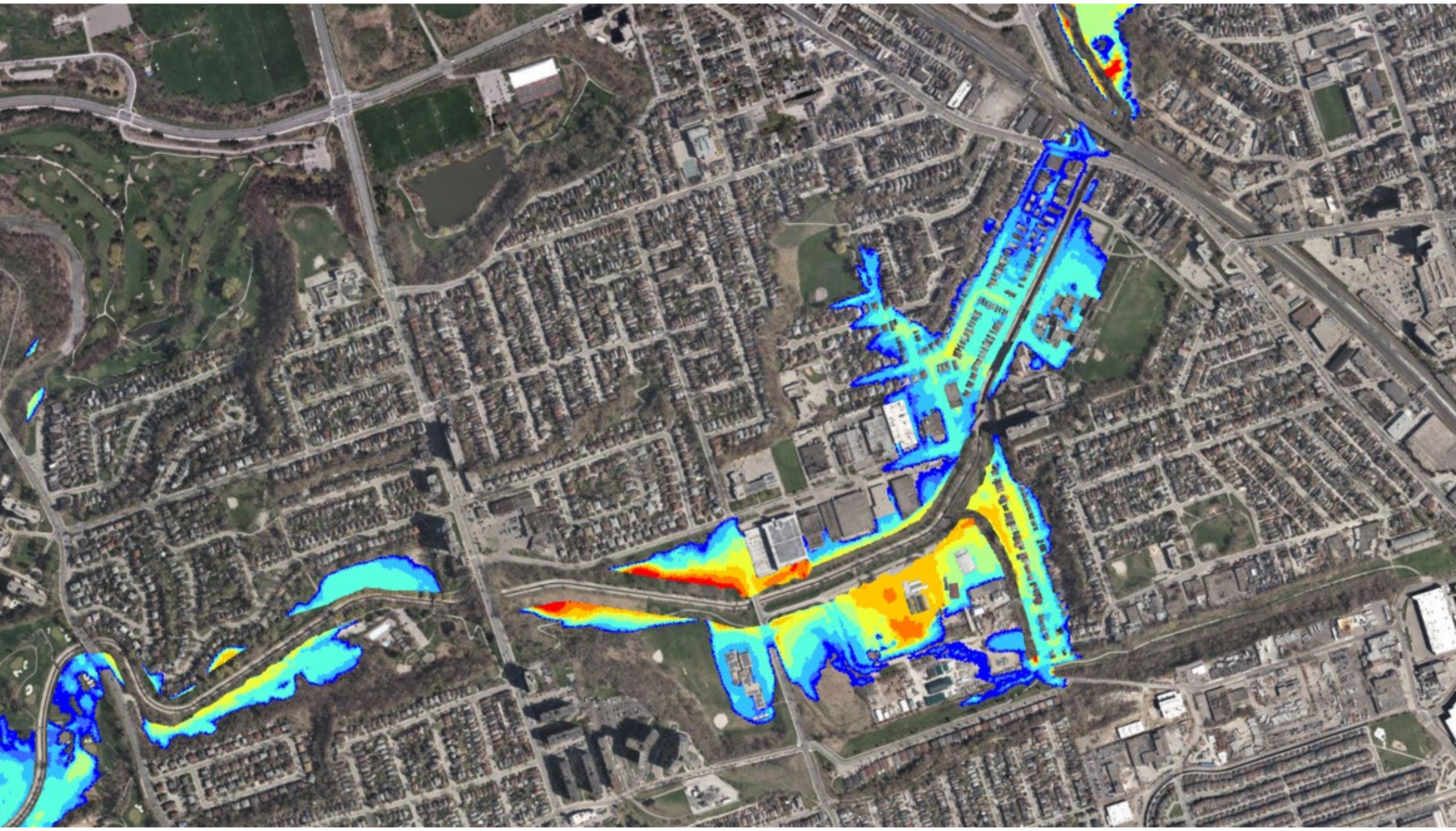
The expert in WATER ENVIRONMENTS

ROCKCLIFFE SPA
2D FLOOD MODELLING AND MAPPING UPDATE 2020



Prepared for:

Toronto and Region Conservation Authority
101 Exchange Avenue
Vaughan, ON L4K 5R6

Prepared by:

DHI Water and Environment Inc.
423 King St E – Unit 2
Cambridge, ON N3H 3N1

Project #: 42802963
January 2020

The expert in **WATER ENVIRONMENTS**

Report

423 King St E – Unit 2
Cambridge, ON N3H 3N1

Tel: (519) 650-4545

e-mail: pad@dhigroup.com
Web: www.dhigroup.com

Rockcliffe SPA 2D Flood Modelling and Mapping Update

Client	Client's representative
Toronto and Region Conservation Authority	Mr. Robert Chan

Project		Project No			
Rockcliffe SPA 2D Flood Modelling and Mapping Update 2020		42802963			
Author: Yi Wang and Patrick Delaney		Date: January 7, 2020			
		Approved by: Patrick Delaney			
Rev	Description	By	Checked	Approved	Date
0	Final Report	YIWA	PAD	PAD	1/7/20

Key words	Classification
	☐ Open ☐ Internal ☒ Proprietary

Distribution		No of copies 1
Client	Mr. Robert Chan	1 Copy (PDF)
DHI	Patrick Delaney	

Table of Contents

List of Figures

1 Introduction

In 2018 DHI developed a 1D-2D MIKE FLOOD hydraulic model of Black Creek for the Rockcliffe Special Policy Area for the purpose of updating the regulatory floodplain maps and characterizing flooding in the area for a range of design storm events (DHI, 2018). The MIKE FLOOD model delivered for that project used the finite difference solver for 2D overland flow and the model required more than 24 hours to run each simulation. The required run-time for the model made it difficult work with and to use for evaluating flood mitigation measures and potential impacts of proposed developments within and adjacent to the special policy area. In addition, follow-up investigation by TRCA revealed that the Lavender Creek culvert at Symes Road is likely causing some of the flooding problems experienced in this area.

In response to this, TRCA conducted a survey of Lavender Creek and the associated road crossing structures and began updating the Rockcliffe SPA MIKE FLOOD model to include a 1D model representation of Lavender Creek. In addition, the model was also updated as described below:

- The hydrological inflow boundary condition representing Lavender Creek was removed and inflow locations and flows were modified to correspond to the updated Humber River hydrology model (Civica, 2018).

- The downstream section of the model was expanded to include a short section of the Humber River to better represent backwater impacts in Black Creek.

- The 2D overland flow model was modified to use the finite volume (flexible mesh) solution of MIKE 21 in order to reduce the computational time.

DHI was hired by TRCA to complete the update of the Rockcliffe SPA MIKE FLOOD model and to update the regulatory floodplain map for the model domain.

2 Update the Existing Coupled 1D-2D Hydraulic Model

2.1 Define the Model Domain

The previous MIKE FLOOD model domain was expanded in the downstream section to include a section of Humber River from upstream of Scarlett Rd to Dundas St W. The horizontal extent was set to avoid any overland flooding reaching the edge of the model domain (thus avoiding a 2D model boundary condition). The model domain extent is shown in Figure 1.

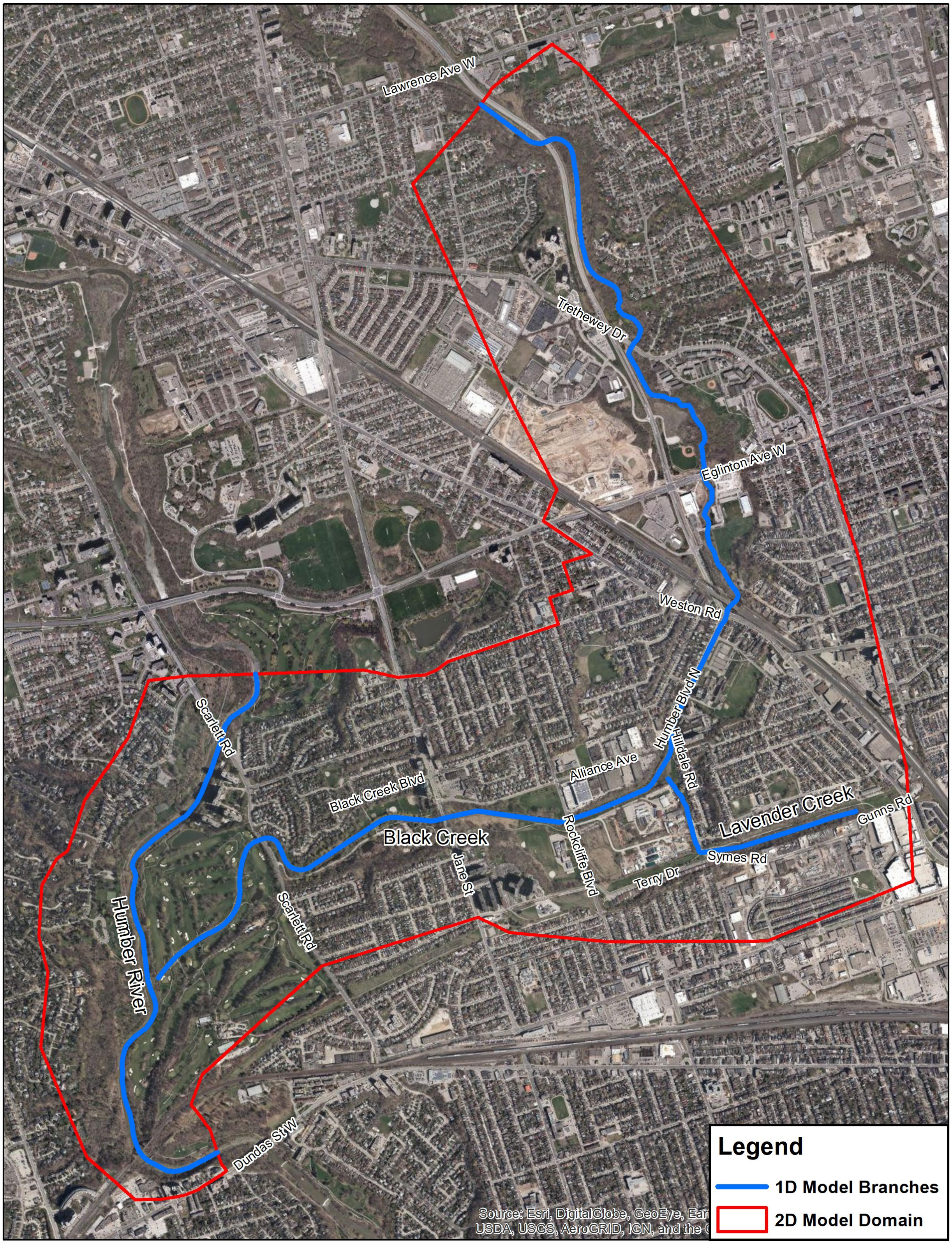


Figure 1   2D model domain and 1D river model network

2.2 1D Model Development

In addition to adding Lavender Creek and Humber River to the 1D channel model, the updated model also includes many additional updates and improvements to the 1D model. This section describes the setup of the 1D channel model, with focuses on the changes made to the existing model in this study.

2.2.1 Numerical Engine

The previous Rockcliffe SPA MIKE FLOOD model used the MIKE 11 software and numerical engine to solve for flow and water levels in the 1D channel model. The updated Rockcliffe SPA model uses the MIKE HYDRO River software and the MIKE 1D numerical engine for modelling the 1D channel network. The reason for making this change is because the MIKE 11 software and numerical engine will soon become obsolete.

2.2.2 1D Channel Network

The 1D model consists of three branches representing Humber River, Black Creek, and Lavender Creek. The Black Creek branch starts immediately downstream of the Lawrence Avenue Bridge and ends at the confluence with Humber River. The Humber River branch starts from upstream of Scarlett Road to upstream of Dundas Street West, and the Lavender Creek branch starts at Gunn Road and extends to the confluence of Black Creek.

There are several other small tributaries which contribute flow to Black Creek but they are accounted for as inflow boundary conditions to Black Creek rather than explicitly represented as 1D branches in the model.

2.2.3 1D Channel Cross Sections

The original Rockcliffe SPA MIKE FLOOD model cross-sections were extended laterally, where possible, to allow for more of the flow in the channel to be represented in the 1D model (see Figure 2). MIKE HYDRO River tools were used to extract the cross-section elevations from LiDAR data for Black Creek and Lavender Creek at distances of 10-15 m between each cross-section. The channel cross-sections for Black Creek on the west side of Scarlett Road and for the Humber River branch were imported from the existing HEC-RAS model.

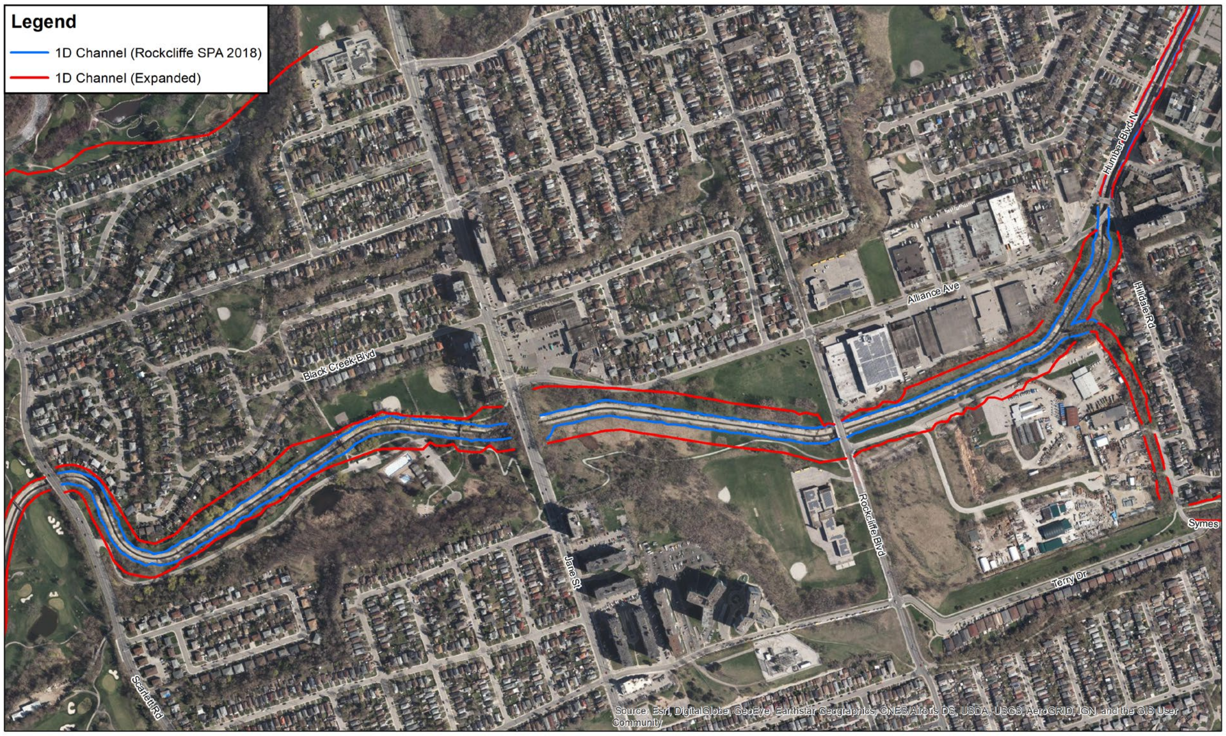


Figure 2 Channel Expansion between Alliance Ave. and Scarlett Rd

The LiDAR generated cross-sections for the stretch of Black Creek between Weston Road and Alliance Avenue (chainage 4082 m to 4670 m) were then modified with manually prepared cross-section geometries based on measurements of the rectangular concrete channel provided by TRCA (measurements were provided via a diagram received on July 14th 2017 – see Figure 3). The dimensions of the low flow channel were not provided so it was estimated to be 0.20 m deep, 2.5 m wide at the bottom and 4 m wide at the top. The top of the rectangular channel for each cross-section was blended into the adjacent LiDAR ground surface.

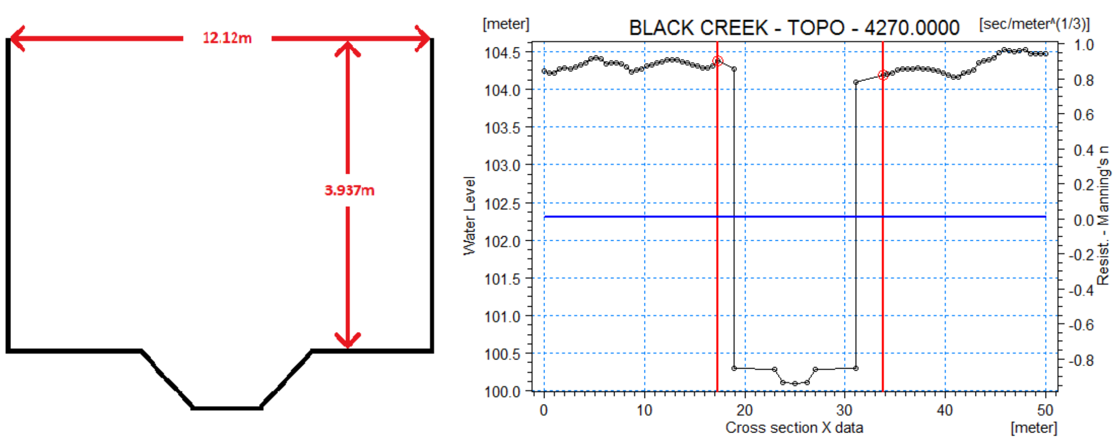


Figure 3 Cross section sketch and inserted between Weston Road and Alliance Avenue

A comparison between a cross section derived from LiDAR and the received drawing is shown in Figure 4 where it can be seen that the bottom and edges are more precisely defined using the channel dimensions obtained from the diagram.

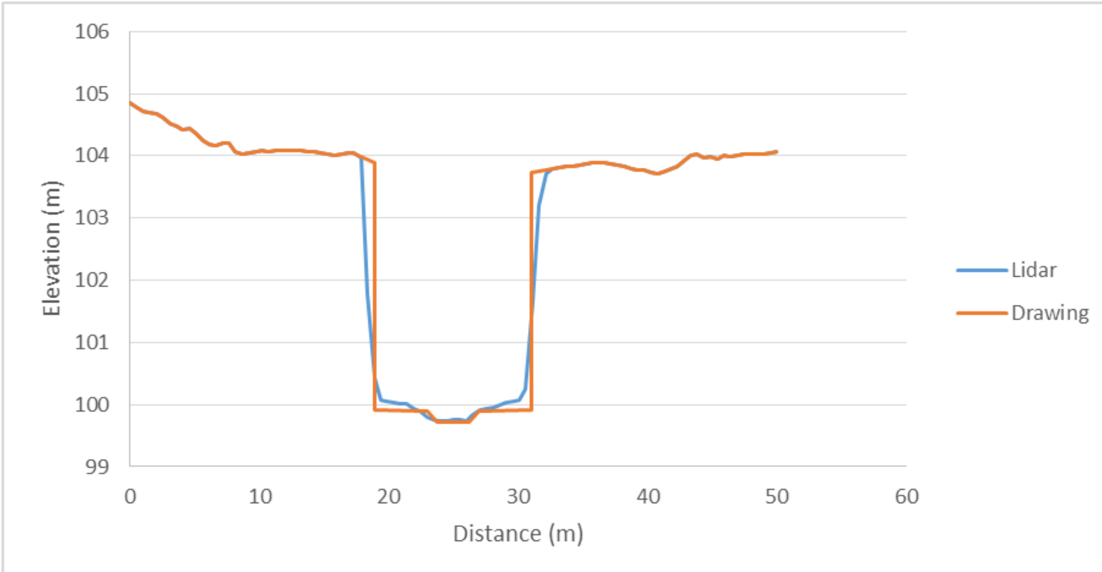


Figure 4 Comparison of cross section geometry derived from LiDAR vs. drawing.

2.2.4 1D Channel Roughness

Table 1 provides a summary of the Manning's n roughness values used in the 1D model channels. In the original Rockcliffe SPA MIKE FLOOD model, the roughness values were inherited from the original HEC-RAS model of Black Creek. In the absence of any flow measurements to calibrate the model, the original roughness values were used in order to maintain consistency with the previous modelling studies. In the updated model, the roughness values from the original Rockcliffe SPA MIKE FLOOD model are preserved. For the cross-sections that were extended, the roughness value for the extended segments was assigned using distributed roughness values according TRCA standard land use roughness values (see Figure 5).

The upstream section of Black Creek from chainage 1150 m to 4005 m consists of natural channel with mostly uniform Manning's n value of 0.035 throughout. Downstream of chainage 4005 m the channel is engineered concrete with a mainly uniform Manning's n value of 0.013.

Downstream of Scarlett Road, the Black Creek cross sections have an extra low flow channel on the left side with a Manning's n of 0.035. This was present in the original HEC-RAS model and it was maintained in the 1D model.

Lavender Creek consists of an engineered concrete channel from Gunn Road to Symes Road, and then a natural channel from Symes Road to the Black Creek.

Humber River cross-sections and roughness values were inherited from the existing HEC-RAS model and were maintained for the updated Rockcliffe SPA MIKE FLOOD model.

Table 1 Summary of channel roughness values (Manning's n)

Start Chainage (m)	End Chainage (m)	Left High Flow ($s/m^{1/3}$)	Low Flow ($s/m^{1/3}$)	Right High Flow ($s/m^{1/3}$)
Black Creek				
1150	1200	0.08	0.035	0.08
1210	4005.3		0.035	
4014.3	4620		0.013	
4660	6741.2	Distributed	0.013	Distributed
Lavender Creek				
0	680	0.08	0.013	0.08
740	1060	0.08	0.035	0.08
Humber River				
47.18	2805.01		0.013	

2.2.5 1D Model Boundary Conditions

The boundary conditions consist of unsteady inflow boundary conditions at the upstream end of Black Creek, Lavender Creek and Humber River, a Q-H rating curve at downstream end of Humber River, and a series of unsteady inflows along the branches to account for tributary inflows and stormwater outfalls.

The upstream inflow boundary conditions for Black Creek, Lavender Creek and Humber River and the internal inflows were provided by TRCA from the Humber River Hydrology Update (Civica, 2018). The Q-H boundary at the downstream end of the Humber River was also provided by TRCA as derived from the results of the Humber River HEC-RAS model.

The locations of the boundary conditions and associated peak flows are shown in Figure 6.

2.2.1 1D Model Structures

There are 16 structures in the model consisting primarily of bridges and road crossings (see locations shown in Figure 7). Most of the bridges have been modelled as combined culvert and weir structures where culverts are used to represent the bridge opening and weirs are used to represent the bridge decks. All of the culvert geometries were inherited from the original HEC-RAS model of Black Creek and some have been modified according to recently collected field survey data. The dimensions of the structures on Lavender Creek were obtained by TRCA during the field survey conducted in 2018.

Table 2 provides a summary of the dimensions for each of the bridges, culverts and crossings followed by a description of the setup for each bridge.

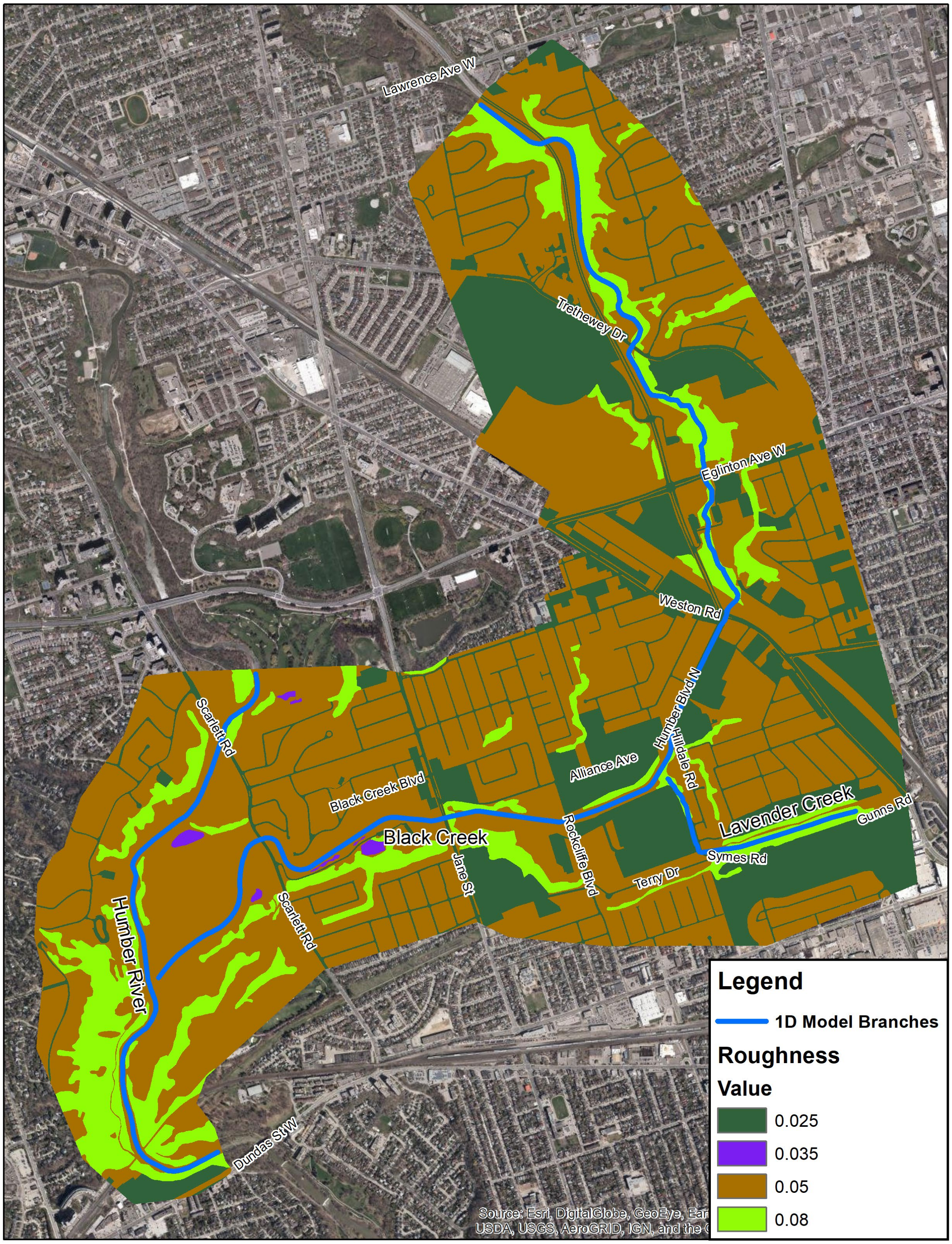


Figure 5 Roughness Values for the Model Domain

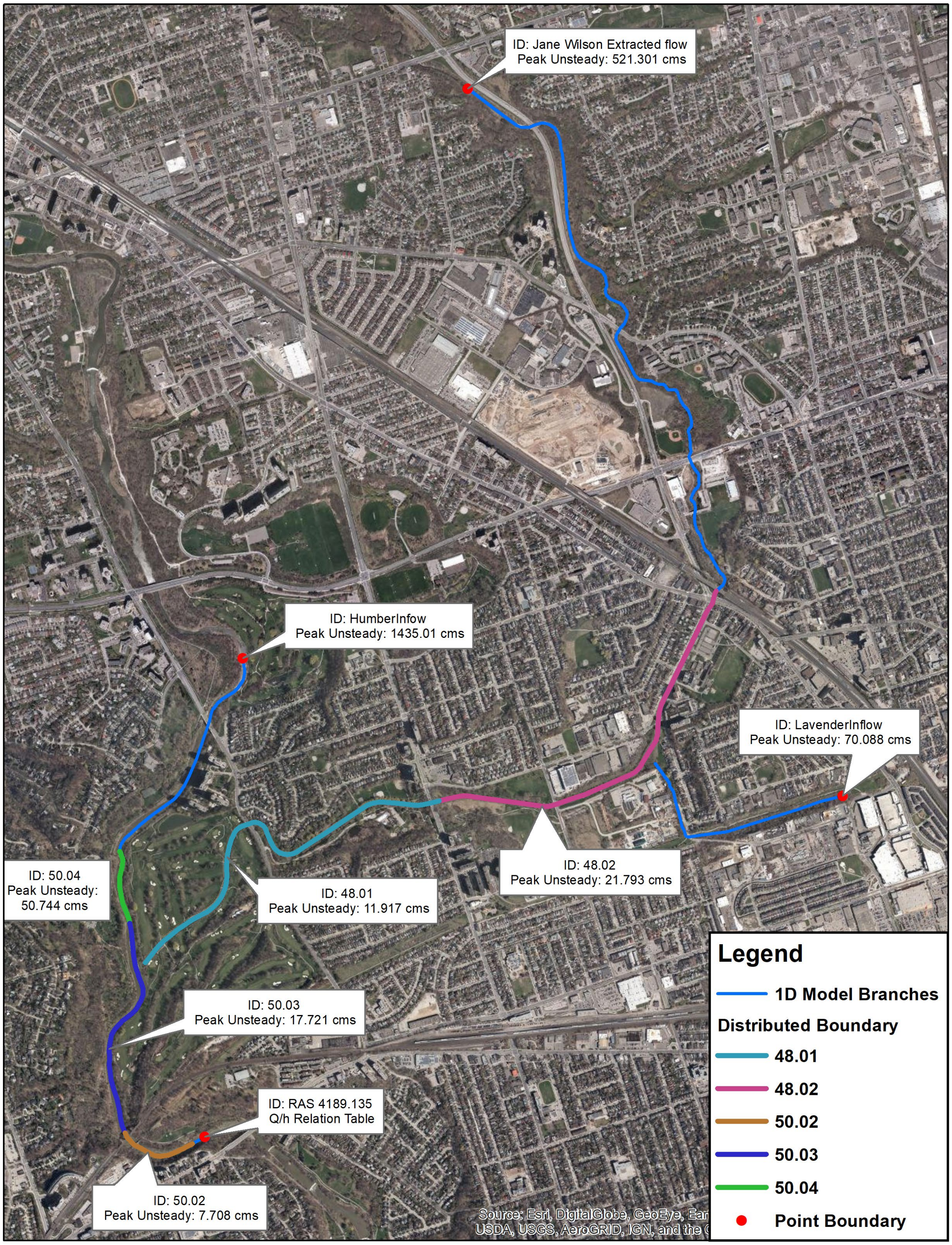


Figure 6 1D Model Boundary Condition Locations and Values

Figure 7 Location of Hydraulic Structures in the 1D Model

Table 2 Model structure locations and dimensions

Chainage	Location Name	Up-stream Invert Level (m)	Soffit Level* (m)	Deck Level* (m)	Area (m^2)	Length (m)	Manning's n
Black Creek							
1484.30	Black Creek Drive	111.57	115.84	116.00	75.5	22	0.035
2605.42	Trethewey Drive	107.42	110.58	110.90	38.4	18	0.035
3364.88	Eglinton Avenue West	105.00	108.60	110.70	78.0	28	0.035
4005.34	CNR	102.31	119.03		520.682	6	0.035
4047.91	Weston Road	100.87	106.10	106.88 / 107.15**	51.0	29	0.035
4610.00	Humber Boulevard	99.24	103.82	105.30	52.5	9	0.013
4641.73	Alliance Avenue	99.5	104.12	105.00	52.9	13	0.013
5262.65	Rockcliffe Boulevard	98.39	102.84	103.45	56.3	10	0.013
5808.15	Jane Street	97.76	104.47	108.37	54.6	45	0.013
6753.81	Scarlett Road	94.10	99.06	100.40	54.2	19	0.013
Lavender Creek							
707.28	Symes Rd	102.92	106.58		3.5	43.2	0.013
777.11	Bridge 2	101.77	104.21	104.8	10.8	8	0.035
857.3	Bridge 1	101.51	104.77	105.01	14.1	13.5	0.035
Humber River							
392.24	Scarlett Humber	96.35	100.43	101.67	258.5	23	0.035
2421.32	Railway	91.5	120.44		1714.2	9	0.035
2473.78	Pedestrian Bridge	91.44	94.91	94.5	151.6	2.5	0.035

Entrance and exit losses for each structure were set to 0.3 and 0.5, respectively, with the exception of Bridge 1 and Bridge 2 on Lavender Creek.

*In the cases where the soffit and deck are not flat, the elevation indicates the lowest point of the soffit and deck. The exception for this rule is the Jane Street structure where the soffit elevation represents the top of the arch.

** Weston Road bridge uses a special configuration (described below) to represent the overflow deck elevations

2.2.1.1 Black Creek Structures

Black Creek Drive Bridge

The Black Creek Drive bridge, at chainage 1484 m, is 22 m long. It has a cross section area of 75.5 m^2 and a geometry (see Figure 8) defined by a Depth-Width table. The bridge deck is represented as a weir structure with a crest level defining the deck of the bridge and sidewalls at the edge of the channel to properly calculate the potential range of flows in the Q-H table for the weir.

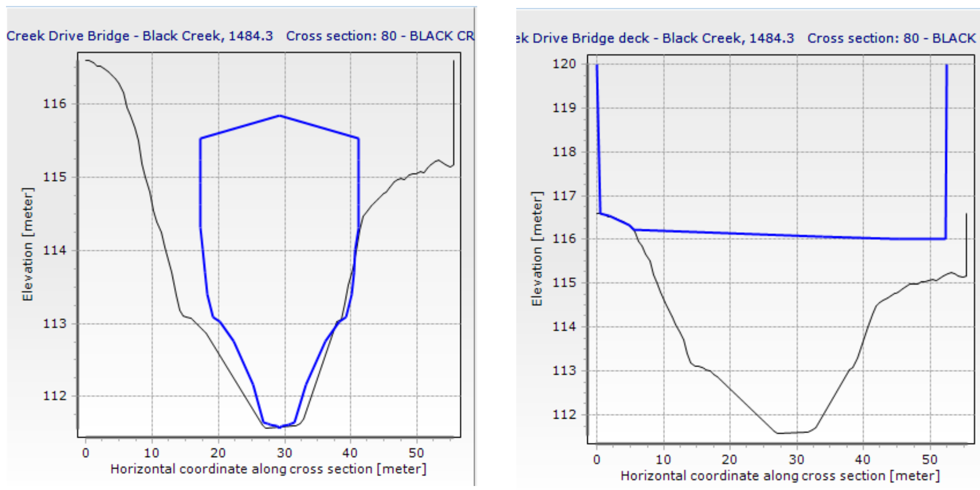


Figure 8 Black Creek Drive Bridge Culvert and Weir Geometries

Tretheway Bridge

The Trethewey Drive bridge, located at chainage 2605 m, is 18 m long. It has a cross section area of 38.4 m^2 and a geometry (see Figure 9) defined by a Depth-Width table. The bridge deck is represented as a weir structure with a crest level defining the deck of the bridge and sidewalls at the edge of the channel to properly calculate the potential range of flows in the Q-H table for the weir.

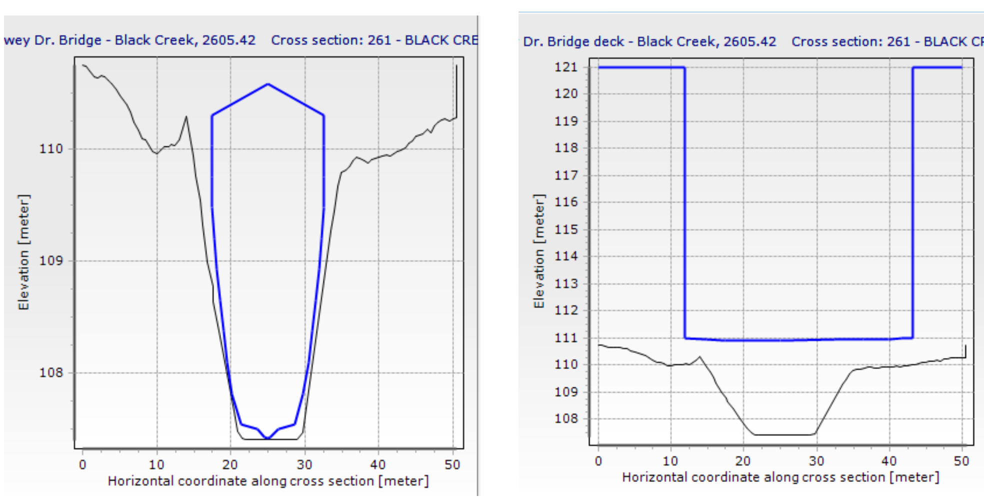


Figure 9 Trethewey Drive Bridge Culvert and Weir Geometries

Eglinton Bridge

The Eglinton Avenue West Bridge, at chainage 3365 m, is 28 m long. It has a cross section area of 78 m^2 and a geometry (see Figure 10) defined by a Level-Width table for the downstream. The bridge deck is represented as a weir structure with a crest level defining the deck of the bridge and sidewalls at the edge of the channel to properly calculate the potential range of flows in the Q-H table for the weir.

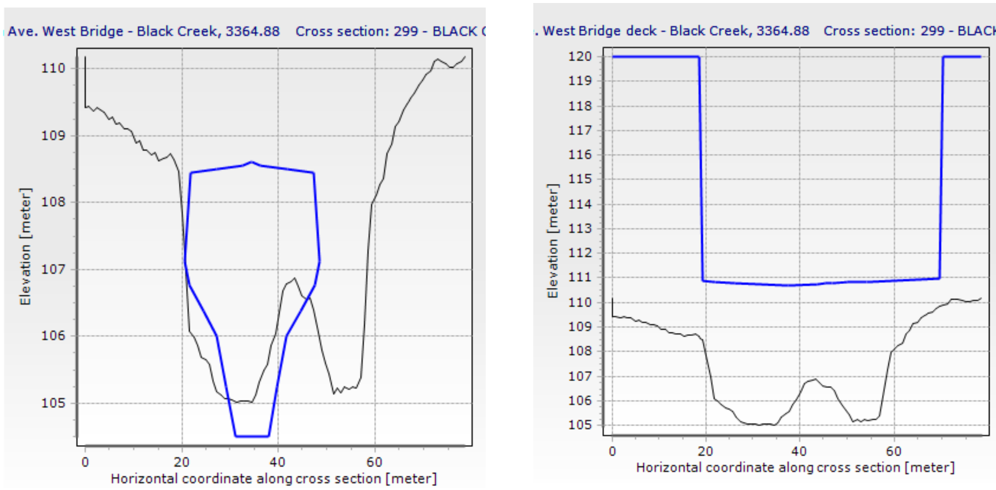


Figure 10 Eglinton Avenue West Bridge Culvert and Weir Geometries

CNR Bridge

The CNR bridge, at chainage 4005 m, is 6 m long. It has an open Cross Section geometry (see Figure 11). The bridge deck is not represented in the model because it is too high for the water level to practically reach under the Regional Storm event.

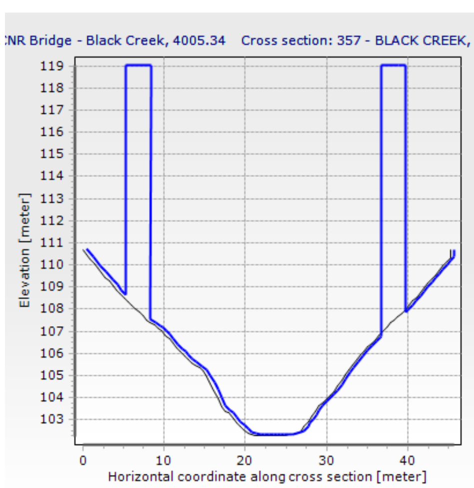


Figure 11 CNR Bridge Culvert Geometry

Weston Road Bridge

The Weston Road bridge, at chainage 4048 m, is 29 m long. It has a culvert with cross section area of 51 m^2 and a geometry (see Figure 12) defined by a Depth-Width table using the same geometry as the HEC-RAS model. The downstream invert was defined using TRCA's field survey data and the upstream invert was defined by assuming the bridge deck was 0.7 m thick and subtracting the height of the opening and the deck thickness from the surface elevation of the bridge.

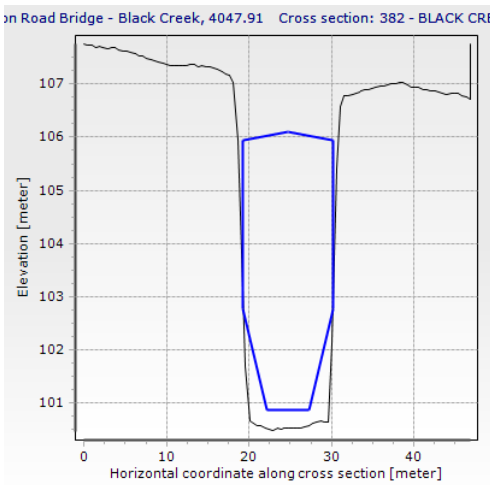


Figure 12 Weston Road Bridge Culvert Geometry

The deck of the Weston Road bridge was handled differently than the other bridges. Weston Road has a considerable slope in the road from the upstream side to the downstream side and each side has a concrete barrier along the section of the bridge crossing over the channel. This arrangement makes it highly unlikely that flow overtopping the upstream barrier will flow directly over the downstream barrier and into the channel. The more likely scenarios is for flow overtopping the upstream concrete barrier to flow around the downstream barrier and along Humber Boulevard North and Humber Boulevard South.

This was represented in the model by including the Weston Road bridge surface in the 2D model and using Standard Links to connect the flow overtopping the channel to the top of the road surface. A similar standard link was used to connect the downstream side of the Weston Road bridge surface to the downstream 1D channel. The standard links were created at the end of short branches that were added to the main channel on the upstream and downstream sides of the bridge. Each short branch consists of a cross-section at the confluence with the main channel, a weir representing bridge deck and barriers, and another cross-section on top of the bridge for the standard link connection with 2D model. Figure 13 shows the structure set up at Weston Rd Bridge. This representation allows flood water from 1D channel to overtop the bridge deck and exchange with water in 2D model domain. It also allows flooding to cross over the bridge in the 2D model, perpendicular to the direction of flow in the 1D channel model.

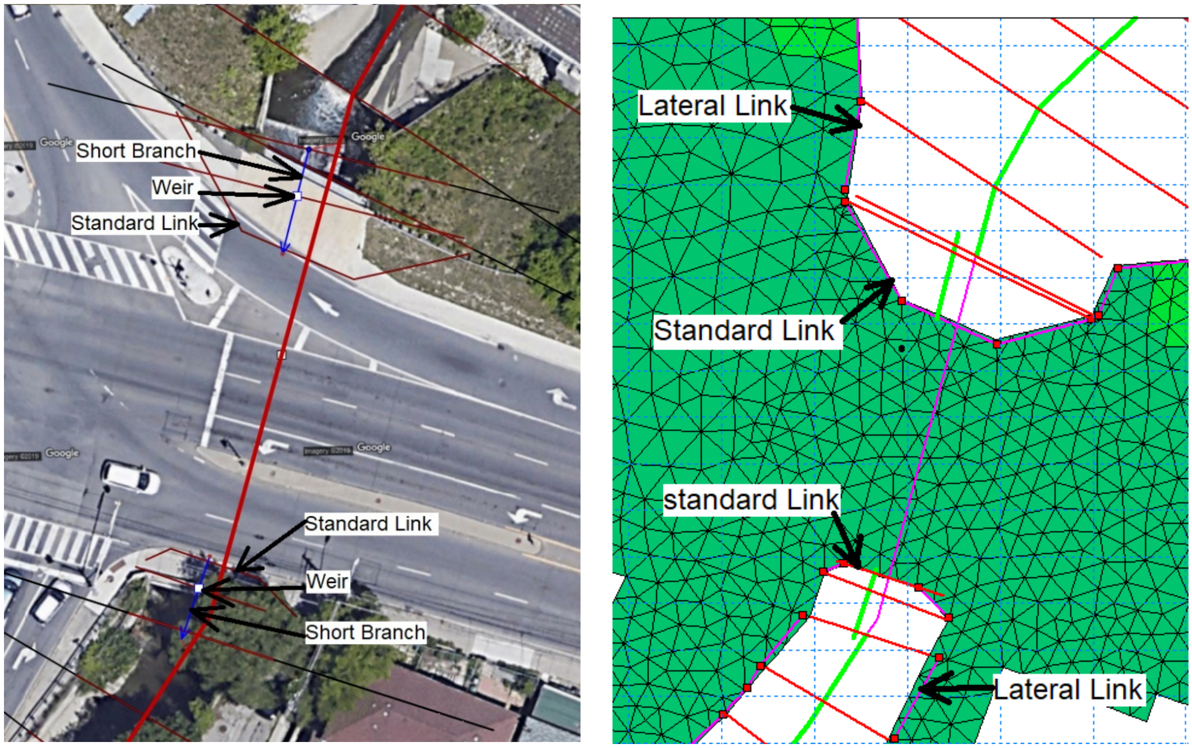


Figure 13 Weston Rd. Bridge Deck Setup in MIKE Flood Model

Humber Boulevard Bridge

The Humber Boulevard bridge at chainage 4610 m is 9 m long. It has a cross section area of 52.5 m^2 (see Figure 14) described in the model using a Depth-Width relationship. The bottom and sides have been dimensioned the same as the upstream cross sections because photos show there is no cross sections changes under the bridge. The invert levels were defined according to TRCA's field survey and the soffit elevation was not changed from the original Rockcliffe SPA MIKE FLOOD model. The bridge deck is represented as a weir structure with a crest level defining the deck of the bridge and sidewalls at the edge of the channel to properly calculate the potential range of flows in the Q-H table for the weir.

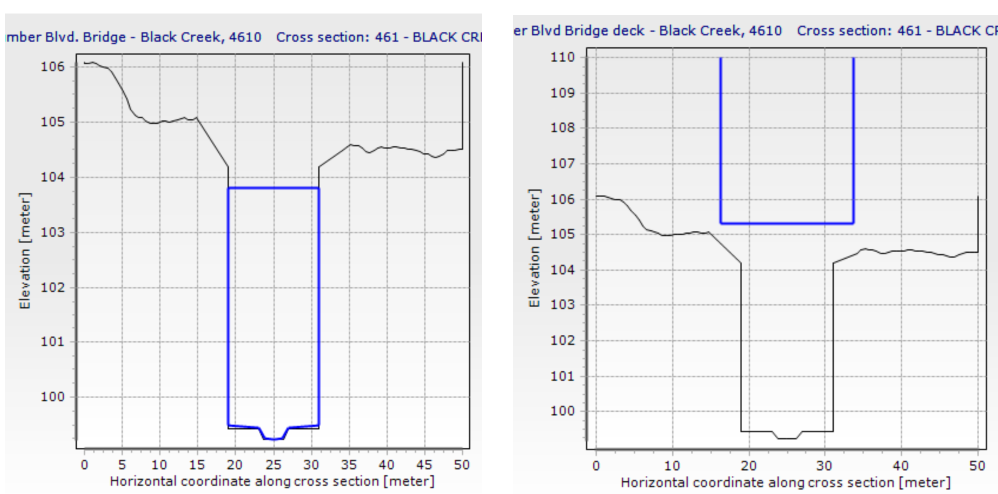


Figure 14 Humber Boulevard Bridge Culvert and Weir Geometries

Alliance Avenue Bridge

The Alliance Avenue bridge at chainage 4642 m is 13 m long. It has a cross section area of 52.9 m^2 (see Figure 15) and is described in the model using a Depth-Width relationship. The bottom and sides have been dimensioned the same as the upstream cross-sections because photos show there is no cross sections changes under the bridge. The invert levels were defined according to TRCA's field survey and the soffit elevation was not changed from the original Rockcliffe SPA MIKE FLOOD model. The bridge deck is represented as a weir structure with a crest level defining the deck of the bridge and sidewalls at the edge of the channel to properly calculate the potential range of flows in the Q-H table for the weir.

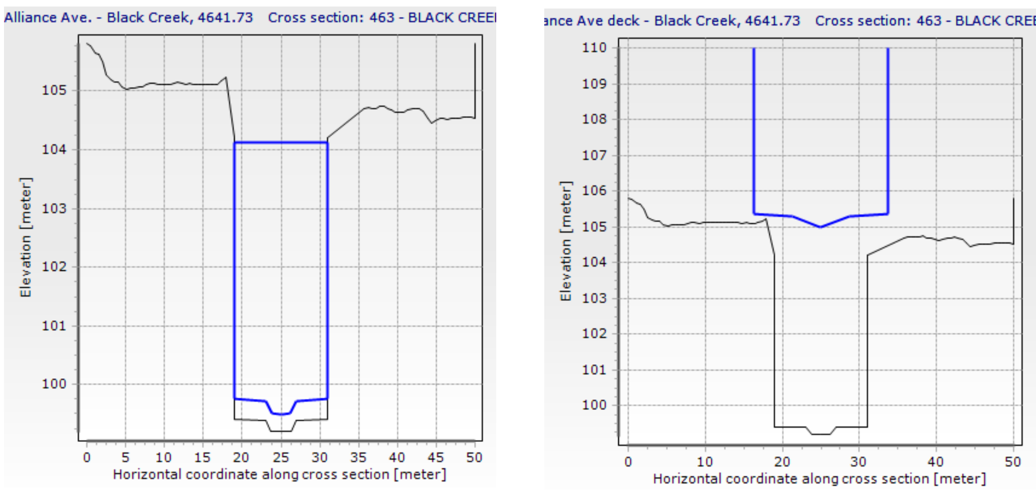


Figure 15 Alliance Avenue Bridge Culvert and Weir Geometries

Rockcliffe Boulevard Bridge

The Rockcliffe Boulevard bridge at chainage 5263 m is 10 m long. It has a cross-section area of 56.3 m^2 (see Figure 16) described in the model using a Depth-Width relationship, including updating the the bottom to include the low flow channel that was absent in the original MIKE FLOOD model. The inverts of the culvert was updated according to the TRCA field survey of the channel. The bridge deck is represented as a weir structure with a crest level defining the deck of the bridge and sidewalls at the edge of the channel to properly calculate the potential range of flows in the Q-H table for the weir. The concrete barrier on the upstream and downstream side of the bridge was manually added to the weir crest geometry using an assumed height of 0.5 m.

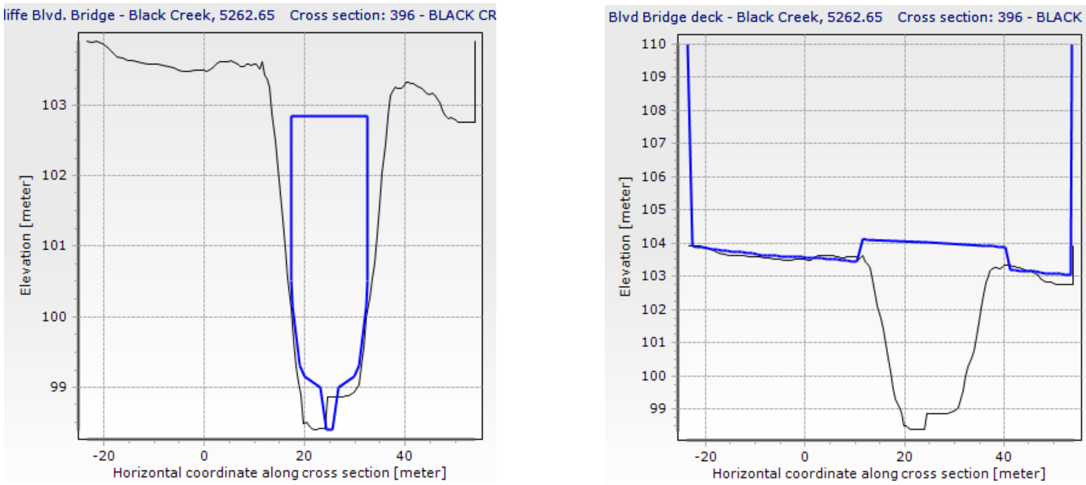


Figure 16 Rockcliffe Boulevard Bridge Culvert and Weir Geometries

Jane Street Crossing

The Jane Street crossing at chainage 5808 m is 45 m long. The dimensions of the culvert were update from the original model using as-built drawings provided by TRCA showing the shape of the culvert arch and the typical channel bottom. The culvert has an area of 54.6 m^2 (see Figure 17) described in the model using a Depth-Width relationship. The upstream and downstream inverts were defined according to TRCA's field survey data. The bridge deck is represented as a weir structure with a crest elevation defining the deck of the bridge.

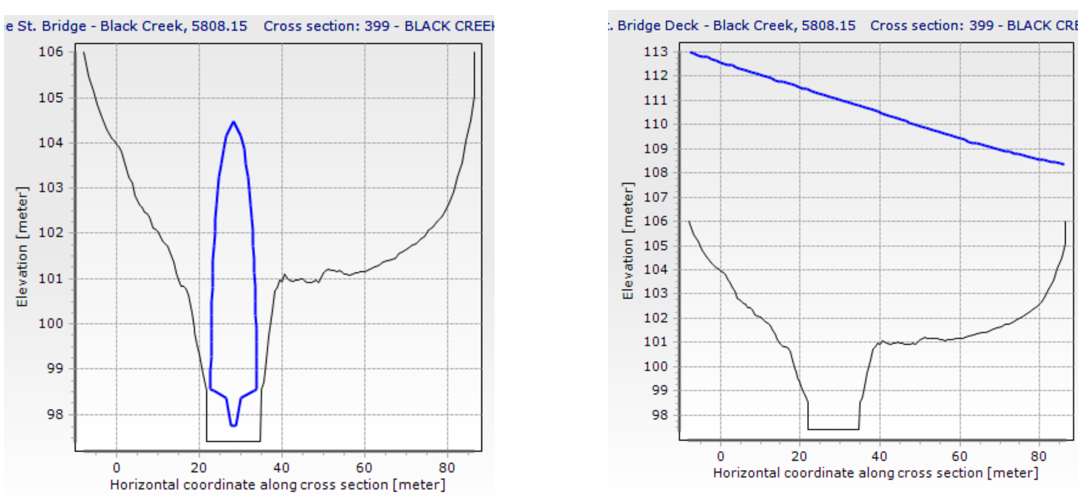


Figure 17 Jane Street Bridge Culvert and Weir Geometries

Scarlett Road Bridge

Scarlett Road Bridge at chainage 6754 is 19 m long. It has a cross section area of 54.2 m^2 (see Figure 18) described in the model using a Depth-Width relationship. The bridge deck is represented as a weir structure with a crest level defining the deck of the bridge and sidewalls at the edge of the channel to properly calculate the potential range of flows in the Q-H table for the weir.

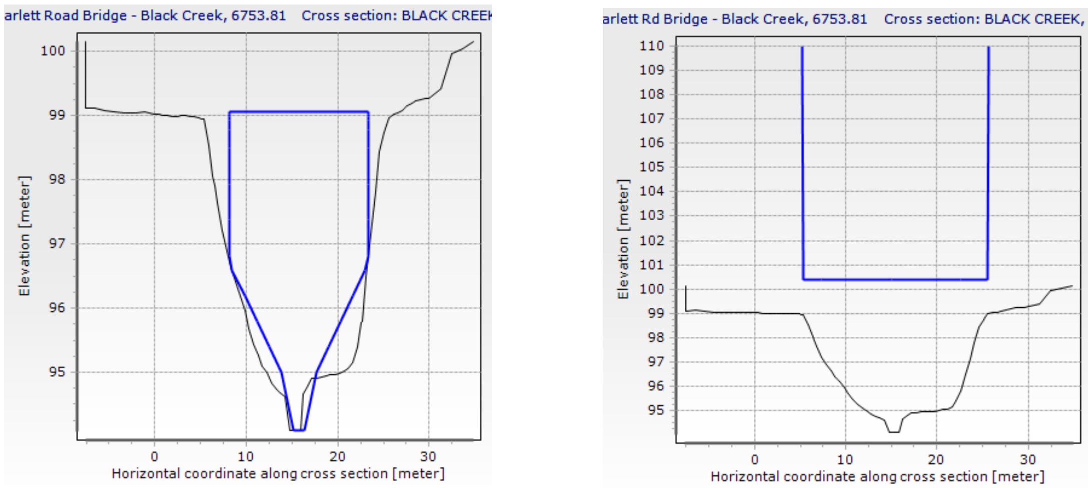
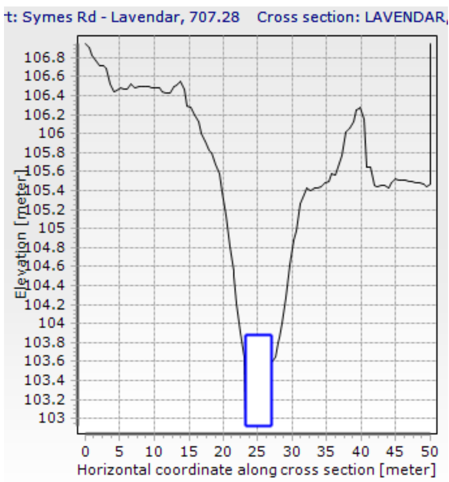


Figure 18 Scarlett Road Bridge Culvert and Weir Geometries

2.2.1.2 Lavender Creek Structures

Symes Road

The Symes Rd bridge at chainage 707 m is 43 m long. The culvert in 1D model has a cross section area of 3.5 m^2 (see Figure 19) described in the model using a rectangular shape. Lavender Creek takes a sharp turn at this location such that flooding overtopping the bridge deck does not necessarily return to channel at the downstream side of the culvert. The relatively flat topography of the area adjacent to the creek indicates a significant portion of flooding will leave the channel and flood the industrial area between Terry Drive and Black Creek, as well as the residential area along Hilldale Road. As such, the Symes Road structure did not include a weir structure to directly transfer overtopping from upstream to downstream. Instead, the road surface was included in the 2D overland flow model to allow flooding to cross the road.



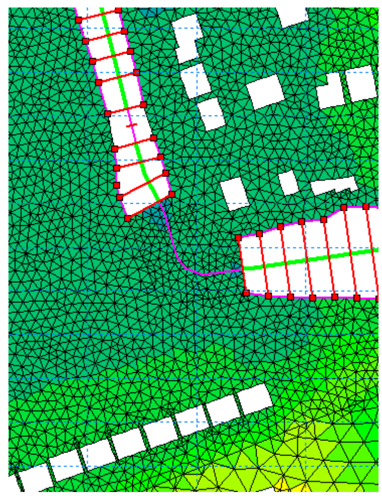


Figure 19 Syme Road Bridge Culvert Geometry and Deck Mesh Elements

Bridge 2

Bridge 2 at chainage 777 m is 8 m long. It has a cross section area of 10.8 m² (see Figure 20) described in the model using the Cross Section Database. The bridge deck is represented as a weir structure. Glass walls are added to the weir structure with a crest level defining the deck of the bridge and sidewalls at the edge of the channel to properly calculate the potential range of flows in the Q-H table for the weir.

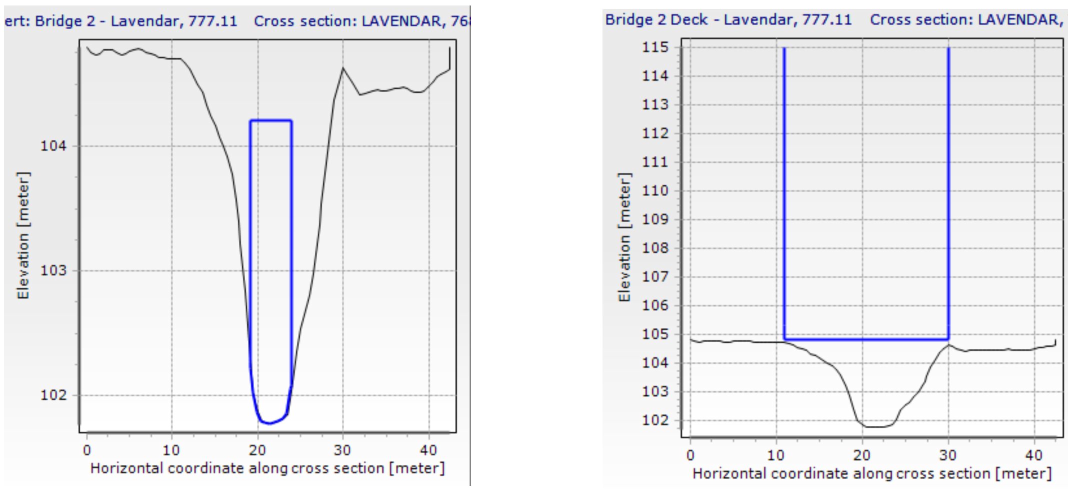


Figure 20 Lavender Creek Bridge 2 Culvert and Weir Geometries

Bridge 1

Bridge 1 on Lavender Creek at chainage 857 m is 13.5 m long. It has a cross section area of 14.1 m² (see Figure 21) described in the model using the Cross Section Database. The bridge deck is represented as a weir structure with a crest level defining the deck of the bridge and sidewalls at the edge of the channel to properly calculate the potential range of flows in the Q-H table for the weir.

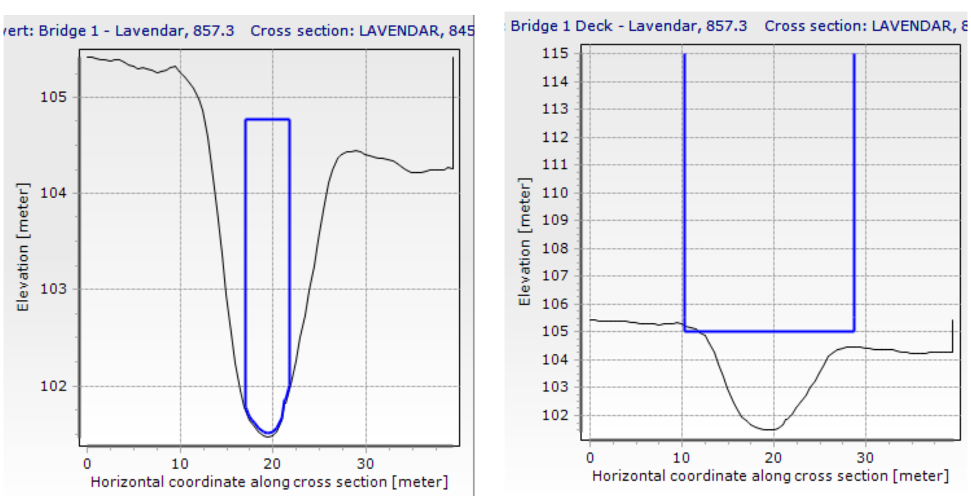


Figure 21 Lavender Creek Bridge 1 Culvert and Weir Geometries

2.2.1.3 Humber River Structures

Scarlett Road Bridge

Scarlett Rd Bridge at chainage 392 m is 23 m long. It has a cross section area of 258.5 m^2 (see Figure 22) described in the model using Cross Section Database. The bridge piers are represented in the cross section as pairs of vertical walls. The bridge deck is represented as a weir structure with a crest level defining the deck of the bridge and sidewalls at the edge of the channel to properly calculate the potential range of flows in the Q-H table for the weir.

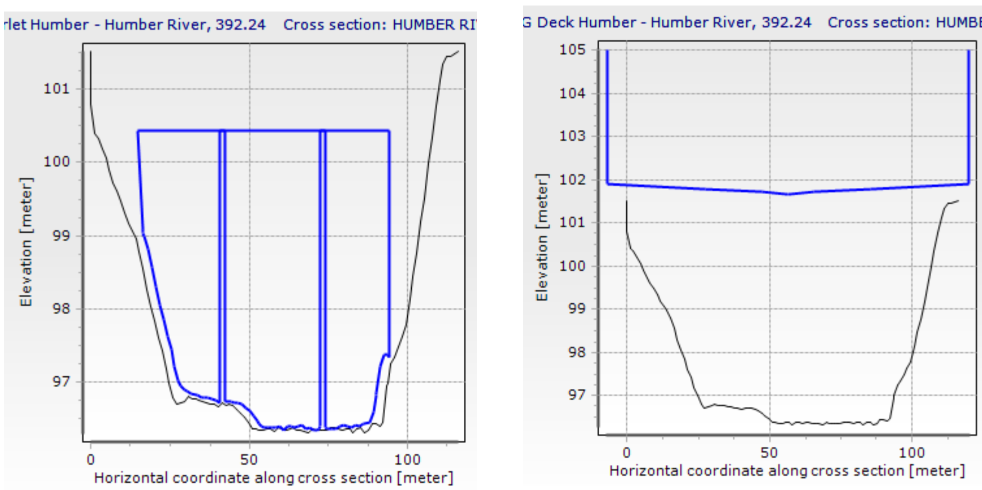


Figure 22 Humber River Scarlett Road Bridge Culvert and Weir Geometries

Railway Bridge

The Railway Bridge at chainage 2421 m is 9 m long. It has an open Cross Section geometry (see Figure 23). The bridge deck is not represented in the model because it is too high for the water level to reach under any modelled storm.

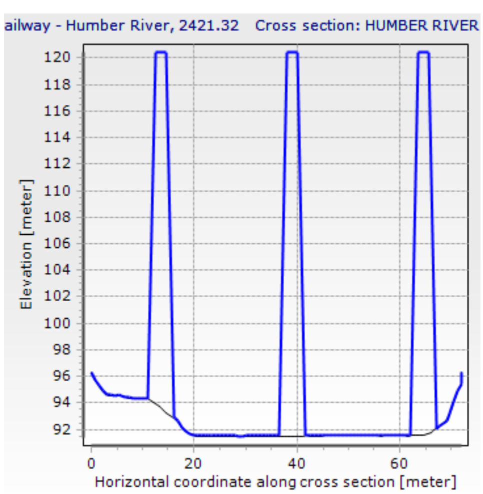


Figure 23 Humber River Railway Bridge Culvert Geometry

Pedestrian Bridge
The Pedestrian Bridge at chainage 2474 m is 2.5 m long. It has a cross section area of 151.6 m^2 (see Figure 22) described in the model using the Cross-Section Database. The bridge deck is represented as a weir structure with a crest level defining the deck of the bridge and sidewalls at the edge of the channel to properly calculate the potential range of flows in the Q-H table for the weir.

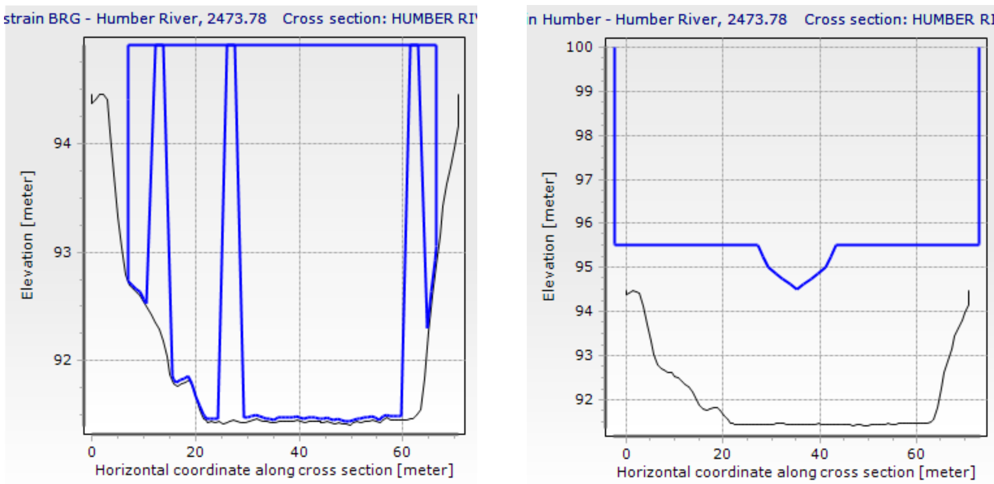


Figure 24   Humber River Pedestrian Bridge Culvert and Weir Geometries

2.2.2   1D Model Settings

The 1D model has been set up with the following settings:

- Engine: MIKE 1D
- Initial Conditions: Water Depth = 0 m and Discharge = 0 m^3/s
- Simulation period unsteady: 1/1/2017 12AM – 1/2/2017 12PM
- Timestep: 1 second
- Results: Storing frequency = 1 minute

2.3 2D Model Setup

The MIKE 21 2D Overland Flow model was constructed using the Flexible Mesh version of MIKE 21 (MIKE 21 FM). The Flexible Mesh model was chosen because the time required for a simulation can be dramatically reduced using parallel processing techniques. The following is a description of the 2D model setup.

2.3.1 2D Model Topography

The model topography was defined using a flexible mesh (Figure 25) with a projection NAD_1983_UTM_Zone_17N. The elevations for the mesh nodes were interpolated from the 1m resolution LiDAR data. The building areas were excluded from the mesh. The 1D river channels were excluded from the mesh to avoid double counting channel flow in both the 1D and 2D model. The horizontal extent of the model domain was chosen such that flooding from the main water courses would not reach the edges of the model domain. Building footprints were excluded from the 2D model mesh such that they represented barriers to overland flow.

The mesh was configured to have a maximum area of 5-15 m^2 in the areas where overland flooding is expected and 100 m^2 elsewhere in the model domain.

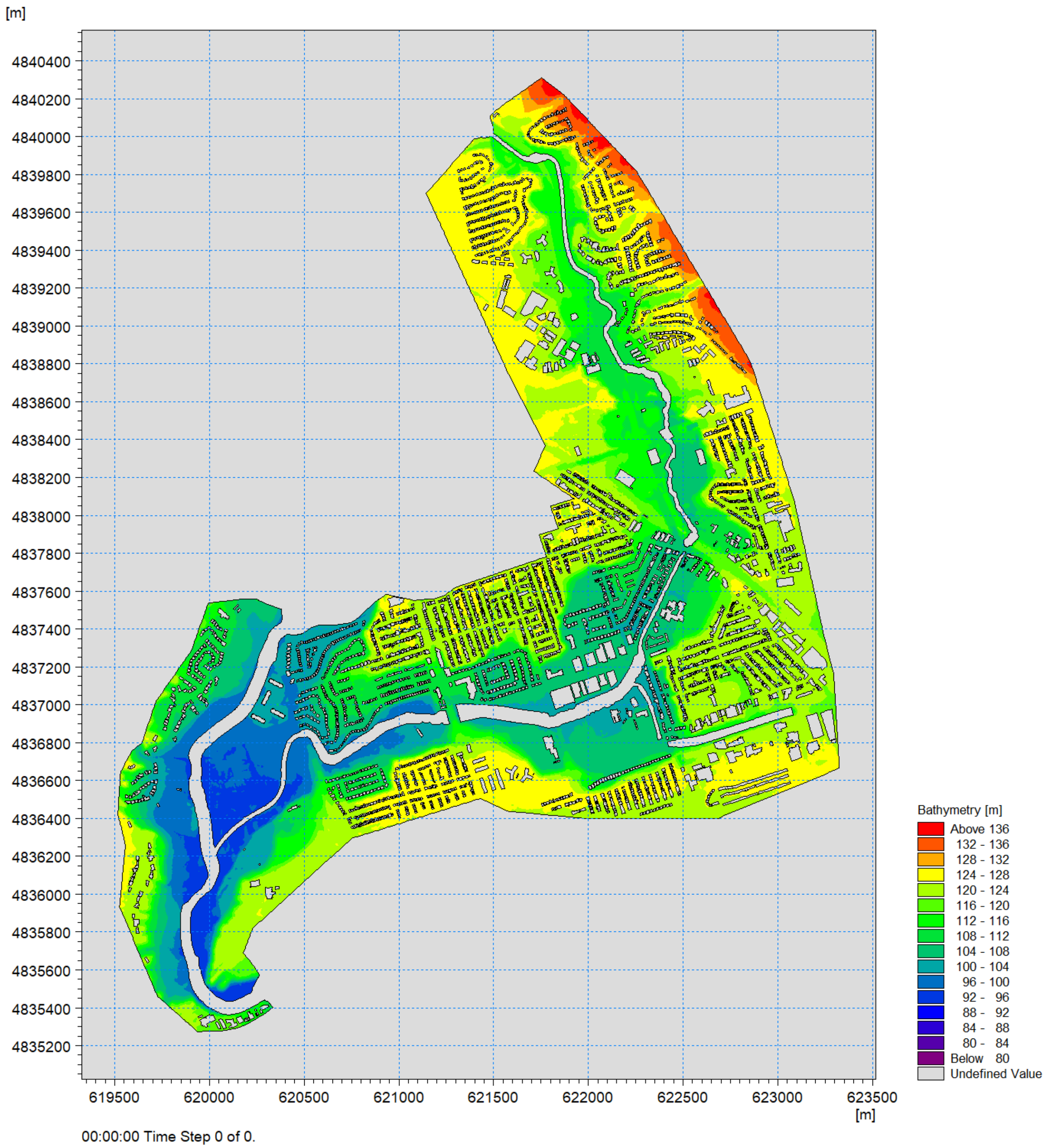


Figure 25 Map of topography used in the MIKE 21 FM model

2.3.2 2D model roughness

The roughness in a MIKE 21 FM model is defined using a Manning's M value (Manning's n is the inverse of Manning's M). A land use shape file was used to generate a map of representative roughness values throughout the study area using TRCA standard roughness values. The roughness values used in the model are listed in Table 3 and a map of roughness values is shown in Figure 26.

Table 3 Roughness used in the MIKE 21 FM model

Manning's M	Manning's n	Area Description
12.5	0.08	Scrubs and trees
20	0.05	Grass areas
25	0.04	Residential areas, including houses and gardens.
28.57	0.035	Water surface including ponds
40	0.025	Hard surfaces including roads and buildings

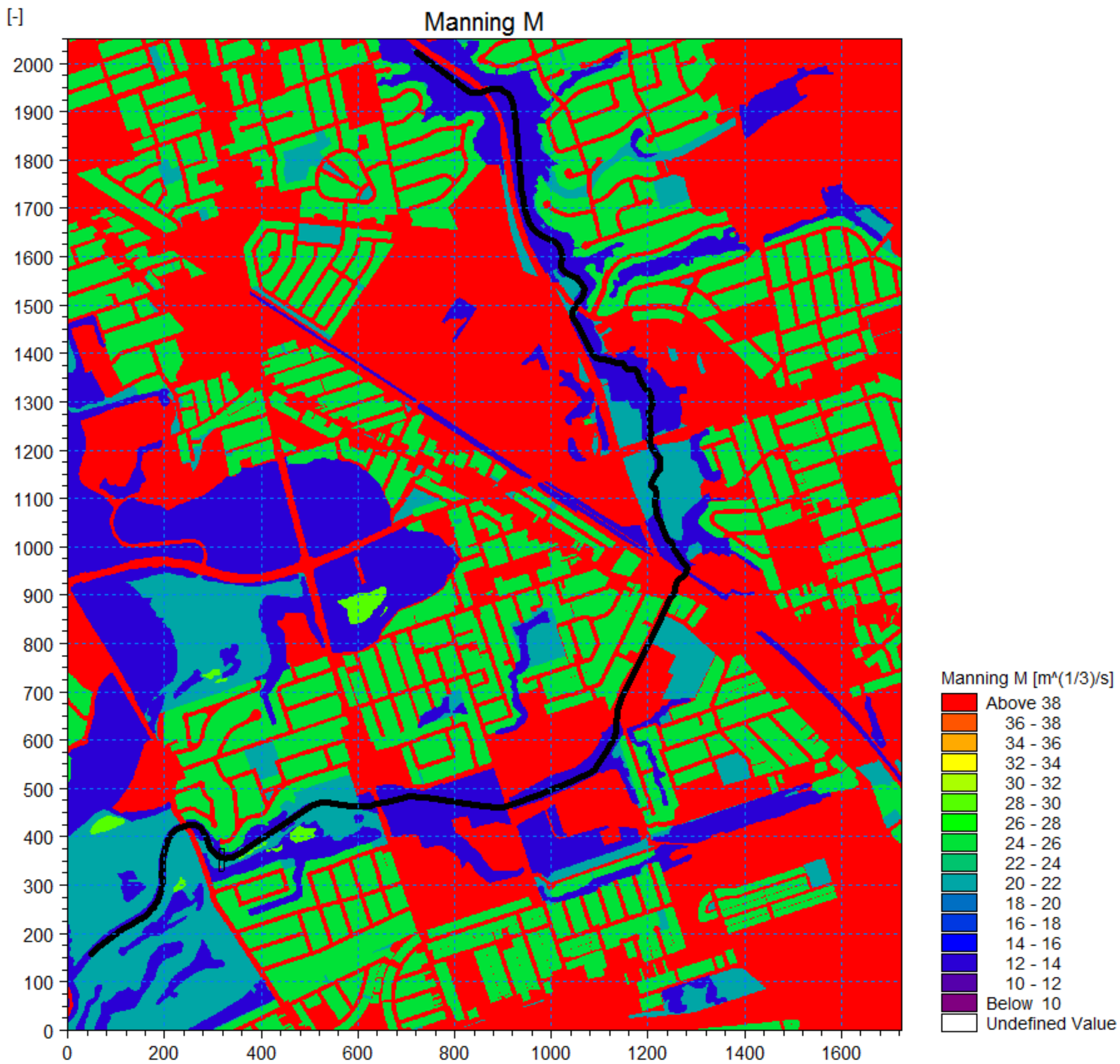


Figure 26 Roughness map used in the MIKE 21 model

2.3.3 2D Model Boundary Conditions

The 2D model has no formal 2D boundary conditions. All the water entering and leaving the 2D model domain is flowing from or to the 1D channel model. Any of the flooding that spills from the 1D channel eventually returns to the channel at downstream locations or remains pooled in a topographic depressions in the 2D model.

2.3.4 2D model settings

The 2D model has been run with the following setup:

- Solution period unsteady runs
  - Time step: 0.5 s
  - Number of time steps: 172,800
  - Start time: 01/01/2017 12:00:00 AM
  - End time: 01/02/2017 12:00:00 AM
- Flood and Dry
  - Flooding depth: 0.01 m
  - Wetting depth: 0.02 m
- Eddy Viscosity: Constant = 1 m^2/s
- Initial Conditions: Surface Water Elevation = 0 m
- Output:
  - Items: Surface Elevation, Total Water Depth, P Flux, Q Flux U Velocity, V Velocity, Current Speed
  - Frequency: 10 minutes (unsteady)

2.4 Coupled 1D-2D Model Development

The MIKE FLOOD software was used to couple the 1D channel model to the 2D overland flow model using Lateral Links along the left and right banks of the 1D model for Black Creek, Lavender Creek, and Humber River. The sections of the 1D model occupied by bridges have not been coupled with 2D model because the 1D model does not calculate water levels at the bridge structures. In cases where flow overtopped the bridges, the overtopping flow is maintained in the 1D model and is transferred directly downstream of the bridge. The Weston Road bridge and the Symes Road culvert were the exceptions. At the Weston Road bridge, Standard Links were used to transfer overtopping flow from the Black Creek channel to the 2D model bridge surface, and also from the 2D model bridge surface into the Black Creek channel on the downstream side of the bridge (see Section 2.2.1.1 and Figure 12 for a more detailed description). (see Section 3.2.5). At the Symes Road culvert, the bridge deck is not represented in 1D model because the channel takes a sharp bend and the ground is relatively flat so the overtopping flow from the channel spills to the areas adjacent to the channel (see Section 2.2.1.2 and Figure 19).

The lateral links used the default settings for all coupling locations along the 1D channel model (i.e. cell-to-cell calculation method, structure type of Weir 1, weir crest elevation source is HGH).

3 Mapping and Analysis of Flood Modelling Results

The flood model was run using Regional Storm and 350-Year Design Storm with an *unsteady* hydrograph flow. The inflow hydrographs for each event were provided by TRCA and were based on the Humber River Hydrology Update (Civica, 2018).

The results from the simulations were used to generate the Regulatory Floodplain Map and a series of maps showing a variety of result presentation formats including:

- Maximum flood depth maps
- Maximum surface water elevation maps
- Maximum velocity maps
- Maximum depth-velocity product maps
- Flood risk maps

Each of these result map types is described in the following sections with an example map provided.

3.1 Flood Maps

3.1.1 Regulatory Floodplain Maps

The Regulatory floodplain maps (Figure 27 and Figure 28) were prepared for the existing condition model runs representing Regional Storm Event and the 350-year Design Storm event. These floodplain maps show the maximum extent of flooding (flood lines) together with land surface contours and other significant surface features. The flood lines were generated using GIS processes to interpret the result files.

3.1.2 Maximum Flood Depth Maps

The maximum flood depth maps show the maximum depth of flooding at each mesh element during the entire simulation period. The maximum map is calculated from the dynamic result file with output time-steps every 10 minutes. Maximum flood depth maps are shown in Figure 29 and Figure 30.

3.1.3 Maximum Water Surface Level Maps

The maximum surface water elevation maps show the maximum water level at each model grid cell during the entire simulation period. The maximum water surface level is calculated from the dynamic result file with output time-steps every 10 minutes. Maximum WSL maps are shown in Figure 31 and Figure 32.

3.1.4 Maximum Velocity Maps

The maximum velocity maps show the maximum velocity of the flooding at each grid cell during the entire simulation period. The maximum velocity map is calculated from the dynamic result file with output time-steps every 10 minutes. Maximum flow velocity maps are shown in Figure 33 and Figure 34.

3.1.5 Maximum Depth-Velocity Product Maps

The maximum depth-velocity product maps show the maximum depth-velocity product at each mesh element during the entire simulation period. This is not a direct result output of MIKE FLOOD and it was calculated as the multiplication of the depth and velocity at each mesh element for each output time step. The maximum value for each mesh element was extracted after that. The reason for not simply multiplying the maximum level with the maximum velocity was that they may have peaked at different times. Maximum depth-velocity product maps are shown in Figure 35 and Figure 36.

3.1.6 Flood Hazard Maps

The Flood Hazard map shows the areas where at least one of three flood hazard criteria have been met during the simulation (at each output time-step). These criteria are adopted from the document, "Technical Guide - River & Stream Systems: Flooding Hazard Limit" (Ontario Ministry of Natural Resources, 2002):

- Flood depth > 0.8 m
- Velocity > 1.7 m/s
- Depth times velocity > 0.37 m^2/s

Flood Hazard maps for the Regional Storm event and the 350-Year Design Storm event are shown in Figure 37 and Figure 38, respectively. The red color indicates locations where there is a flood hazard, and blue color indicates location where flooding is occurring, but it does not meet the criteria of being a flood hazard.

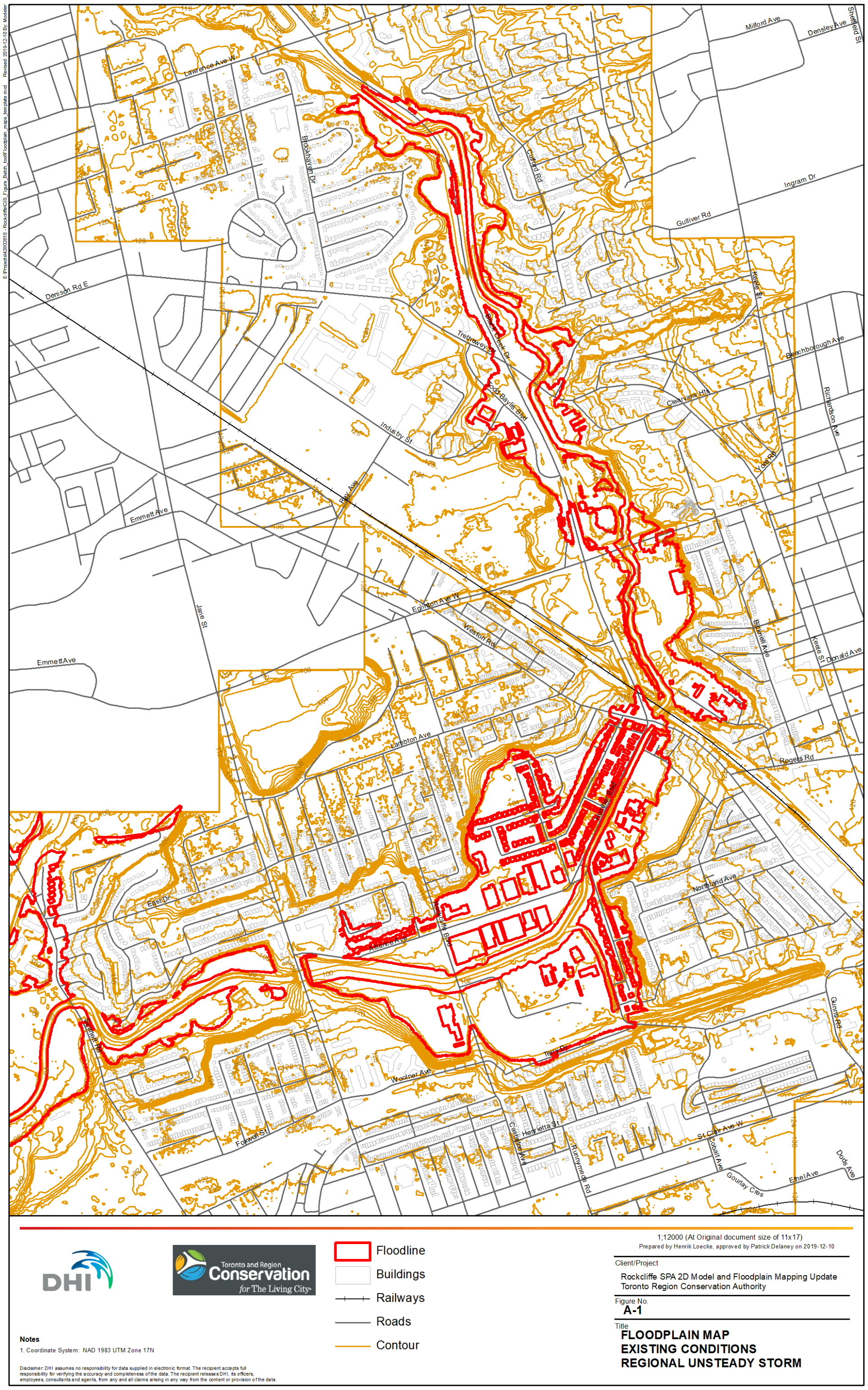


Figure 27 Floodplain Map – Regional Unsteady

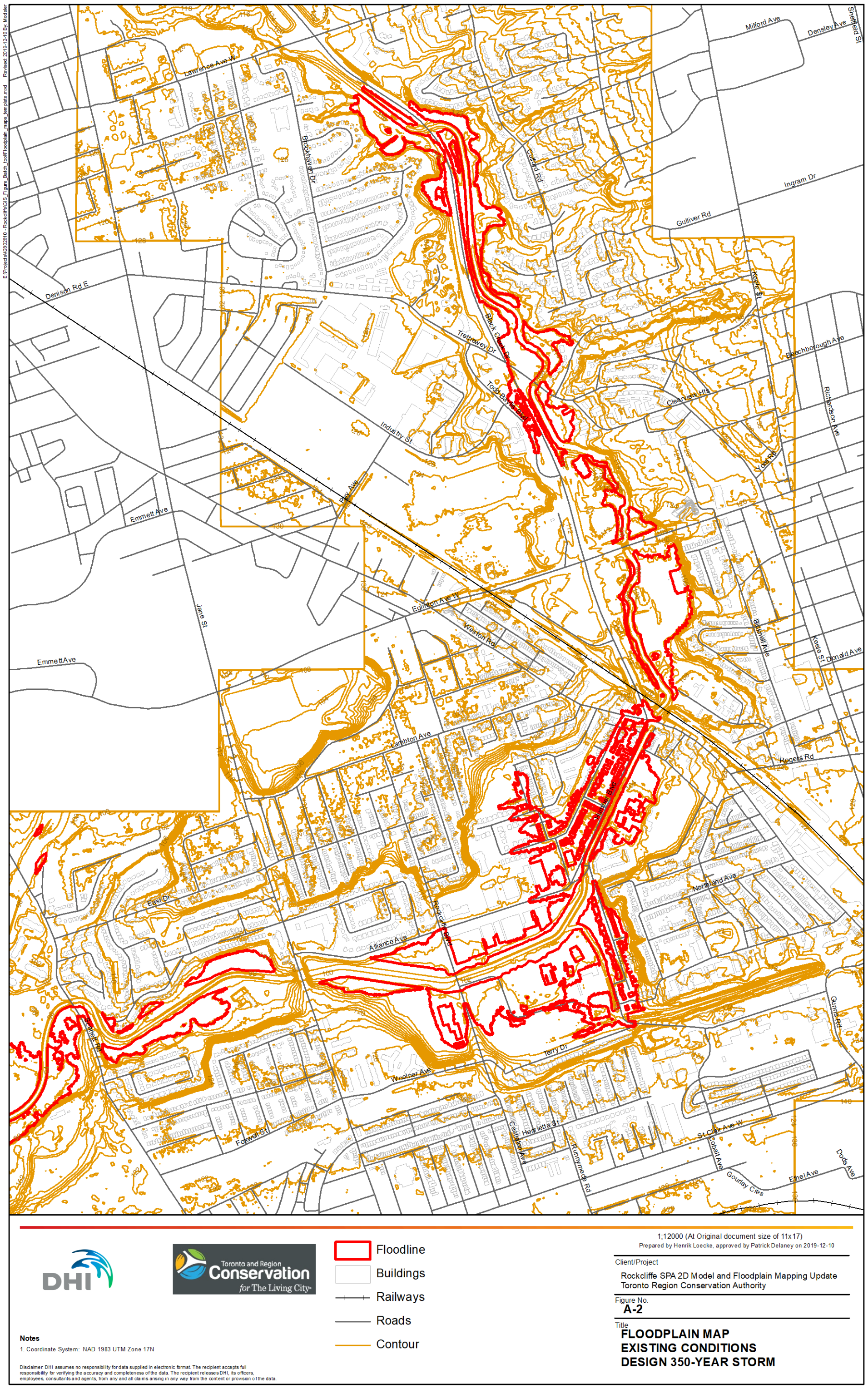


Figure 28 Floodplain Map – 350-Year Design Storm

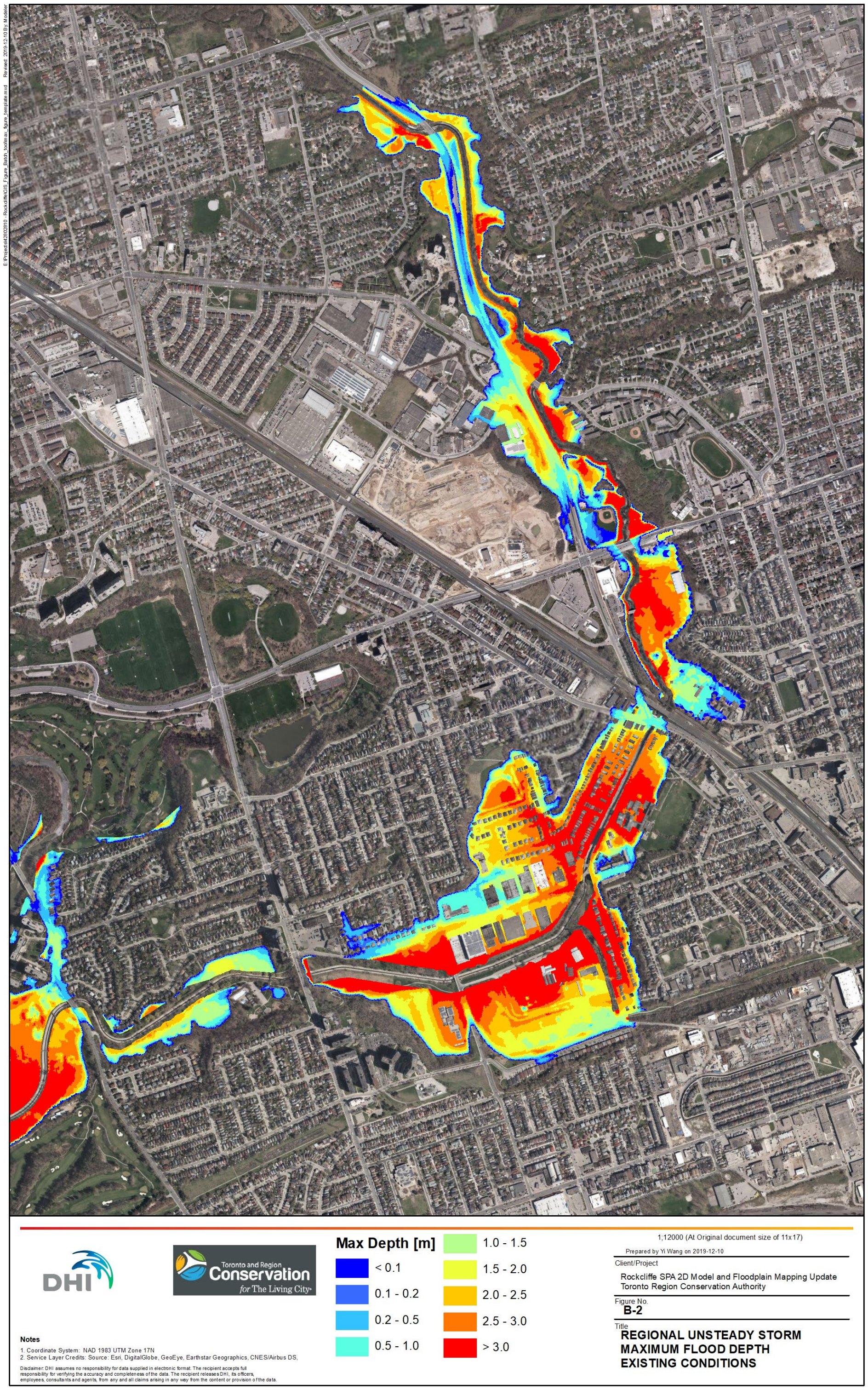


Figure 29 Maximum Flood Depth Map – Regional Unsteady

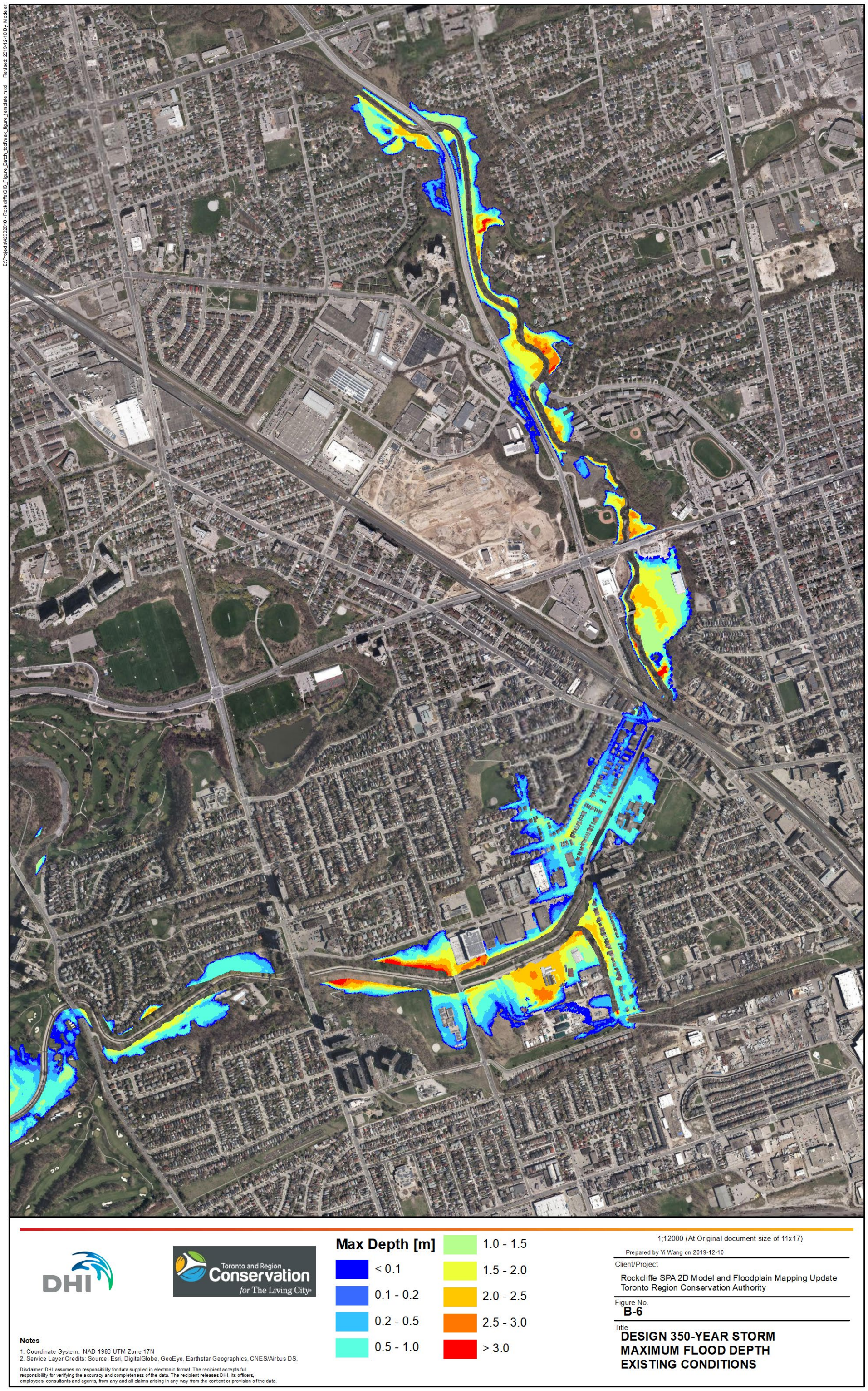


Figure 30 Maximum Flood Depth Map – 350-Year Design Storm

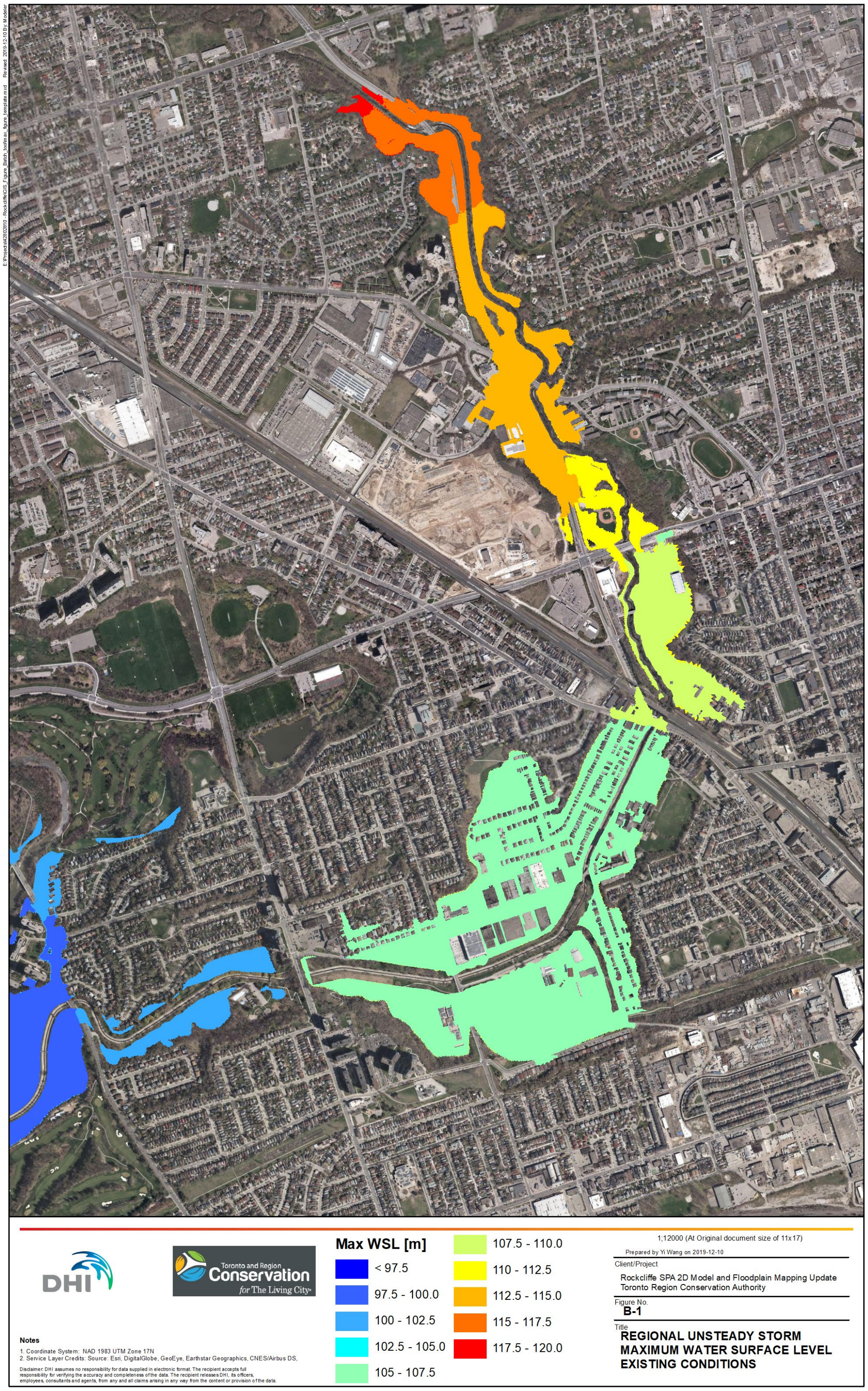


Figure 31 Maximum Flood Elevation Map – Regional Unsteady

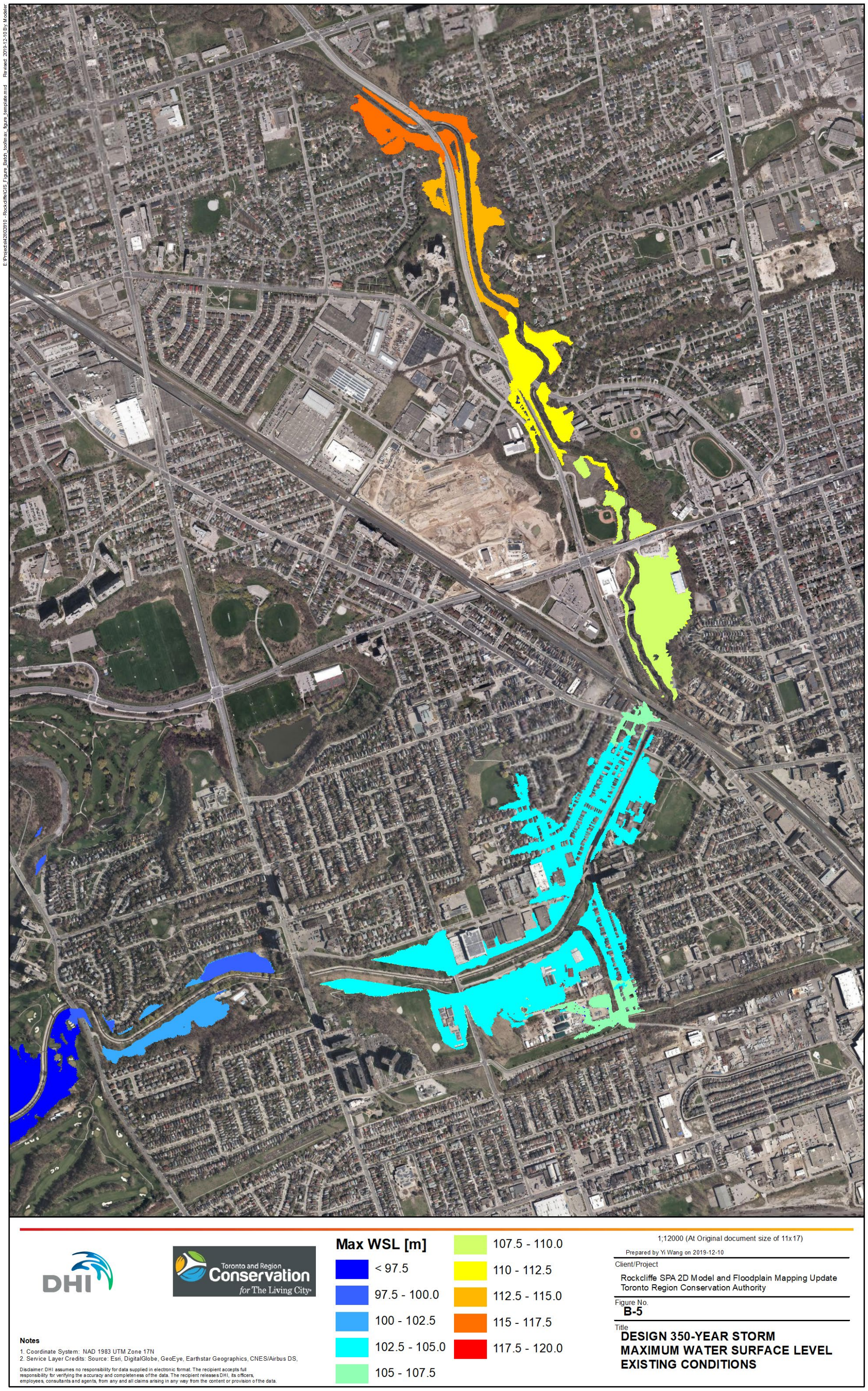


Figure 32 Maximum Flood Elevation Map – 350-Year Design Storm

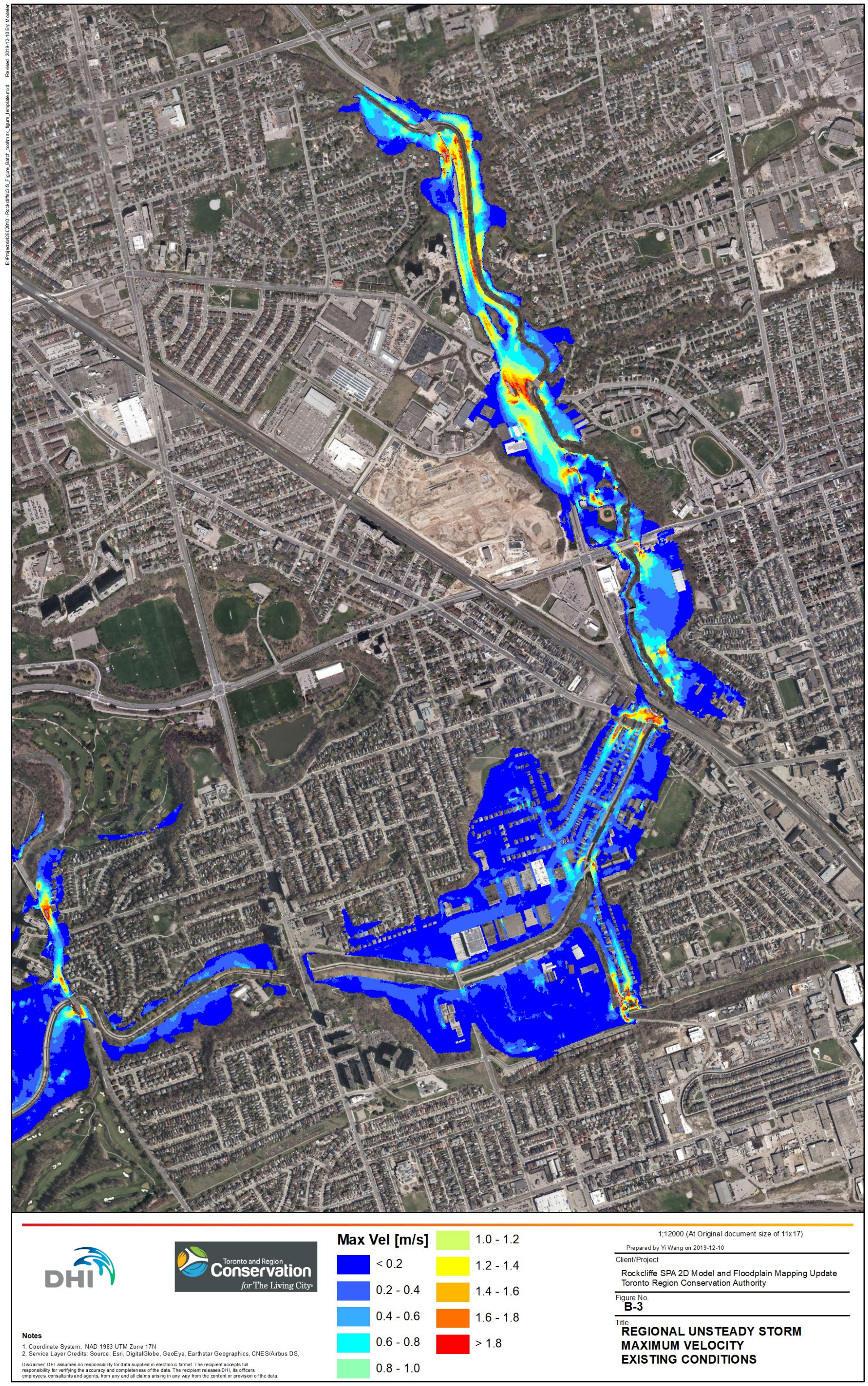


Figure 33 Flood Velocity Map – Regional Unsteady

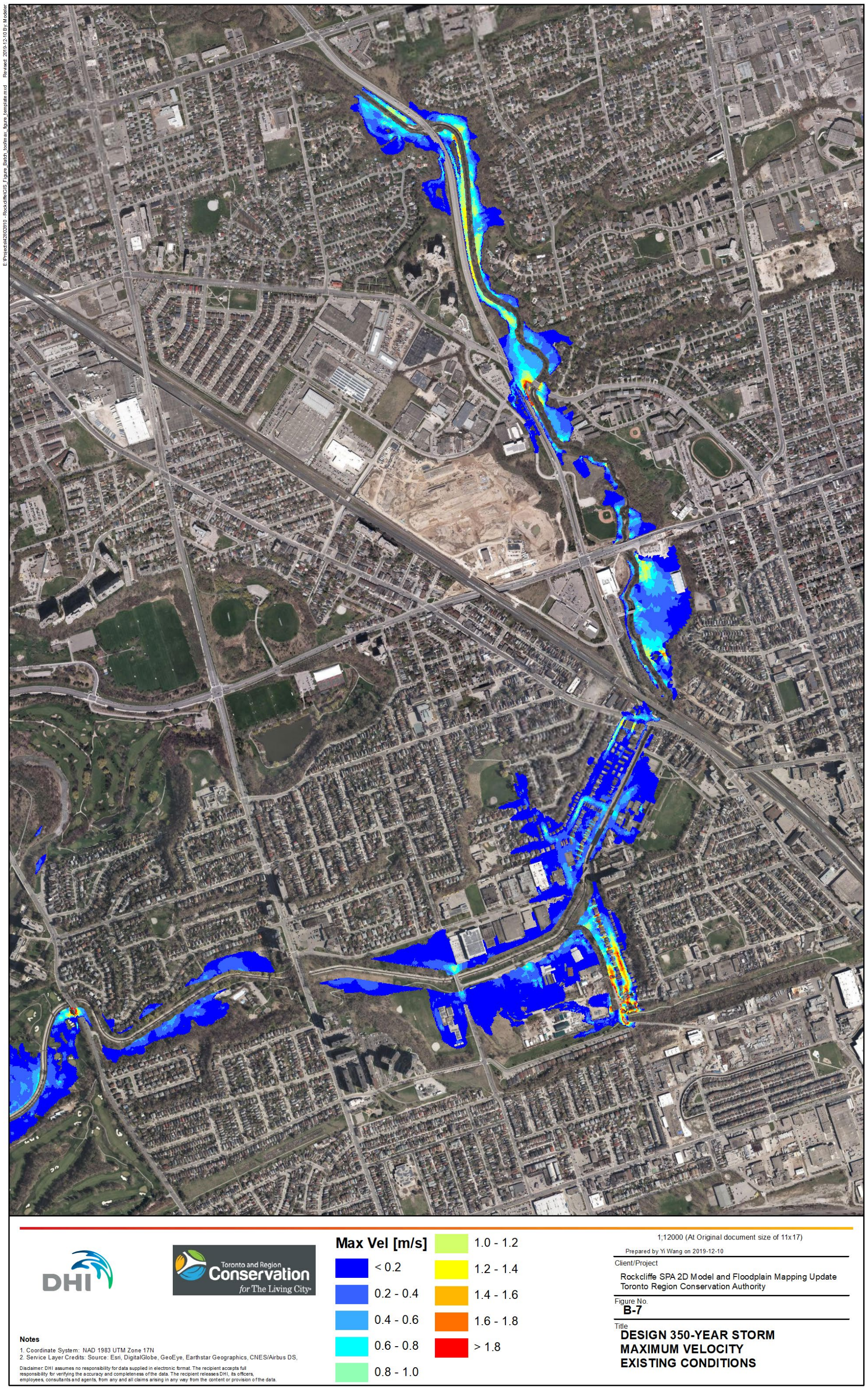


Figure 34 Flood Velocity Map – 350-Year Design Storm

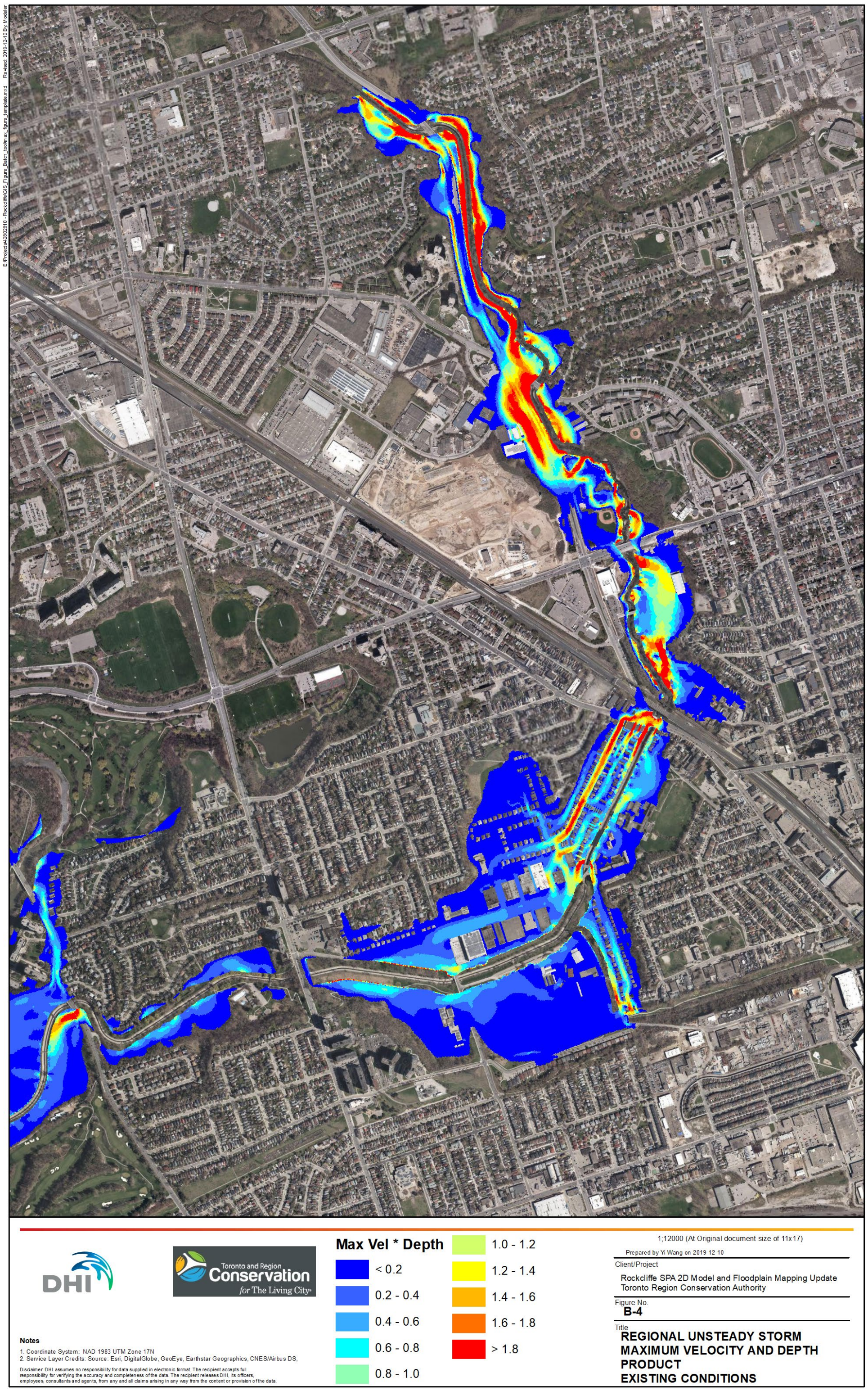


Figure 35 Maximum Flood Depth x Velocity Product Map – Regional Unsteady

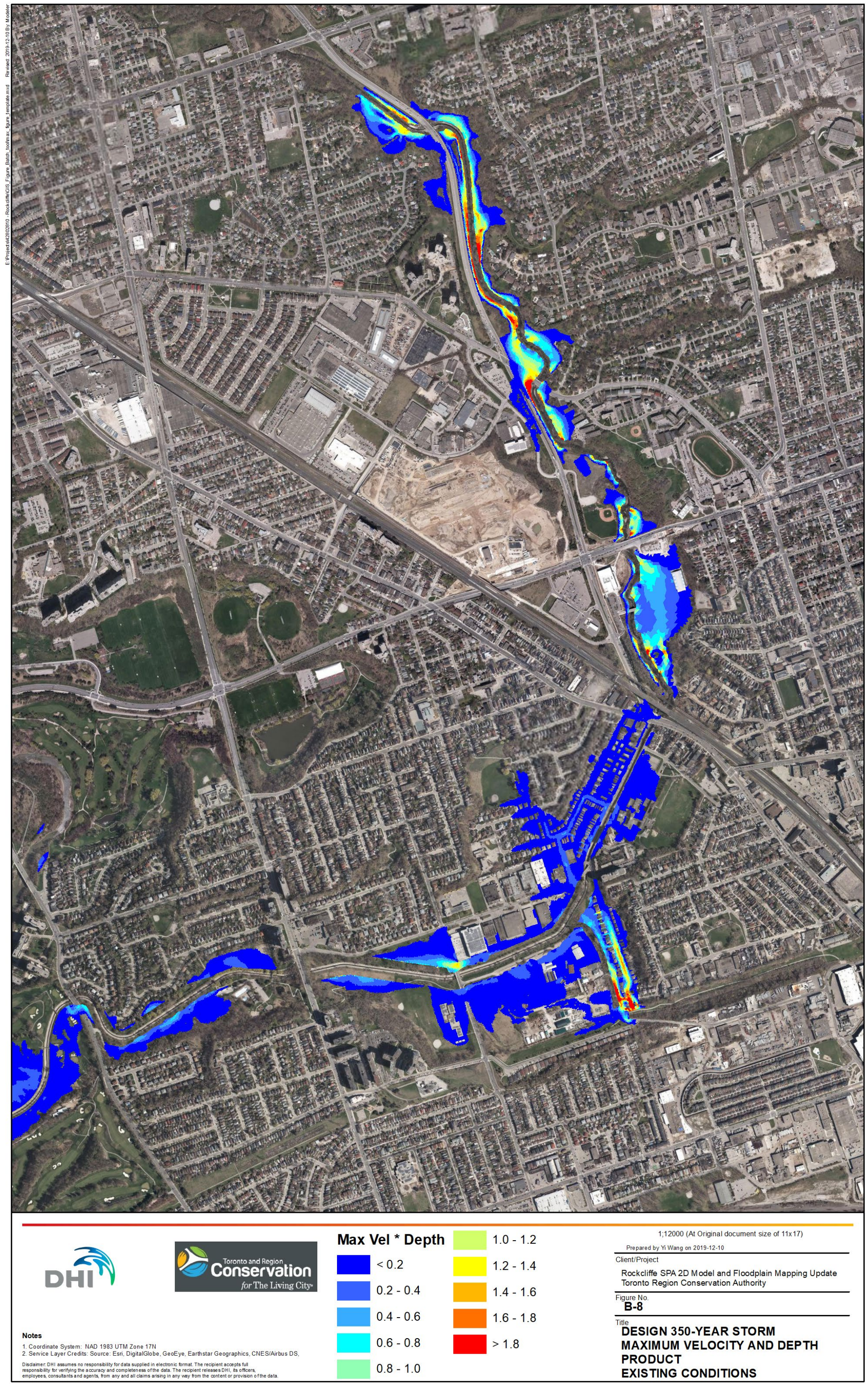


Figure 36 Maximum Flood Depth x Velocity Product Map – 350-Year Design Storm

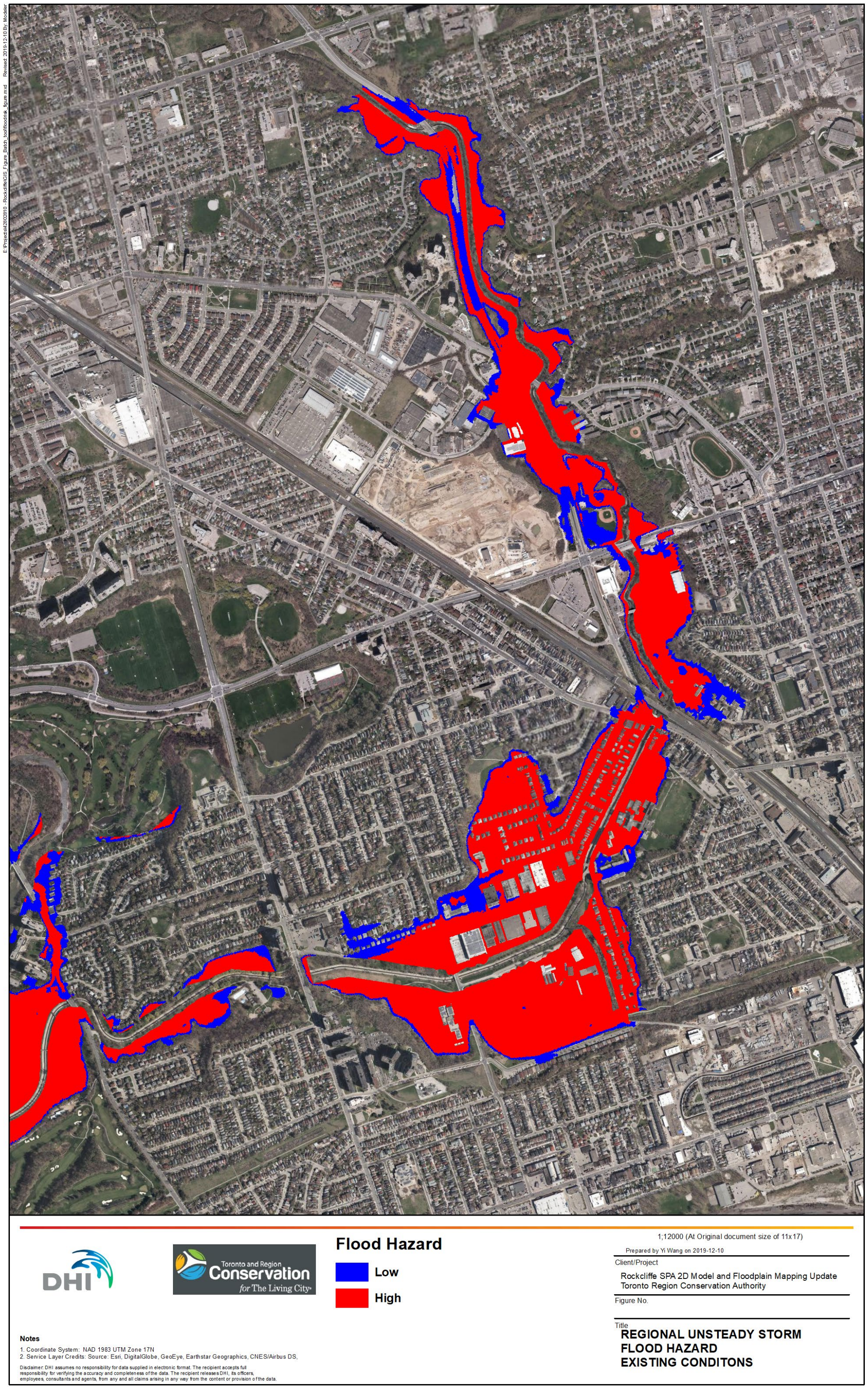


Figure 37 Flood Hazard Map – Regional Unsteady

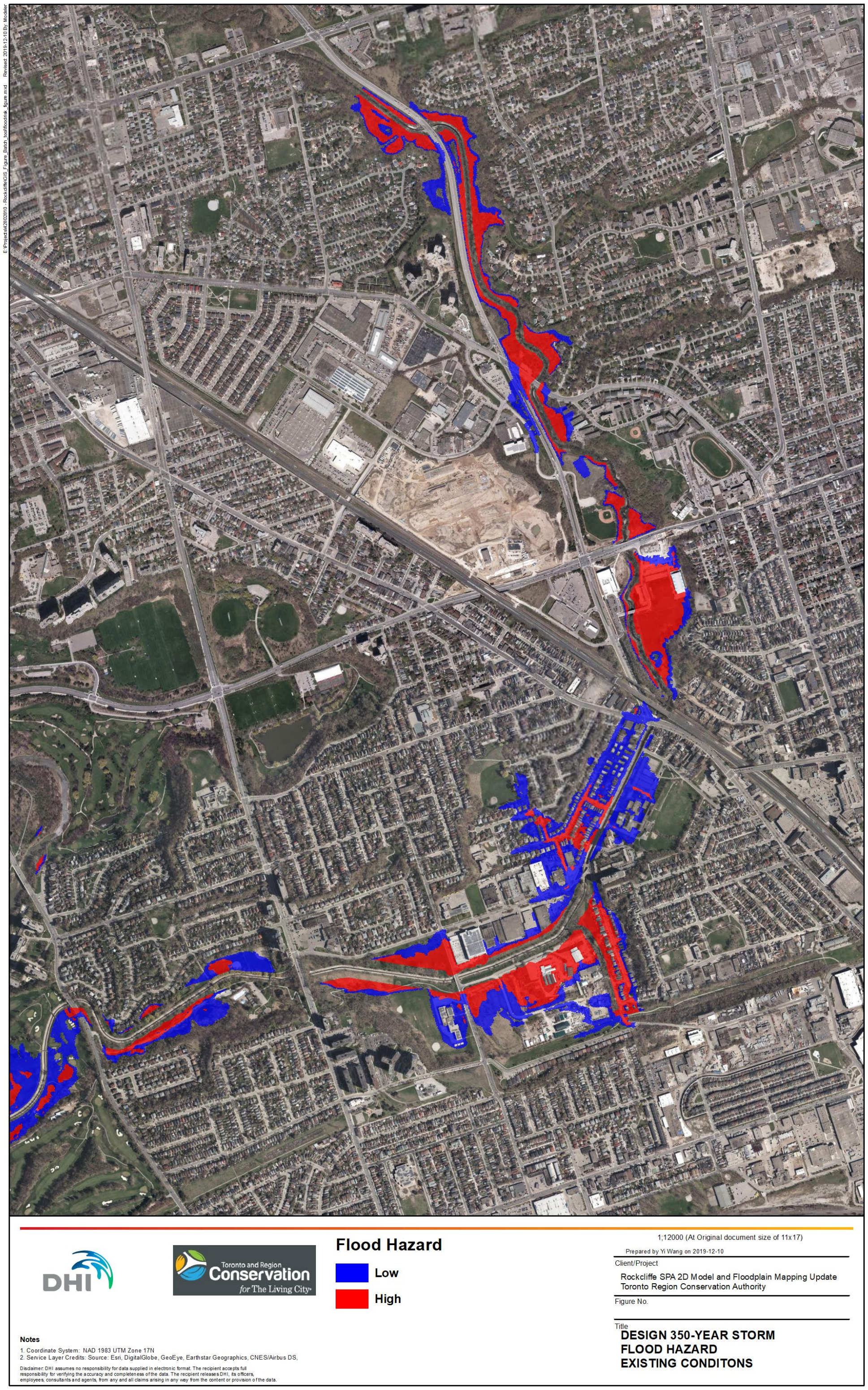


Figure 38 Flood Hazard Map – 350 Year Design Storm

3.2 Bridge Water Level and Discharge Analysis

Peak water levels and combined discharge for each bridge is shown for Regional Storm and 350-Year Design Storm in Table 4 and Table 5. The following are some general observations about the water level and discharge through the bridges:

- Large head losses are observed at Jane Street Structure – 5.6 m in regional storm event and 4.8 m in 350-Year Design Storm event.
- Weston Road Bridge and Scarlett Road Bridge showed > 1 m head loss in both events.
- Eglinton Avenue West Bridge also showed > 1 m head loss in regional storm event.
- Some bridges pass less water than upstream bridges due to water leaving the channel and passing via overland flooding.

Table 4 Peak water levels (upstream and downstream) and combined discharge at each bridge on Black Creek for the *unsteady* Regional Storm event

Location	Unsteady Regional Storm		
	Max Upstream WL [m]	Max Downstream WL [m]	Max Combined Q* [m^3/s]
Black Creek Drive Bridge	117.55	116.83	448.6
Trethewey Drive Bridge	113.28	112.93	284.0
Eglinton Avenue West Bridge	111.82	110.28	474.1
CNR Bridge	109.03	109.02	496.6
Weston Road Bridge	109.27	106.47	335.0
Humber Boulevard Bridge	107.49	107.33	327.6
Alliance Avenue Bridge	106.71	106.41	304.5
Rockcliffe Boulevard Bridge	106.45	106.43	420.9
Jane Street Structure	106.47	100.85	418.0
Scarlett Road Bridge	101.05	99.38	324.6

* Max Combined Q is simulated flow in the 1D model structures and does not include 2D overland flow around the structure

Table 5 Peak water levels (upstream and downstream) and combined discharge at each bridge on Black Creek for the 350-Year Design Storm event

Location	350-Year Design Storm		
	Max Upstream WL [m]	Max Downstream WL [m]	Max Combined Q* [m^3/s]
Black Creek Drive Bridge	116.37	115.97	311.9
Trethewey Drive Bridge	112.10	111.39	235.5
Eglinton Avenue West Bridge	109.55	108.72	302.4
CNR Bridge	107.42	107.32	290.7
Weston Road Bridge	107.07	104.71	288.9
Humber Boulevard Bridge	104.80	104.55	271.0
Alliance Avenue Bridge	104.55	104.46	271.2
Rockcliffe Boulevard Bridge	104.87	104.79	231.5
Jane Street Structure	104.83	99.99	260.4
Scarlett Road Bridge	99.89	96.84	245.9

* Max Combined Q is simulated flow in the 1D model structures and does not include 2D overland flow around the structure

3.3 Flooded and High Flood Risk Properties

Flooded properties were evaluated by GIS analysis using the building shapefile (toronto_BuildingFootprints_2015.shp) and the flood outline maps. For each flood outline map, the GIS tool “Select by Location” tool was used, selecting any house which was fully or partly within the flood extent such that a house is considered flooded if it overlaps with flooding at any depth. For Regional Storm event, 403 properties are flooded, and 342 of them are in high flood risk zone. For the 350-Year Design Storm event, 229 properties are flooded, and 83 of them are in high flood risk zone.

4 Conclusions

A coupled 1D-2D MIKE FLOOD hydraulic model of Black Creek was developed for the section of the creek starting from Lawrence Avenue down to the confluence with the Humber River. The model was run under unsteady flow conditions for the Regional Storm and the 350-Year Design Storm events. The model results were used to update the Regulatory Floodplain maps.

5 References

DHI, 2018, Rockcliffe SPA 2D Flood Modelling and Mapping Update, April 2018, DHI Water and Environment, Inc.

Civica, 2018, Humber River Hydrology Update, April 2018, Civica Infrastructure, Inc.

Respectfully submitted,
DHI Water and Environment, Inc.

LICENSED PROFESSIONAL ENGINEER
P. G. DELANEY
100516936
PROVINCE OF ONTARIO

Jan 7, 2020

Yi Wang
Water Resources Modeller

Patrick Delaney, M.A.Sc., P.Eng.
President

Disclaimer

This report was prepared by DHI Water and Environment, Inc. (DHI) for the client in accordance with the agreement between DHI and the client. This report is based on information provided to DHI which has not been independently verified.

The disclosure of any information contained in this report is the sole responsibility of the client. The material in this report, accompanying spreadsheets and all information relating to this activity reflect DHI's judgment in light of the information available to us at the time of preparation of this report. Any use which a third party makes of this report, or any reliance on or decisions to be made based on it, are the responsibility of such third parties. DHI accepts no responsibility for damages, if any, suffered by a third party as a result of decisions made or actions based on this report.

DHI warrants that it performed services hereunder with that degree of care, skill, and diligence normally provided in the performance of such services in respect of projects of similar nature at the time and place those services were rendered. DHI disclaims all other warranties, representations, or conditions, either express or implied, including, without limitation, warranties, representations, or conditions of merchantability or profitability, or fitness for a particular purpose.

This Standard Limitations statement is considered part of this report.