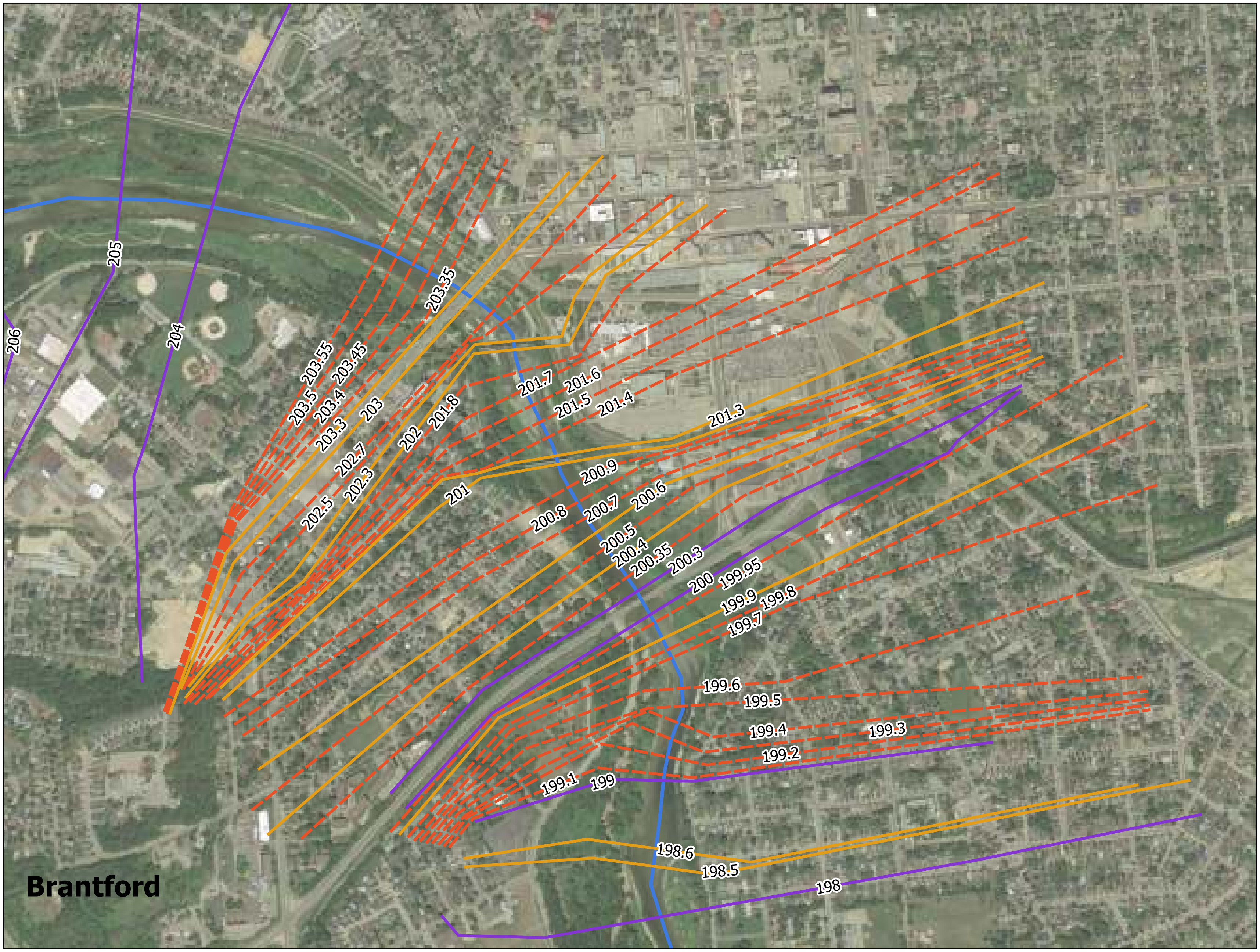
Figure 1. Location of the three bridge crossings in the City of Brantford (City of Brantford, 2020)

2. Model Development

2.1 Geometry

The hydraulic model was developed using the existing 1D steady-state HEC-RAS (Brunner, 2016) model, provided by the Grand River Conservation Authority. This model was modified from the existing model to increase the cross-section resolution within the study area to approximately 40 m section spacing where possible. The cross-sections were aligned with existing GRCA cross-sections where feasible to facilitate a comparison to previous modelling results. The model cross-sections between sections 204 and 200, inclusive, were updated. The location of the modelled cross-sections are provided in **Figure 2**.

Note that in the provided figure, the cross-sections with geometries used as provided by the GRCA are labelled as “GRCA cross-sections from GIS”, all of which are used within the Existing conditions model. Additional cross-section geometry was defined for some sections which are included in the Existing conditions model but not provided in the GRCA cross-section shapefile, labelled as, “Added geometry for Existing Conditions model”. Finally, additional cross-sections were added for the Basis of Comparison model are also shown.



City of Brantford
Three Grand River Crossings

Figure 2
HEC-RAS Cross-Sections

Legend

HEC-RAS Sections
- GRCA cross-sections from GIS
- Added geometry for Existing Conditions model
- Added cross-sections for BOC model
- Grand River

Google Satellite

EPSG:26917

1:8000

Project Name: 2012 Three Grand River Crossings
Date: 12/2020

Data Sources: Ecosystem Recovery Inc., Grand River Conservation Authority

E:\2012 - GMB Three Bridges\5 - GIS\04 QGIS\2012_workspace.qgz

A digital terrain model (DTM) was generated for the purpose of updating the cross-section topographic information, including the in-channel bathymetry and overbank information. This DTM was generated in CGVD28 vertical datum for usage in the hydraulic model using the following sources:

- LiDAR-collected bathymetry data, provided by the GRCA;
- Bathymetry data collected via survey by ASI Marine, provided by GM BluePlan;
- Terrestrial LiDAR data collected by 3DS in the vicinity of the three crossings , provided by GM BluePlan; and
- Terrestrial LiDAR data provided by Land Information Ontario from a 2018 collection

Note that in some locations where the GRCA bathymetry data did not cover a complete profile across the Grand River, the existing HEC-RAS in-channel elevations were adopted. In some locations the GRCA bathymetry data has gaps due to snow/ice cover during the LiDAR collection, which is frequently within deeper sections of the river within this study area. Thus, the bathymetry data in those sections must be treated with caution, as the omitted deeper sections of the cross-sections tend to have a controlling influence on the hydraulics of the river.

The three subject crossings in this study were updated from the provided hydraulic model using existing condition bridge survey profile data provided by GM BluePlan (Appendix A). In comparison the Existing model representation of the three bridges, the pedestrian bridge soffits were between approximately 0.5m and 0.2m lower following the update to the bridges from survey data. The existing condition bridge crossing characteristics are summarized in **Table 1**.

Table 1. Summary of three bridge crossings existing conditions characteristics

Bridge	**Lorne Bridge**
Parameter	**Dimension**
Deck Elevation (m)	208.24 – 211.25
Soffit Elevation (m)	202.50 – 208.29
Channel Invert Elevation (m)	195.0
Span (m)	~45-48
Effective Span (m)	39.6 – 42.7
Piers	East girder, two 4.5m piers
Deck Width (m)	23
Photo (facing South, downstream from Dike Trail on left bank, North side of Grand River)	
Bridge	**Brant's Crossing Bridge (CN Railway Bridge)**
Parameter	**Dimension**
Deck Elevation (m)	203.62 – 203.79
Soffit Elevation (m)	202.14 – 202.35
Channel Invert Elevation (m)	194.4
Span (m)	~23 - 38
Effective Span (m)	20.9 – 35.0
Piers	3 piers, approximately 3.6 m widths
Deck Width (m)	6
Photo (facing South, downstream from left bank, East side of Grand River)	

Bridge	**TH&B Crossing Bridge**
Parameter	**Dimension**
Deck Elevation (m)	203.38 – 203.49
Soffit Elevation (m)	201.91 – 202.05
Channel Invert Elevation (m)	194.2
Span (m)	~30.6 – 31.1
Effective Span (m)	27.0 – 28.0
Piers	Two piers 3.1 m width, East pier approximately 6 m width
Deck Width (m)	5
Photo (facing North, upstream, from the Veterans Memorial Parkway)	

Note: All elevations provided in CGVD28 vertical datum. Photos provided using Google Imagery

All bridges used the standard step method in the bridge modelling approach. For the ice jam scenarios, a dynamic ice jam was computed through the bridge section for Brant's Crossing Bridge only; the other bridges were modelled with ice forming on one side of the bridge only. It is noted that the impact of the bridge soffit and other structural elements of the bridge are not taken into account in the ice jam calculation (Daly and Vuyovich, 2002).

2.2 Hydraulic Assessment

Given the concern from the 2018 flooding and ice jam event, this study was intended to consider both open water and ice jam effects in its hydraulic assessment.

Open Water Conditions

The open water flood frequency analysis used the analysis undertaken by the GRCA for the Water Survey Canada (WSC) gauge in Brantford on the Grand River (02GB001), located between the TH&B Crossing Bridge and the Veteran's Memorial Parkway Bridge. The open water flows used in this assessment are provided in **Table 2**.

Table 2. Open Water Flows used in Hydraulic Assessment

Return Period (years)	Annual Exceedance Probability (%)	Flow (m^3/s)
2	0.5	600
5	0.2	908
10	0.1	1107
20	0.05	1307
25	0.04	1371
50	0.02	1570
100	0.01	1769
200	0.005	1968
500	0.002	2232
Regional		2560

Ice Jam Conditions

A number of ice jam events have occurred in the City of Brantford since 1965. The GRCA have compiled a list of these events, with data collected at the WSC Station 02GB001. Between 1965 and 2018 (53 years), 33 ice jams occurred with notable peaks in water level. During 11 of those 33 years multiple peaks in water level occurred attributable to ice jams. Generally, events occurred in January or February; however, one event occurred in December and three events occurred in March.

In subsequent discussions with the City of Brantford and GRCA, it was determined that the WSC-provided geodetic datum of 195.682 m was based on a 1910 datum, and that a more accurate conversion of gauge levels to water levels in a CGVD28 datum was 195.409 m. The CGVD28 has been used in this assessment.

The ice jam analysis utilizes information from the KGS (2019) study, which reviewed the 2018 ice jam event and provided additional modelling and analysis for ice jam events along the Grand River. This study provided a frequency analysis for ice jam events at the Brantford WSC gauge (02GB001), relating gauge water levels to a return period. Photos of the February 21, 2018 ice jam event in the study area of the three crossings, as well as the February 26th floodplain inspection, are provided in **Appendix B**.

The hydraulic model simulated ice jam formation in channel in HEC-RAS between Lorne Bridge and the TH&B Crossing Bridge, as observed in the 2018 event (KGS, 2019). The ice thickness in a section downstream of the three crossings in this event was estimated in the range of 2 m - 3 m, with broken ice rubble chunks discovered in the floodplain on February 26th, 2018, which were in the order of 0.5 m thickness.

A flow of 1,220 m^3/s was used for the 100-year ice jam event, consistent with the estimated peak flow from the 2018 ice jam event. Based on the GRCA flow frequency analysis (refer to **Table 2**), a flow of 1,220 m^3/s is approximately equivalent to somewhere between a 10-year and 20-year open water event. The combination of the open water and ice jam was noted to have a return period of approximately 100-year based on the KGS analysis. The flow and stage plot of the February 21, 2018 ice jam event (generated by KGS) is provided in **Figure 3**.

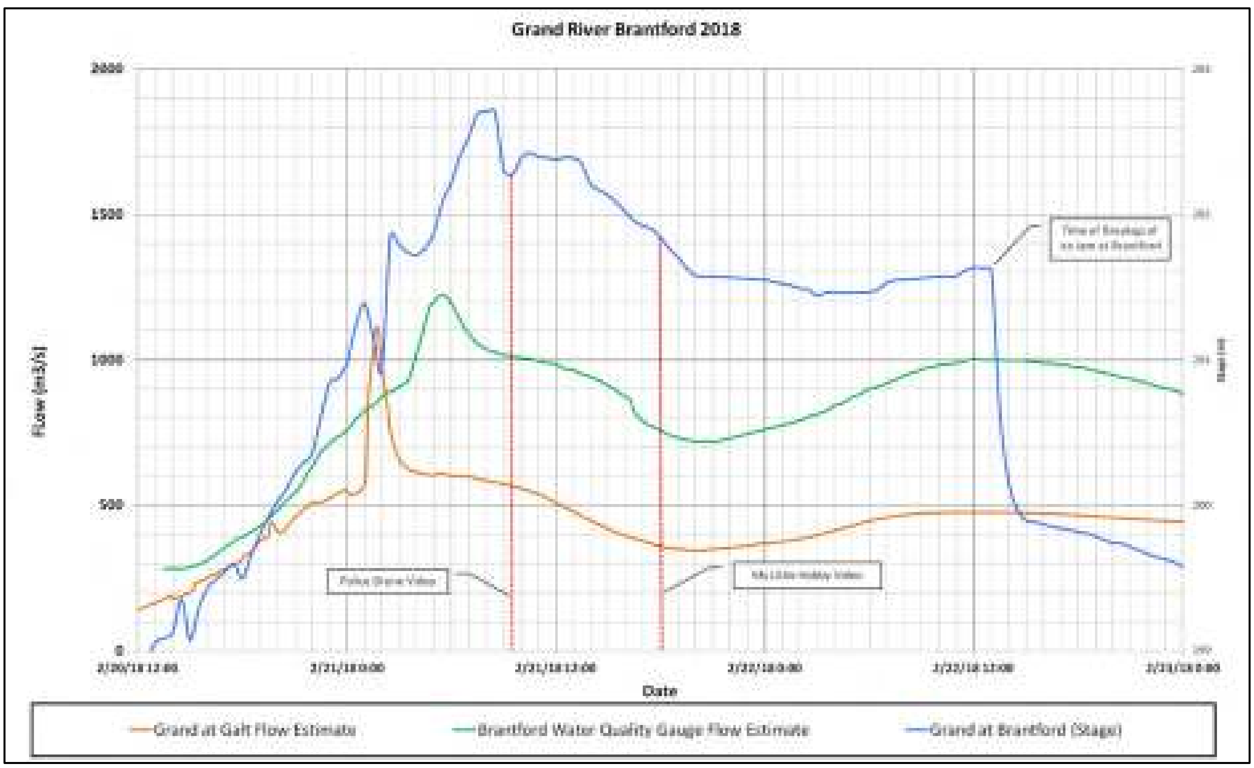


Figure 3. Ice jam event flow and stage estimates (Figure 5, KGS 2019)

Using the 1,220 m^3/s flow value, the recorded levels of the 2018 event in vicinity of the three crossings study area (KGS 2019, Table 5), and the KGS (2019) frequency analysis for gauge levels (KGS 2019, Table 2) corrected to the CGVD28 datum, the hydraulic model was calibrated to recreate the observed top of ice elevations of the 2018 event and the 100-year gauge elevation.

Minimum ice thicknesses inputted to the model between Lorne Bridge and TH&B Crossing Bridge ranged between 1 m - 2 m in order to achieve a reasonable fit to the recorded levels. Once the model was sufficiently calibrated to achieve a reasonable fit for the 100-year event, the model was used to determine appropriate return period flows for other return period events (5, 10, 20, 50-year) in order to match the gauge level frequency analysis from KGS (2019) for ice jam events (Table 5).

A summary of the gauge elevations matched in the hydraulic model (based on the KGS frequency analysis), and the associated ice jam flows, is provided in **Table 3**.

Table 3. Ice Jam Elevations from KGS frequency analysis and flows estimated in Hydraulic Assessment

Return Period*	Gauge Levels (m)*	WSE (WSC geodetic)*	WSE (CGVD28)	Ice Jam Flows (m^3/s)***
2.5	2	197.7	197.43	
5	3.8	199.4	199.13	290
10	4.5	200.3	200.03	480
20	5.3	201.0	200.73	668
50	6.2	201.9	201.63	970
100	6.8	202.5	202.23	1220

*obtained from Table 2 of KGS (2019) report
**open water flows based on the GRCA Flood Frequency analysis
***ice jam flows determined from matching the CGVD28 WSE at the gauge location in the hydraulic model

2.3 Design Standards and Criteria

The road classification for the three crossings is an important step in determining the design criteria required for assessing the crossings. According to the available City of Brantford records, the section of Colborne Street West over Lorne Bridge is an arterial road, while the other two crossings are not specified but are known to act as pedestrian bridges (high vulnerability, low volume recreational structures). The City of Brantford engineering guidelines do not specify their own standards for assessing hydraulic crossing structures, thus the standards from the Ministry of Transportation (MTO) Drainage Manual are adopted for this assessment.

These criteria use the MTO Design Flow Criteria, which examines flow under the bridge during intended use of the structure, as well as the MTO Relief Flow Criteria, which examines an overtopping of the crossing structure during the Regulatory event. Given the nature of the potential for ice jams in this study area, the Design Flow Criteria are examined using both open water and ice jam flood events. The design criteria adopted in this assessment for the three crossings are summarized in **Table 4**.

Table 4. Summary of the MTO Design Flow and Relief Flow Criteria applied for Three Crossings

	Lorne Bridge	**Pedestrian Bridges (Brant Crossing, TH&B Crossing)**
Road Class	Arterial	Pedestrian crossing
Design Flow Criteria		
Design Flow Event	100-year (open water and ice)	10-year (open water and ice)
Min. Freeboard (m)	0.3	0.3
Min. Soffit Clearance (m)	0.3	0.3
Relief Flow Criteria		
Design Flow Event	Regulatory	Regulatory
Max. Depth of Flow at Bridge Deck (m)	0.3	0.3
Max. Depth of Flow at Road (m)	0.3	0.3
Max. Depth-Velocity Product (m^2/s)	0.8	0.8

In these criteria, the soffit clearance is calculated as the difference in the water surface elevation and the bridge soffit, while the freeboard is typically calculated as the difference in the water surface elevation and the lowest point in the adjacent road profile. For the three bridges evaluated in this study the relief point is a low-point adjacent to the crossing along the approach where flow would overtop first. Refer to **Appendix C** for relief point locations. Further definition of these terms is provided in the MTO Drainage Design Standards (2008).

3. Hydraulic Results

3.1 Model Verification and Validation

Basis of Comparison

To facilitate a comparison first to the existing GRCA HEC-RAS model, a basis of comparison (BOC) model is constructed. The BOC model also reflects the “existing” conditions of the study area, but is updated from the GRCA provided model with the additional cross-sections, topographic and bathymetric data sources, and other modifications described in **Section 2.1**. Here, the Existing model is referred to as the GRCA-provided model. The flows in the Existing model are updated to use the same open water flows as the BOC model to enable a comparison of results.

The results in key cross-sections between the Existing and BOC model for the 100-year and Regional events are provided in **Table 5**. These results indicate a maximum increase of 0.22 m in WSE during the 100-year event and 0.07 m during the Regional event, both at cross-section 203.3 (just upstream of Lorne Bridge). The WSE across the examined sections increases somewhat during the 100-year event in most sections examined, and is approximately the same as the Existing model in examining the Regional event.

The BOC model is impacted by a number of factors, including the use of higher resolution DTM cross-section data, the adjustments to the bridge representations, the addition of more cross-sections, etc., so some differences between these models is anticipated.

The bed profile and 100-year results for the open water Existing and BOC models are provided in **Figure 4**.

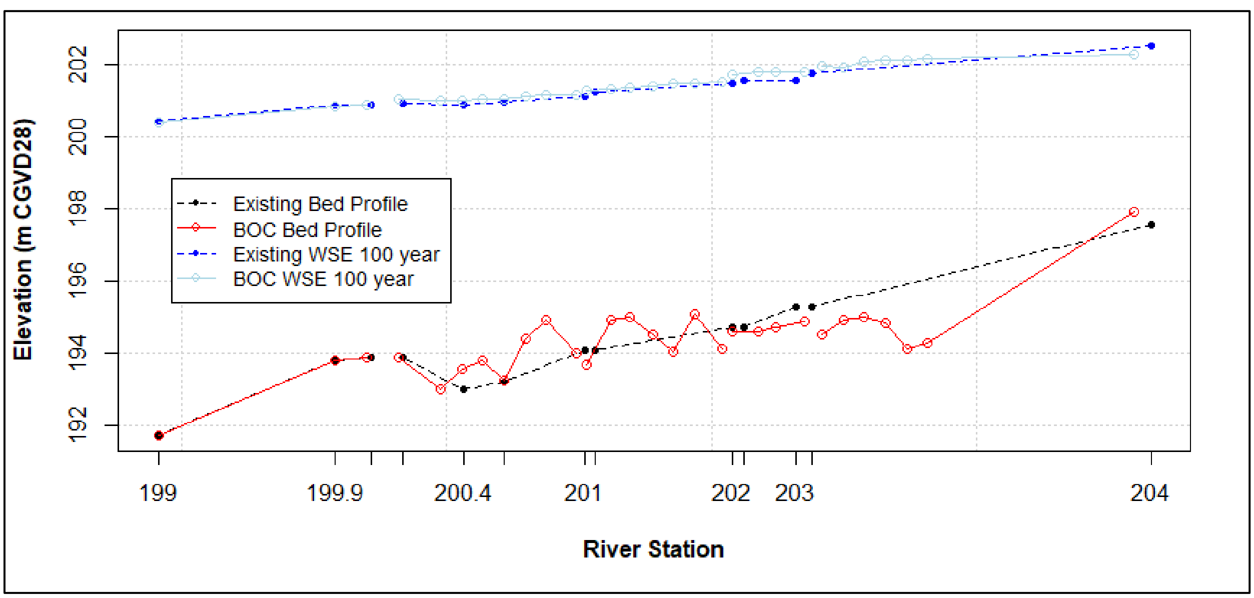


Figure 4. Profile plot of the Existing and BOC model conditions at the 100 year event

In addition, the minimum channel elevation in a number of sections is lower than the Existing model. For example, section 203.3, with a minimum channel elevation that is 0.75m lower than in the Existing model, is located just upstream of Lorne Bridge. This may be due to the lowering of the bed via scour around bridge sections or may be to due to the higher resolution data available in this study than since the previous model update.

Overall, the BOC model is deemed suitable for analysis in this project, where some deviation from the Existing model is anticipated as the model is adjusted to the latest available data. These adjustments should be reviewed and considered further prior to any updates to the regulatory GRCA model.

Table 5. Existing Conditions Hydraulic Assessment Results for Lorne Bridge (100 year and Regional event)

100-year		Existing				BOC				Difference (BOC - Existing)			
Section	Flow (m^3/s)	Min. Chnl Elev (m)	WSE (m)	Velocity (m/s)	Flow Area (m^2)	Min. Chnl Elev (m)	WSE (m)	Velocity (m/s)	Flow Area (m^2)	Min. Chnl Elev (m)	WSE (m)	Velocity (m/s)	Flow Area (+/- %)
204	1769	197.55	202.5	2.28	849.79	197.91	202.26	2.12	889.37	0.36	-0.24	-0.16	5%
203.3	1769	195.27	201.73	2.78	636.36	194.52	201.95	2.21	800.36	-0.75	0.22	-0.57	26%
Lorne Bridge													
203	1769	195.27	201.56	2.88	613.26	194.88	201.77	2.55	692.84	-0.39	0.21	-0.33	13%
202.3	1769	194.69	201.54	2.45	722.41	194.6	201.7	2.42	730.92	-0.09	0.16	-0.03	1%
Brant's Crossing Bridge													
202	1769	194.69	201.48	2.48	714.51	194.11	201.49	2.44	725.58	-0.58	0.01	-0.04	2%
201.3	1769	194.06	201.23	2.71	653.58	193.68	201.27	2.71	653.21	-0.38	0.04	0	0%
TH&B Crossing Bridge													
201	1769	194.06	201.12	2.77	639.45	194	201.14	2.76	640.06	-0.06	0.02	-0.01	0%
200.3	1769	193.88	200.92	2.3	809.65	193.88	201.04	2.16	818.39	0	0.12	-0.14	1%
Veteran's Memorial Parkway Bridge													
200	1769	193.88	200.87	2.32	802.45	193.88	200.87	2.13	831.76	0	0	-0.19	4%
199	1769	191.72	200.42	3.36	852.61	191.72	200.38	3.5	844.61	0	-0.04	0.14	-1%

Regional		Existing				BOC				Difference (BOC - Existing)			
Section	**Flow (m^3/s)**	**Min. Chnl Elev (m)**	**WSE (m)**	**Velocity (m/s)**	**Flow Area (m^2)**	**Min. Chnl Elev (m)**	**WSE (m)**	**Velocity (m/s)**	**Flow Area (m^2)**	**Min. Chnl Elev (m)**	**WSE (m)**	**Velocity (m/s)**	**Flow Area (+/- %)**
204	2560	197.55	203.83	2.37	1204.97	197.91	203.49	2.24	1226.97	0.36	-0.34	-0.13	2%
203.3	2560	195.27	203.06	3.13	818.88	194.52	203.13	2.63	971.94	-0.75	0.07	-0.5	19%
Lorne Bridge													
203	2560	195.27	202.85	3.24	790.44	194.88	202.87	3.03	845.51	-0.39	0.02	-0.21	7%
202.3	2560	194.69	202.83	2.91	880.41	194.6	202.75	2.99	854.77	-0.09	-0.08	0.08	-3%
Brant's Crossing Bridge													
202	2560	194.69	202.68	2.97	861.74	194.11	202.6	2.99	856.62	-0.58	-0.08	0.02	-1%
201.3	2560	194.06	202.39	3.22	794.77	193.68	202.33	3.28	781.58	-0.38	-0.06	0.06	-2%
TH&B Crossing Bridge													
201	2560	194.06	202.24	3.3	776.1	194	202.12	3.37	759.26	-0.06	-0.12	0.07	-2%
200.3	2560	193.88	202.03	2.74	996.63	193.88	202.02	2.6	986.05	0	-0.01	-0.14	-1%
Veteran's Memorial Parkway Bridge													
200	2560	193.88	201.98	2.77	988.02	193.88	202.02	2.46	1039.23	0	0.04	-0.31	5%
199	2560	191.72	201.45	3.97	1098.66	191.72	201.4	4.17	1085.76	0	-0.05	0.2	-1%

Open Water Conditions

The daily levels and flow values recorded at the Brantford gauge (02GB001) were analyzed to gain an understanding of the differences between gauge and modelled values. In this analysis, the Gumbel distribution was fitted to gauge levels to determine the gauge level associated with various return periods. This same analysis was done to the flow values recorded at the gauge. Note that due to differences in the data availability, and differences in levels with a given flow value, the gauge analysis for levels and flows should be viewed as independent.

These values are compared to the modelled flow values (provided by the GRCA flood frequency analysis (FFA) for the managed system) and the water surface elevation results for those associated flows from the model. These are shown in **Table 6**.

Table 6. Comparison of gauge levels to open water modelled conditions

Return Period (year)	Gauge Frequency Analysis		Modelled Values	
	Gauge Levels (m CGVD28)	Gauge Flows FFA (m^3/s)	Modelled Flows (GRCA FFA, m^3/s)	W.S. Elev (CGVD28)
5	199.24	806	908	199.39
10	199.74	972	1107	199.8
20	200.23	1131	1307	200.17
50	200.85	1337	1570	200.69
100	201.32	1492	1769	201.04

The results indicate that for all events, the overall levels estimated from both approaches in the open water model results are similar. It is noted as well that the GRCA FFA tends to produce somewhat more conservative flow estimates for each event than the gauge analysis performed here.

It is noted that the gauge analysis is sensitive to the data availability and period examined, as well as the statistical assumptions embedded in the analysis. Overall, the model results are close to those found from a gauge frequency analysis, noting the differences in methodologies and the flows used in the model.

Ice Jam Conditions

In comparing the simulated ice jam conditions to the 2018 ice jam event, the values reported from KGS (2019) were used as a check to ensure that the hydraulic model is capable of approximately replicating the results of the 2018 ice jam flood. The 2018 event was noted by KGS to register approximately as a 100-year event. While there is inevitably some uncertainty around the recorded ice elevations, as well as a consistent datum for multiple sources of reported elevations, **Table 7** provides a comparison to the reported 2018 elevations and the modelled conditions.

Table 7. Comparison of recorded levels from the 2018 ice jam event and the 100 year ice jam modelled event

Location	Ice/Water	2018 Recorded Elevation (estimated. CGVD28)	Modelled 100 year elevation (CGVD28)
Lorne Bridge	Ice Top	203.2	203.49
Brant's Bridge	Ice Top	203	203.38
TH&B Bridge	Ice Top	202.75	202.46
WSC Gauge	Water	202.4	202.23
VMP	Water	202	202.26

The results indicate some variation in the levels, but the modelled ice jam elevations are within 30-40cm of the estimated recorded 2018 event levels at key sections in the study area.

3.2 Evaluation of Existing Bridge Hydraulics

The hydraulic results for the three crossings under existing conditions were assessed according to the MTO design criteria. The results for the 5-year, 10-year, 50-year, 100-year, and Regional events are summarized in **Tables 3-5**. Note that all elevations provided in the following tables are in the CGVD28 datum, and all hydraulic model results are taken from the bridge upstream section unless noted otherwise. The highlighted criteria indicate the selected design criteria.

For the Lorne Bridge Crossing, evaluated at the 100-year event, clears the soffit requirement for the open water and ice jam Design Flows, as well as the Relief Flow Regional event. The road profile is low to trigger an insufficient freeboard requirement during the 100-year ice jam event, which is a hazard to be considered as part of an emergency management plan. It is noted that without modifications to the hydraulic characteristics of the channel and other crossings, the freeboard criteria is unlikely to be met, and raising the soffit of the Lorne Bridge would not allow the freeboard criteria to be met. Therefore, modifications to raise the soffit of Lorne bridge are not recommended from a hydraulics perspective.

The two pedestrian bridges, the Brant's Crossing Bridge and the TH&B Crossing Bridge, are both evaluated using the 10-year events. Both structures meet the minimum freeboard and clearance criteria for the open water event, but fail the criteria for the ice jam event. The top of ice elevation also exceeds the soffit elevation for both structures. It is noted that in this case, since the top of ice elevation is higher than the soffit elevation of these structures, it is likely that the ice and water level elevations would be higher than simulated by the hydraulic model, as the hydraulic model does not consider impacts of the bridge structure elements in ice calculations.

Table 8. Existing Conditions Hydraulic Assessment Results for Lorne Bridge

Parameter	5-year	10-year	50-year	100-year	Regional
Deck Elevation (m)	208	208	208	208	208
Soffit Elevation (m)*	207.74	207.74	207.74	207.74	207.74
Approach Road Profile Low Point (m)**	203.69	203.69	203.69	203.69	203.69
MTO Design Flow Criteria					
Return Period Open Water Level (m)	200.15	200.6	201.57	201.95	203.13
Open Water Freeboard (min 0.3 m)	3.54	3.09	2.12	1.74	0.56
Open Water Soffit Clearance (min 0.3 m)	7.59	7.14	6.17	5.79	4.61
Return Period Ice Jam Water Level (m)***	201.44	202.49	203.41	203.48	n/a
Return Period Top of Ice Elevation (m)	201.52	202.56	203.45	203.49	n/a
Ice impacting bridge soffit?	No	No	No	No	n/a
Ice Jam Water Level Freeboard (min 0.3 m)***	2.25	1.2	0.28	**0.21**	n/a
Ice Jam Water Level Soffit Clearance (min 0.3 m)***	6.3	5.25	4.33	4.26	n/a
MTO Relief Flow Criteria					
Return Period Open Water Level (m)	200.15	200.6	201.57	201.95	203.13
Overtops?	No	No	No	No	No
Depth of Flow Over Road (max 0.3 m) at Bridge Deck	0	0	0	0	0
Depth of Flow Over Road (max 0.3 m) at Road Profile Low Point	0	0	0	0	0
Product of Velocity Depth on Road (max 0.8 m^2/s) at Bridge Deck	0	0	0	0	0

*Soffit Elevation - Lowest top of arch elevation
Reference Point - West bank along top of flood proofing wall immediately north of bridge, refer to **Appendix C
***Freeboard and Clearance based on ice jam water level not top of ice
Note: Top of Ice Elevation - assumed to form downstream of bridge only - as per KGS 2019

Table 9. Existing Conditions Hydraulic Assessment Results for Brant's Crossing Bridge

Parameter	5-year	10-year	50-year	100-year	Regional
Deck Elevation (m)	203.62	203.62	203.62	203.62	203.62
Soffit Elevation (m)	202.14	202.14	202.14	202.14	202.14
Approach Road Profile Low Point (m)*	202.68	202.68	202.68	202.68	202.68
MTO Design Flow Criteria					
Return Period Open Water Level (m)	200	200.43	201.34	201.7	202.75
Open Water Freeboard (min 0.3 m)	2.27	1.84	0.93	0.57	-0.48
Open Water Soffit Clearance (min 0.3 m)	2.14	1.71	0.8	0.44	-0.61
Return Period Ice Jam Water Level (m)**	201.41	202.44	203.22	203.27	n/a
Return Period Top of Ice Elevation (m)	201.52	202.55	203.41	203.38	n/a
Ice impacting bridge soffit?	No	**Yes**	Yes	Yes	n/a
Ice Jam Water Level Freeboard (min 0.3 m)**	1.27	**0.24**	-0.54	-0.59	n/a
Ice Jam Water Level Soffit Clearance (min 0.3 m)**	0.73	**-0.3**	-1.08	-1.13	n/a
MTO Relief Flow Criteria					
Return Period Open Water Level (m)	200	200.43	201.34	201.7	202.75
Overtops?	No	No	No	No	Yes
Depth of Flow Over Road (max 0.3 m) at Bridge Deck	-3.62	-3.19	-2.28	-1.92	0
Depth of Flow Over Road (max 0.3 m) at Road Profile Low Point	-2.68	-2.25	-1.34	-0.98	**0.07**
Product of Velocity Depth on Road (max 0.8 m^2/s) at Bridge Deck	0	0	0	0	0

*Reference Point – low-point along multi-use trail approach to bridge, refer to **Appendix C**
**Freeboard and Clearance based on ice jam water level not top of ice

Table 10. Existing Conditions Hydraulic Assessment Results for TH&B Crossing Bridge

Parameter	5-year	10-year	50-year	100-year	Regional
Deck Elevation (m)	203.38	203.38	203.38	203.38	203.38
Soffit Elevation (m)	201.91	201.91	201.91	201.91	201.91
Approach Road Profile Low Point (m)*	203.24	203.24	203.24	203.24	203.24
MTO Design Flow Criteria					
Return Period Open Water Level (m)	199.55	199.98	200.91	201.27	202.33
Open Water Freeboard (min 0.3 m)	2.31	1.88	0.95	0.59	-0.47
Open Water Soffit Clearance (min 0.3 m)	2.36	0.68	1	0.64	-0.42
Return Period Ice Jam Water Level (m)**	201.11	202.23	202.73	202.29	n/a
Return Period Top of Ice Elevation (m)	201.29	202.42	201.90	202.46	n/a
Ice impacting bridge soffit?	No	**Yes**	No	Yes	n/a
Ice Jam Water Level Freeboard (min 0.3 m)**	2.13	1.01	0.51	0.95	n/a
Ice Jam Water Level Soffit Clearance (min 0.3 m)**	0.8	**-0.27**	0.18	-0.38	n/a
MTO Relief Flow Criteria					
Return Period Open Water Level (m)	199.55	199.98	200.91	201.27	202.33
Overtops?	No	No	No	No	No
Depth of Flow Over Road (max 0.3 m) at Bridge Deck	-3.83	-3.4	-2.47	-2.11	0
Depth of Flow Over Road (max 0.3 m) at Road Profile Low Point	-3.69	-3.26	-2.33	-1.97	-0.91
Product of Velocity Depth on Road (max 0.8 m^2/s) at Bridge Deck	0	0	0	0	0

*Reference Point - low-point along multi-use trail approach to bridge, refer to **Appendix C**
**Freeboard and Clearance based on ice jam water level not top of ice

3.3 Existing Brantford Dyke System

The existing Brantford dyke system sufficiently confines all design flow events to the main channel, including the open water Regulatory event and 100-year ice jam event through the study area. As a result, the bridges convey the majority of all flows between their respective embankments and there is little opportunity to provide relief flow around the bridge structures along the approaches. As a reference, the following figure illustrates the existing dyke alignment and crest elevations through the three bridges study area.

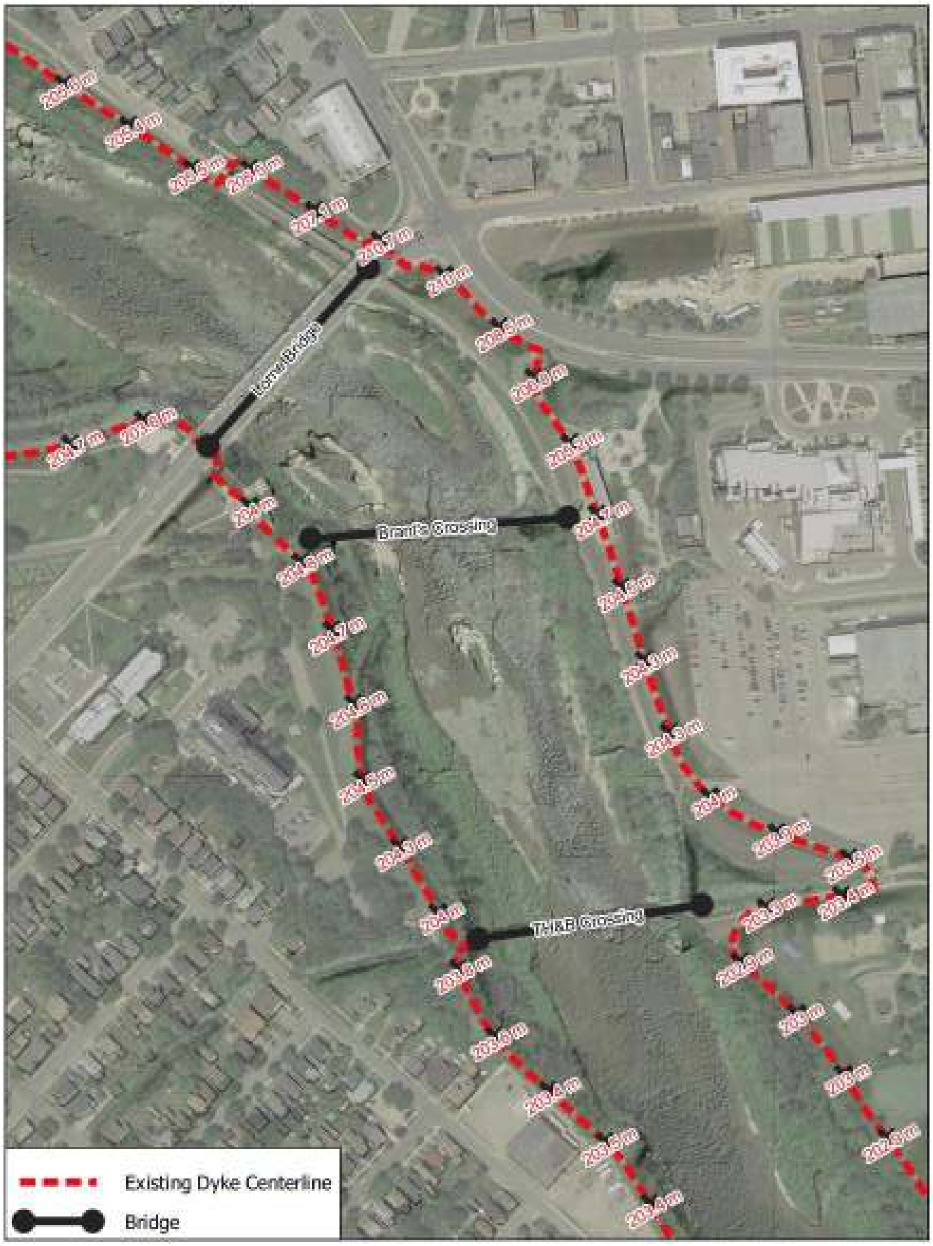


Figure 5. Existing Brantford Dykes Alignment and Elevations

3.4 Design Opportunities

3.4.1 Required Increase in Soffit Elevations

The hydraulic modelling results indicate that the Lorne Bridge soffit elevation is sufficient under existing conditions, while the soffit elevations of the two pedestrian bridges would require an increase in order to meet the MTO Design Criteria for the evaluated ice jam events. Consideration should also be made for the potential to increase the soffit elevation sufficiently to convey the Regulatory event.

Based on the existing conditions hydraulic assessment, a summary of the existing conditions and required soffit elevations is provided in **Table 11**.

Table 11. Summary of Design Criteria and Approximate Soffit Increases to Meet MTO Design Standards

Parameter	Lorne Bridge	Brant's Crossing Bridge	TH&B Crossing Bridge
Soffit (m)	207.74	202.14	201.91
Ice Top (m)	203.49	202.55	202.42
Open Water Reg. WSE (m)	203.13	202.75	202.33
Required Soffit Increase to Meet Design Flow Clearance (m)	0	0.71	0.81
Required Soffit Increase to Meet Relief Flow Clearance (m)	0	0	0
Soffit Increase to Meet MTO Design Criteria (m)	0	0.71	0.81
Soffit Increase Required to Meet Regulatory Clearance (m)	0	0.91	0.72
Soffit Increase to Meet MTO **and** Regulatory Clearance (m)	0	0.91	0.81

These results indicate that in order to meet the MTO Design Criteria, the two pedestrian crossings would require an approximate increase in the soffit elevation of 0.71m – 0.81m. In order to meet a 0.3m soffit clearance on the Regulatory event, the soffit increase would be approximately 0.91m for Brant's Crossing Bridge and 0.72m for the TH&B Crossing Bridge.

An additional model scenario was run for the open water conditions with the Brant's Crossing and TH&B Crossing bridge soffits increased by 0.91m and 0.81m, respectively to meet the MTO Design Criteria and clearance on the Regulatory event. This scenario will demonstrate the reduction in water surface elevations as a result of raising the bridges (i.e. the reduction of backwater caused by bridges acting as obstructions).

The results of this scenario will determine the regulatory water surface elevations free of influence by the existing soffit elevations of the bridges. The final proposed soffit elevations will be established based on the updated regulatory water surface elevations, with 0.3m clearance.

Table 12. Summary of Minimum Soffit Elevations to Meet 0.3m Clearance of Regulatory Event (Modelled)

Bridge	Open Water Reg. WSE (m)		Reg. WSE Change (+/- m)	Adjusted Soffit (m)	Soffit Change (+/- m)
	With Existing Soffit	With Raised Soffit			
Lorne Bridge	203.13	203.05	-0.08	207.74	0
Brant's Crossing	202.75	202.67	-0.08	202.97	+0.83
TH&B Crossing	202.33	202.29	-0.04	202.59	+0.68

3.4.2 Closing of Lorne Bridge East Girder

In addition to the existing conditions assessment provided, a consideration was requested for closing off the east girder on Lorne Bridge, with the opening replaced by a simple box culvert (modelled as a 3 m x 3 m box culvert matched approximately to existing grades). This scenario was modelled as a proposed condition option.

In comparing the open water BOC and proposed conditions, as well as the ice jam event BOC and proposed conditions, no substantial differences in WSE and velocity were found for the 100 year and Regional events. Thus, the closing of the Lorne Bridge East girder and replacing with a 3 m x 3 m box culvert is not anticipated to have any detrimental impacts to the hydraulic assessment of the Lorne Bridge Crossing. The results also do not support any impacts to the downstream crossings.

3.4.3 Recommended Minimum Soffit Elevations

The recommended soffit elevations for the three bridges, considering all design criteria including open water and ice cover scenarios, is summarized in the following table. The minimum soffit elevation for each bridge is the greater of the regulatory water surface elevation or top of ice elevation plus 0.3m freeboard.

Table 13. Summary of Recommended Soffit Elevations

Bridge	Existing Soffit (m)	Open Water Reg. WSE (m)	Top of Ice (10-year) (m)	New Soffit Elevation (m)	Soffit Change (+/- m)
Lorne Bridge	207.74	203.05	203.49	207.74	0
Brant's Crossing Bridge	202.14	202.67	202.55	202.97	+0.83
TH&B Crossing Bridge	201.91	202.29	202.42	202.72	+0.81

Highlighted cell denotes governing flow condition for soffit elevation

Based on the above results, it is recommended to raise the soffit of the Brant's Crossing and TH&B Crossing bridges by a height of 0.83m, and 0.81m, respectively.

4. Conclusions

The Lorne Bridge is found to meet the required MTO Design Flow Criteria under both the 100 year open water and ice jam events.

The two downstream pedestrian bridges, the Brant's Crossing bridge, and the TH&B Crossing bridge, are both evaluated using the 10 year open water and ice jam event. Both bridges meet the open water event criteria but fail the ice jam event criteria for Design Flow criteria. To achieve the outlined MTO design criteria for the 10-year ice jam event, it is recommended to raise the Brant's Crossing bridge and the TH&B bridge by 0.71m and 0.81m, respectively.

Raising the soffits of the pedestrian bridges to convey the open water Regulatory event would provide a benefit throughout the reach and is of similar magnitude to the required raising above the ice jam elevations. To ensure that both pedestrian bridges are raised above the 10-year ice jam event, and the open water Regulatory event, it is recommended to raise the Brant's Crossing bridge and the TH&B bridge by 0.83m and 0.81m, respectively.

In consideration of closing the Lorne Bridge East girder and replacing it with a 3 m x 3 m box culvert opening, the hydraulic model does not provide any evidence of detrimental flood impacts resulting from this modification to Lorne Bridge.

5. References

City of Brantford, 2020. *Three Grand River Crossings Environmental Assessment*. Obtained on December 3, 2020 from https://www.brantford.ca/en/your-government/three-grand-river-crossings.aspx

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Daly, S. F. and Vuyovich, C. M. (2002). *Modeling river ice with HEC-RAS*. CGU HS Committee on River Ice Processes and the Environment 12th Workshop on the Hydraulics of Ice Covered Rivers Edmonton, AB, June 19-20, 2003

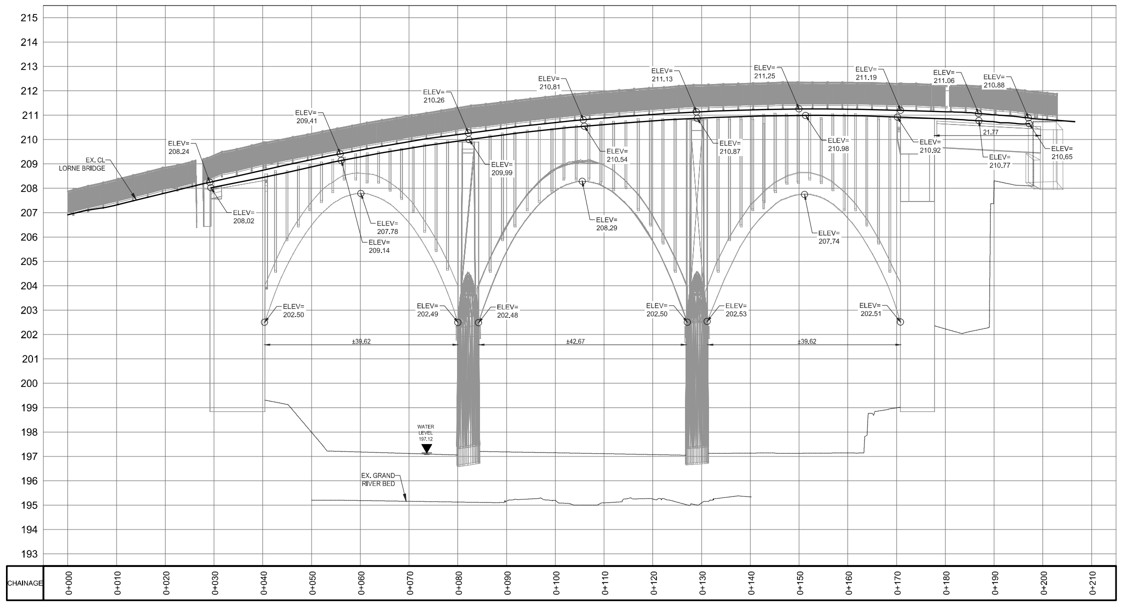
KGS (2019). *Brantford Ice Jam Study*. Prepared for the Grand River Conservation Authority on April 30th, 2019.

MTO (2008). *Highway Drainage Design Standards*. Revised February 8, 2008. Available from https://www.library.mto.gov.on.ca/SydneyPLUS/Sydney/Portal/default.aspx?component=AAAAIY&record=51bb97c8-3a86-41b6-9bbf-cc0c2e7a45fa

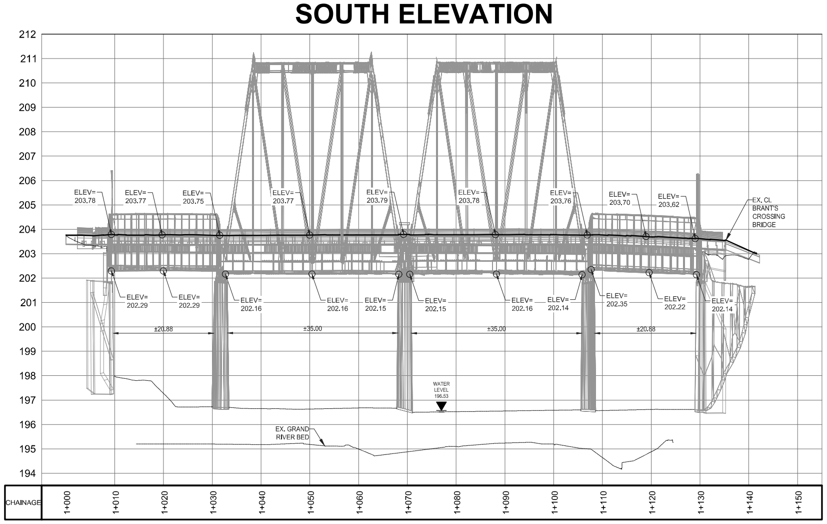
Appendix A

Three Bridge Crossing Existing Conditions Profiles

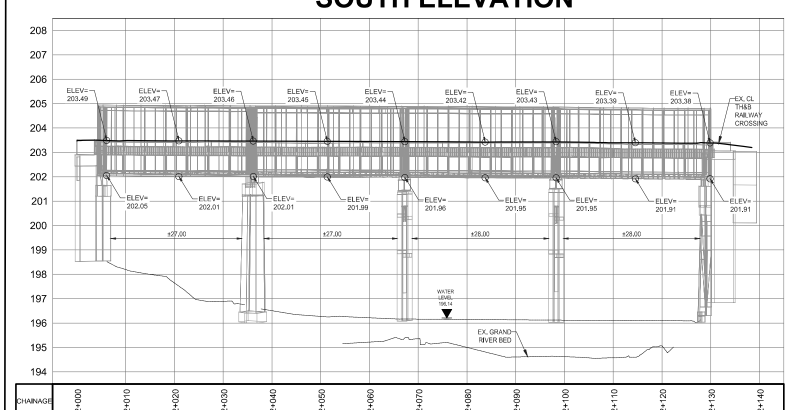
LORNE BRIDGE
SOUTH ELEVATION



BRANT'S CROSSING BRIDGE
SOUTH ELEVATION



TH&B RAILWAY RIVER CROSSING
SOUTH ELEVATION



CITY OF BRANTFORD
KEY PLAN
NOT TO SCALE

NOTES :

1. EXISTING TOPOGRAPHIC INFORMATION PROVIDED BY 3DS TECHNOLOGIES INC. BASED ON SURVEY COMPLETED MARCH 5, 2020.
2. EXISTING GRAND RIVER BED INFORMATION PROVIDED BY ASI MARINE BASED ON BATHYMETRIC SURVEY COMPLETED ON MAY 5, 2020.

BENCH MARKS :

THE POSITION OF POLE LINES, CONDUITS, WATERMAINS, SEWERS AND OTHER UNDERGROUND AND OVERGROUND UTILITIES AND STRUCTURES IS NOT NECESSARILY SHOWN ON THE CONTRACT DRAWINGS, AND, WHERE SHOWN, THE ACCURACY OF THE POSITION OF SUCH UTILITIES AND STRUCTURES IS NOT GUARANTEED.

BEFORE STARTING WORK, THE CONTRACTOR SHALL INFORM HIMSELF OF THE EXACT LOCATION OF ALL SUCH UTILITIES AND STRUCTURES, AND SHALL ASSUME ALL LIABILITY FOR ANY DAMAGE TO THEM.

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GRAND RIVER BRIDGES EA

BRANTFORD

CITY OF BRANTFORD

BRIDGE PROFILES

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DESIGNED BY :	DATE :	SCALE :	
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Appendix B

Photo record of the 2018 ice jam event (KGS, 2019)

PHOTO 1

PHOTO 2

PHOTO 3

PHOTO 4

PHOTO 5

PHOTO 6

PHOTO 7

PHOTO 8

PHOTO 9

PHOTO 10

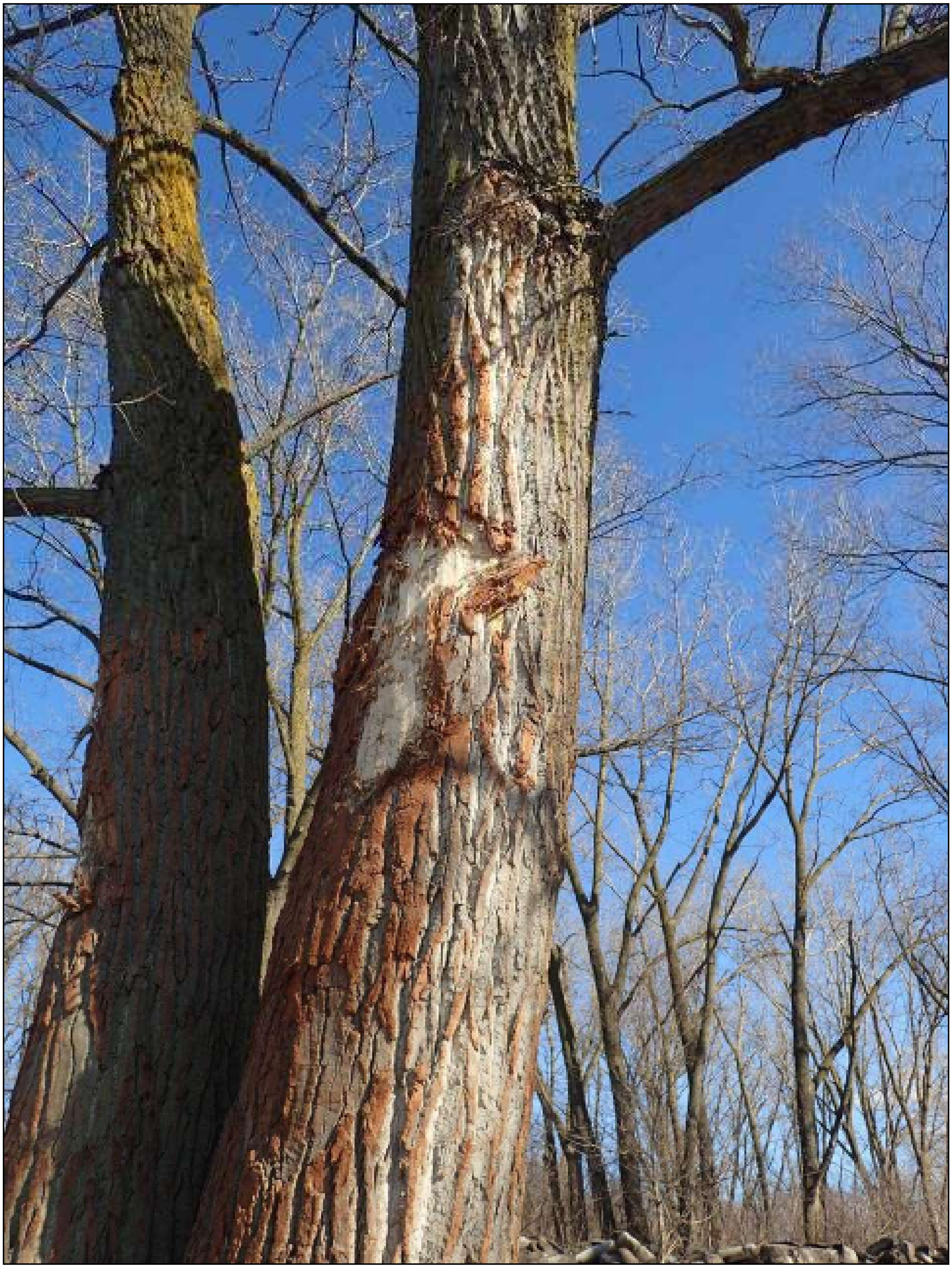


PHOTO 11

PHOTO 12

PHOTO 13

PHOTO 14

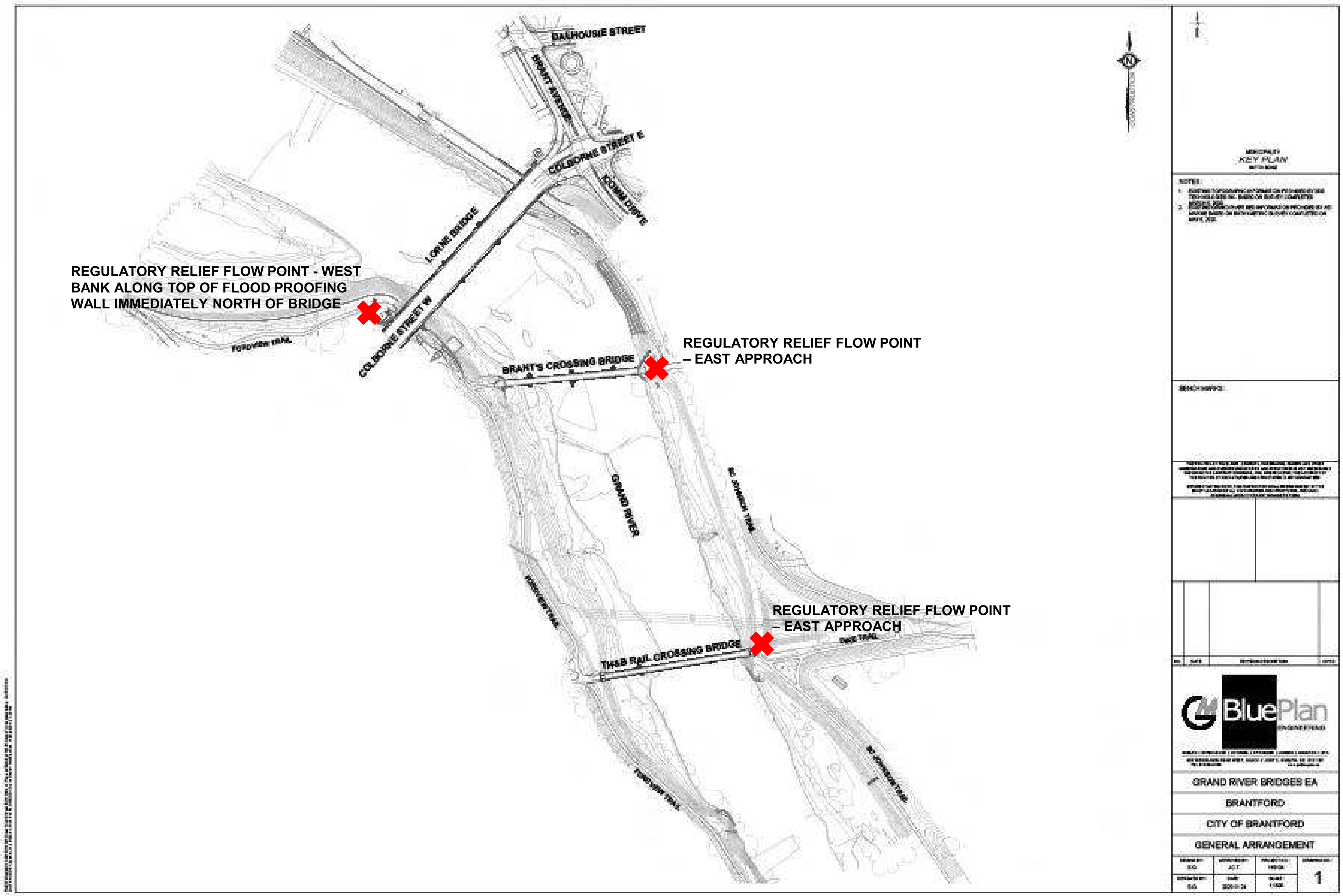
PHOTO 15

FIGURE 13
ICE JAM REMNANTS – FEBRUARY 26 2018

FIGURE 14
VIEW DOWNSTREAM OF TOE OF ICE JAM - FEBRUARY 21 2018

Appendix C

Regulatory Flow Relief Point Locations



REGULATORY RELIEF FLOW POINT - WEST BANK ALONG TOP OF FLOOD PROOFING WALL IMMEDIATELY NORTH OF BRIDGE
REGULATORY RELIEF FLOW POINT – EAST APPROACH
REGULATORY RELIEF FLOW POINT – EAST APPROACH
DALHOUSIE STREET
BRANT AVENUE
COLBORNE STREET E
COLBORNE STREET W
LORNE BRIDGE
BRANT'S CROSSING BRIDGE
GRAND RIVER
TH&B RAIL CROSSING BRIDGE
FORDVIEW TRAIL
KEY PLAN
NOTES:
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1