SPRING CREEK 2D MODELLING EXTENSION AND FLOODPLAIN MAPPING UPDATE

Report Prepared for:
TORONTO AND REGION CONSERVATION AUTHORITY

Prepared by:
MATRIX SOLUTIONS INC.

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Guelph, Ontario

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Report prepared for Toronto and Region Conservation Authority, May 2019

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VERSION CONTROL

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V1.0	10-May-2019	Final	22062-531 R 2019-05-10 final V1.0.docx	Updates throughout; Issued to client
V2.0	15-May-2019	Final Revised	22062-531 R 2019-05-15 final V2.0.docx	Updates throughout; Issued to client

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1 INTRODUCTION

Toronto and Region Conservation Authority (TRCA) retained Matrix Solutions Inc. (Matrix) to update and extend an existing integrated one-dimensional (1D) and 2-dimensional (2D) hydraulic model of Spring Creek using MIKE FLOOD based on the latest Light Detection and Ranging (LiDAR) data (2015) and Hydrology Update (MMM 2013). The final objective of this project is to complete floodplain mapping within the extended study area. To complete the objective, updates to the MIKE FLOOD hydraulic model are required to append additional tributaries, generate water surface elevations, and subsequently produce Regulatory floodplain maps.

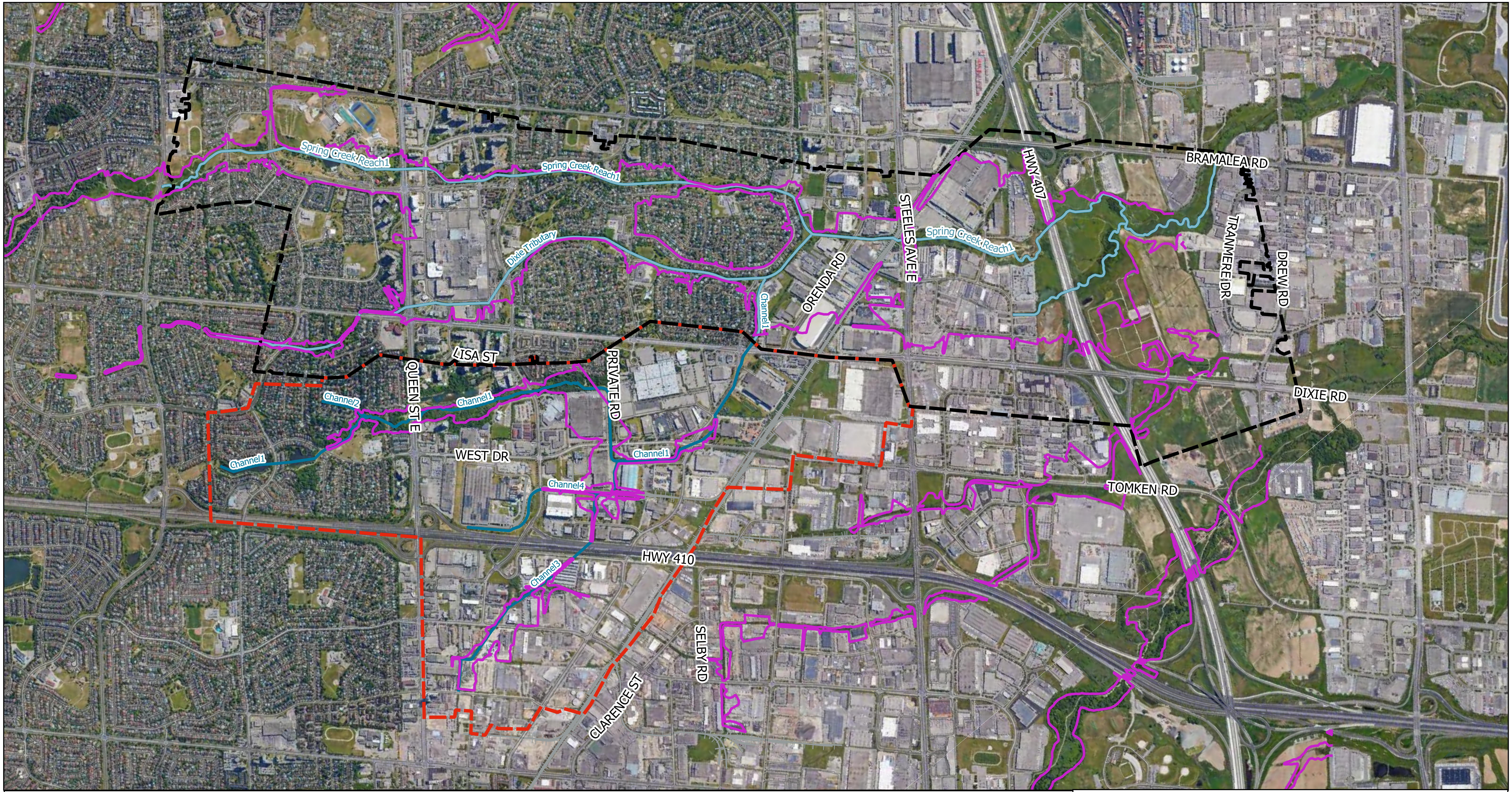
1.1 Project Background and Purpose

Over the past several years, TRCA has been undertaking updates to floodplain mapping within its watersheds to current TRCA and Ministry of Natural Resources and Forestry (MNRF) standards. Updated floodplain mapping in the Spring Creek watershed was completed by MMM Group Limited in 2016 using a 1D-2D coupled MIKE FLOOD model for the two main branches of Spring Creek (MMM 2016). Floodplain mapping was also completed for the Spring Creek tributaries by Aquafor Beech in 2016 using HEC-RAS, which indicated spills north of West Drive at both Orenda Road and Private Drive. Due to limitations of 1D modelling for complex flow patterns such as these, TRCA retained Matrix to extend the 1D-2D coupled MIKE FLOOD model to encompass these tributaries and spills such that the floodplain mapping can be updated. The project was funded through the National Disaster Mitigation Program.

The purpose of this study is to update hydraulic modelling such that spills are fully delineated and Regulatory flood hazard limits are defined for the Spring Creek tributaries. Understanding the floodplain extent is a key component of TRCA's mandate and is required to identify areas of flood risk for the purpose of protecting people and property from flood hazards.

1.2 Study Area Overview

The study area for the current Spring Creek extension, shown on Figure 1, includes the entire extent of the previous study area (MMM 2015) in addition to the tributaries west of the previous study area. These tributaries, labelled as Channels 1 to 4 in the model, are small watercourses that primarily receive runoff from commercial and industrial lands. The study area is generally bounded by Kennedy Road to the west, Queen Street to the north, the CN railway to the south, and Dixie Road to the east. The current model domain encompasses the original 2D model study area and therefore extends to Bramalea Road to the east. The original study area was included in the model domain for the current study to ensure that the full extent of spill from Channel 1 near Private Drive and West Drive could be delineated and characterized. Review of 2015 LiDAR data and 2016 HEC-RAS modelling results and floodplain delineation (Aquafor 2016) indicated that spill in this area may travel east and south into the original study area. Therefore, appending the extended study area to the original MIKE FLOOD model enabled Matrix to assess these spill conditions in a comprehensive manner such that TRCA can update their understanding of existing flood risk.



Study Area (Original, MMM 2016)

Study Area (Extended)

Watercourses (Original Study Area)

Watercourses (Extended Study Area)

Roads

Railway

Existing Floodline

This drawing must be used in conjuction with the attached report, Spring Creek 2D Modelling Extension and Floodplain Mapping Update (May 2019) and is subject to the same limitations and conditions stated in the report.

0 250 500 750 1000 m

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Spring Creek 2D Modelling Extension and Floodplain Mapping Update

Project #22062

Study Area

J. McArthur
K. Molnar

Figure 1

T:\22062-162714 Spring Creek 2D Update\05 Analysis\GIS\22062-162714_BaseMap.qgs

1.3 Study Scope and Approach

The scope and objectives of the Spring Creek Floodplain Mapping Update study are outlined as follows:

- Achieve a more complete knowledge of existing flood risk along the Spring Creek tributaries by extending an existing 1D-2D coupled MIKE FLOOD model for Spring Creek.
- Undertake model simulations for seven design storm events and the Regulatory storm event.
- Identify existing areas at risk to riverine flooding, characterize flood risk, and identify flood mechanisms for all modelled storms.
- Prepare flood risk mapping (for design storms) and Regulatory floodplain mapping (for Regulatory storm event).
- Document methodology for completion of the above tasks in a final report.

1.4 Previously Completed Studies

The following subsections summarize previous studies that were reviewed as part of this project.

1.4.1 Etobicoke Creek Hydrology Update

The *Etobicoke Creek Hydrology Update Study* (MMM 2013) was used to extract peak flows and hydrographs for the current study. The MMM 2013 study assessed both existing and future conditions of land use. The study also developed a stormwater quantity control strategy for upstream developments to improve flood risk management and mitigate impacts caused by future conditions. Spring Creek is within the Etobicoke Creek watershed and therefore the Visual OTTHYMO (VO) model prepared during the Etobicoke Creek Hydrology Update Study was used to extract inflow data for the current study.

1.4.2 Spring Creek Floodplain Update Study

The *Spring Creek Floodplain Update Study* (MMM 2015) was completed for the TRCA and included the development of an integrated 1D-2D hydraulic model for using MIKE FLOOD. The MIKE FLOOD model includes: the Spring Creek main branch extending from south (downstream) of Williams Parkway to west (upstream) of Bramalea Road; Dixie Tributary from south (downstream) of Williams Parkway to the confluence with the main branch just south of Orenda Road; and two small unknown tributaries. The purpose of the study was to use the MIKE FLOOD model to update flood hazard mapping for Spring Creek and to provide a modelling tool that will aid in assessment of flood risk. The modelling was completed for the 2-year through 350-year design storms and the Regional storm event. The MIKE FLOOD model developed during the MMM study was used as a starting point for the current study.

1.4.3 Spring Creek Flood Characterization

The *Spring Creek Flood Characterization Report* (MMM 2016) was prepared as part of the Spring Creek Floodplain Update Study and uses the results of the modelling discussed in Section 1.4.2. The purpose of the report was to characterize flooding in the Spring Creek study area including identifying flood mechanisms and areas of high flood risk, identifying flooding characteristics in vulnerable land use areas, and provide preliminary potential mitigation measures to reduce flooding.

1.4.4 Etobicoke Creek Floodplain Mapping Update

The *Etobicoke Creek Floodplain Mapping Update* study (Aquafor 2016) was completed to append the Spring Creek tributaries to the existing Etobicoke Creek HEC-RAS model, update flow data to incorporate results of the *Etobicoke Creek Hydrology Update Study* (MMM 2013), and complete Regulatory floodplain mapping through Toronto, Mississauga, Brampton, and Caledon. Two spills were identified by Aquafor along West Drive, which fall within the model domain for the current study. These spills could not be fully delineated using HEC-RAS as part of the Aquafor study and therefore it was recommended that 2D modelling be completed. That is the basis for the current study.

2 EXISTING CONDITIONS MIKE FLOOD MODEL UPDATE

To extend the MIKE FLOOD model, modifications to the 1D riverine model and the 2D mesh were required. Details of these updates are provided in the following sections.

2.1 Data Review and Preparation

Matrix reviewed available data and information as part of the background review, as summarized in the following subsections.

2.1.1 Available Data and Information

The following data and information was collected and reviewed as part of this project:

- Etobicoke Creek VO hydrologic model and report (MMM 2013)
- MIKE FLOOD model and reports prepared by MMM for Spring Creek (MMM 2015, 2016)
- HEC-RAS model and report for the Spring Creek tributaries floodplain mapping (Aquafor 2016)
- MIKE FLOOD model prepared by Matrix Solutions and DHI for a concurrent study of the Central Area of the City of Brampton; this model encompasses the extent of the current study area
- simplified building footprints
- LiDAR data (2013 and 2015)
- as-built drawings for structures

2.1.2 Preparation of Digital Elevation Model

As part of the background review, TRCA provided LiDAR datasets from 2013 and 2015. The Spring Creek study completed by MMM was initiated prior to the collection of the 2015 LiDAR data and therefore used LiDAR data from 2013. While the 2015 dataset would provide the most up to date information across the model domain for the current study, Matrix used 2013 LiDAR in the original study limit and 2015 LiDAR in the new extended study area for the western tributaries. This approach ensures consistency with the original Spring Creek study.

2.2 MIKE 11 1D Riverine Model

The development of the 1D riverine component was completed in MIKE 11 and included the following:

- define channel geometry for tributaries (centreline, cross-sections)
- insert hydraulic structures
- define channel roughness (Manning's n)
- assign boundary conditions

A schematic of the MIKE 11 1D riverine model setup is provided in Figure 2 including the river centreline, cross-sections, flow input locations, and boundary conditions.

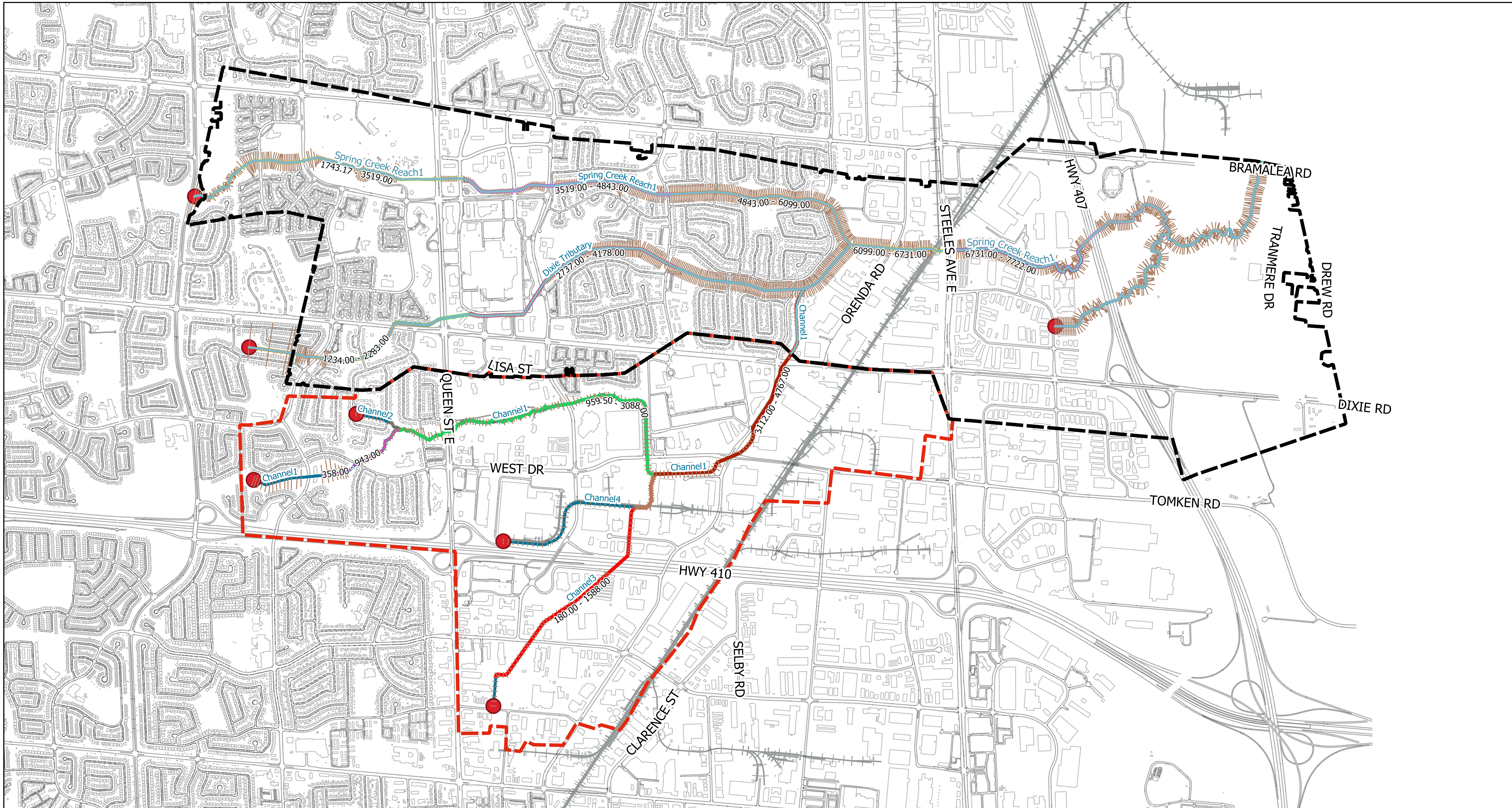
2.2.1 Riverine Network

The channel geometry for the Spring Creek tributaries including river centreline was prepared using available GIS data and the LiDAR-based digital elevation model (DEM), as described in the following sections.

2.2.1.1 Channel Network

The river centreline shapefile provided by TRCA was imported to the original MIKE 11 model to generate the river reaches for the additional tributaries. Four new reaches were added to the MIKE 11 model, as shown on Figure 2: Channel 1 is 4.8 km long, extending from La France Road to Dixie Tributary at Birchbank Road and includes Parr Lakes located upstream and downstream of Vodden Street; Channel 2 is 0.3 km long, extending from Hillside Drive to Channel 1; Channel 3 is 1.9 km long, extending from Hanson Road South to Channel 1 near West Drive; and Channel 4 is 1.0 km long, extending from upstream of Clark Boulevard to Channel 3 downstream of Tilbury Court. The reaches in the original Spring Creek MIKE FLOOD model domain were not changed.

The extent of the MIKE 11 model was set such that it is far enough beyond the study area to ensure boundary conditions do not impact flood results in the areas of interest.



Study Area (Original, MMM 2016)

Study Area (Extended)

Roads

Buildings

Railway

Point Source Flow Input Locations

Distributed Source Flow Input Locations (multicolour)

Cross-Sections

N

0 250 500 750 1000 m

This drawing must be used in conjuction with the attached report, Spring Creek 2D Modelling Extension and Floodplain Mapping Update (April 2019) and is subject to the same limitations and conditions stated in the report.

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Spring Creek 2D Modelling Extension and Floodplain Mapping Update

Project #22062

1D Riverine Model Schematic

K. Molnar

Figure 2

2.2.1.2 Cross-Sections

The reaches in the extension area are small tributaries and would not have much baseflow; therefore it was determined that cutting sections from LiDAR with no further bathymetry modifications is appropriate. An exception to this was at the Vodden ponds located at the upstream end of Channel 1. The LiDAR picked up the water surfaces of the ponds, which were significantly higher than the culvert located between the two ponds. Here a 3:1 side slope was assumed below the water surface and the cross-sections within the two ponds were extended down to match inverts from design drawing.

Channel cross-sections were cut using the DHI MIKE HYDRO Tool and the LiDAR-based DEM. The cross-section spacing was set to a maximum of 30 m separation which is reasonable given the mesh resolution. The extracted cross-sections were then trimmed to the top of bank to allow the 1D channelized flow to be calculated in MIKE 11 while the overbank flows will be calculated by the 2D MIKE 21 overland flow model (refer to Section 2.3.1 for details). The cross-sections at the inflow boundary and downstream boundary locations on the main branches of Spring Creek were maintained at full width to accommodate boundary conditions. The additional tributaries are fully contained within the 2D model domain and therefore cross-sections along these branches were trimmed to the top of bank. An example of full and trimmed cross-section is provided in Figure 3.

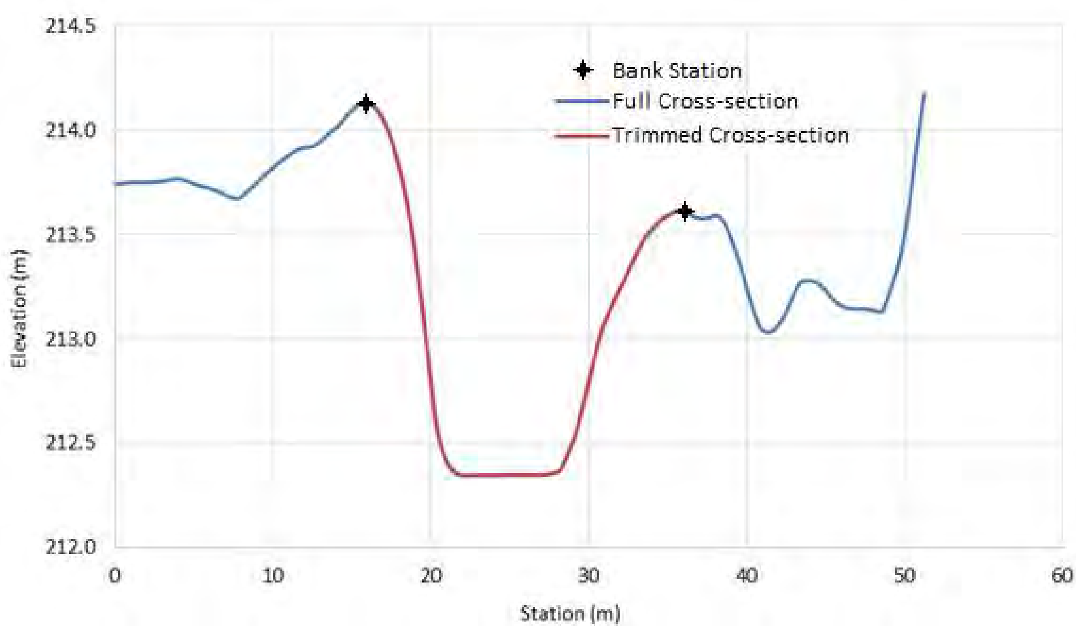


FIGURE 3 Comparison of Full Cross-Section and Trimmed Cross-Section

2.2.1.3 Structures

There are a total of 48 structures in the MIKE 11 model. Of these, 30 structures were in the MMM Spring Creek model and the remaining 18 were added as part of this study. Table 1 lists all structures in the MIKE 11 model. The geometry of the additional 18 structures was obtained from as-built drawings, as available. Structures for which as-built drawings were not available were measured onsite by Matrix as part of a concurrent study with an overlapping study area. Following standard practice for MIKE 11 modelling, the majority of the structures were represented as a combination of a culvert and weir at the same chainage. This methodology allows flow in excess of the culvert capacity to spill over the roadway into the channel downstream. An example schematic of the structure modelling methodology with culvert and weir representation is provided in Figure 4.

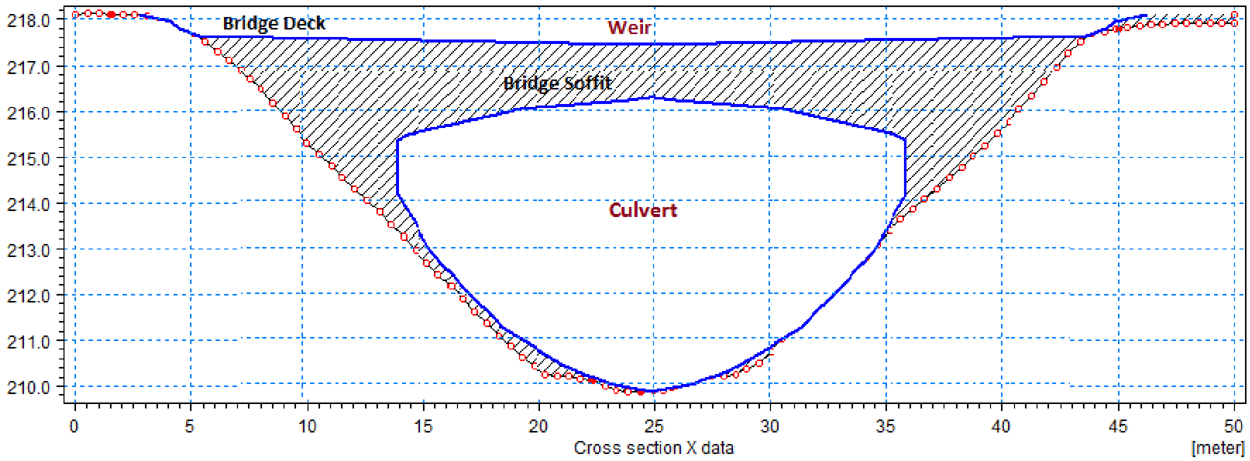


FIGURE 4 Bridge Modelling Schematic with Combined Culvert and Weir

TABLE 1 Structure Summary

Location		Modelled Structure Type
Structure Name	Reach	
Vodden Street	Channel1	Culvert
Laurelcrest Street	Channel1	Culvert
Pedestrian Bridge No.16	Channel1	Culvert + Weir
Pedestrian Bridge No.17	Channel1	Culvert + Weir
Lambeth Street	Channel1	Culvert + Weir
Queen Street East	Channel1	Culvert + Weir
Pedestrian Bridge No. 20	Channel1	Culvert + Weir
Clark Boulevard	Channel1	Culvert + Weir
West Drive	Channel1	Culvert + Weir
Orenda Road / West Drive	Channel1	Culvert
Orenda Road / Dixie Road	Channel1	Culvert
Birchbank PS Driveway	Channel1	Culvert + Weir
Hillside Drive	Channel2	Culvert + Weir
Trail Bridge	Channel2	Culvert +Weir
Rutherford Road South	Channel3	Culvert + Weir
Heart Lake Road / Highway 410	Channel3	Culvert + Weir
Tilbury Court	Channel3	Culvert + Weir
CN Rail	Channel3	Culvert + Weir
Clark Boulevard	Channel4	Culvert + Weir
EC 17-14R Hilldale Crescent *	Spring Creek	Culvert + Weir
EC 17-13R Central Park Drive *	Spring Creek	Culvert + Weir

Location		Modelled Structure Type
Structure Name	Reach	
EC 17-5R Chinguacousy Park *	Spring Creek	Bridge + Weir
EC 17-4R Chinguacousy Park *	Spring Creek	Bridge + Weir
EC 17-3R Queen Street *	Spring Creek	Culvert + Weir
EC 17-2R Kensington Road *	Spring Creek	Culvert + Weir
EC 17-1R Knightsbridge Road *	Spring Creek	Culvert + Weir
EC 16-8R Clark Boulevard *	Spring Creek	Culvert + Weir
EC 16-3R Balmoral Drive *	Spring Creek	Culvert + Weir
EC 16-2R Algonquin Boulevard *	Spring Creek	Culvert + Weir
EC 16-1R Avondale Boulevard *	Spring Creek	Culvert + Weir
EC 15-5R Orenda Road *	Spring Creek	Culvert + Weir
EC 15-4RR CNR *	Spring Creek	Culvert + Weir
EC 15-3R Steeles Avenue East *	Spring Creek	Culvert
EC 15-2R Alfred Kuehne Blvd *	Spring Creek	Culvert + Weir
EC 15-1R Hwy 407 *	Spring Creek	Bridge
EC 14-2R Bramalea Road *	Spring Creek	Culvert + Weir
Lakehurst Street *	Dixie Tributary	Culvert + Weir
Howden Boulevard *	Dixie Tributary	Culvert + Weir
Hazelwood Drive *	Dixie Tributary	Culvert + Weir
Dixie Road *	Dixie Tributary	Culvert + Weir
Queen Street *	Dixie Tributary	Culvert
Bramalea CC North Access Road *	Dixie Tributary	Culvert + Weir
Bramalea City Centre Parking Lot Access *	Dixie Tributary	Culvert
Bramalea CC South Access Road *	Dixie Tributary	Culvert + Weir
Clark Boulevard *	Dixie Tributary	Culvert
Balmoral Drive *	Dixie Tributary	Culvert + Weir
EC 16-5R Brentwood Drive *	Dixie Tributary	Culvert + Weir
EC 16-4R Birchbank Road *	Dixie Tributary	Culvert + Weir
Hwy 407 Culvert *	Unknown Tributary	Culvert

* Structures in the existing Spring Creek model (MMM 2015)

In some cases, due to topography and/or culvert configurations, it is not always appropriate to assume that flow will re-enter the channel on the downstream side of the structure. This is particularly true for long culverts (i.e., the Orenda Road / West Drive and Orenda Road / Dixie Road structures) where spilled flow may travel down roadways and re-enter the creek at another location, if at all. The 1D-2D coupled modelling approach used in this study allows for representing the culvert in the 1D model, while overland flow is represented in the 2D model. This enables spilled flow to follow appropriate flow paths based on topography. The following four structures on the Spring Creek channels listed in Table 1 did not include a weir:

- Vodden Street culvert on Channel 1: The pedestrian underpass connecting the two parks north and south of Vodden Street was cut into the 2D surface since any spill from the north pond would flow through this underpass before overtopping Vodden Street as weir flow (refer to Figure 5).

- Laurelcrest Street culvert on Channel 1: The culvert connecting the south Parr Lake to the channel downstream is long and extends under an open park area (refer to Figure 6). Due to this orientation, the roadway does not act as a weir.

- Orenda Road / West Drive culvert on Channel 1: This culvert flows under the intersection of Orenda Road and West Drive. Due to this orientation, the roadway does not act as a weir (refer to Figure 7). Spill flows along Orenda Road to the east instead of re-entering the watercourse on the downstream side.

- Orenda Road / Dixie Road culvert on Channel 1: This is a long culvert / sewer along Orenda Road and due to this configuration, weir flow is not appropriate (refer to Figure 8). Spill from the upstream end of the culvert flows along the 2D surface on Orenda Road.

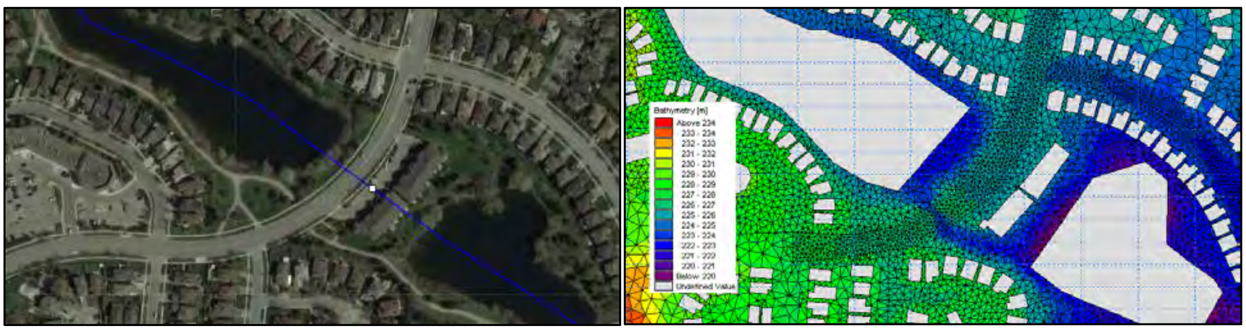


FIGURE 5 Vodden Street Culvert on Channel 1

FIGURE 6 Laurelcrest Street Culvert on Channel 1

FIGURE 7 Orenda Road / West Drive Culvert on Channel 1

FIGURE 8 Orenda Road / Dixie Road Culvert on Channel 1

2.2.1.4 Bend Losses

Two culverts in the original study area (Queen Street culvert and Clark Boulevard culvert on Dixie Tributary) and two culverts in the new study area (Orenda Road/West Drive culvert and Orenda Road/Dixie Road culvert on Channel 1) have significant bends along the structure length which will influence the hydraulic performance of the culverts. Consistent with the previous study, we determined appropriate head loss factors due to bends and assigned them to the appropriate structure in MIKE 11. The bend loss coefficients were determined from the values shown in Table 2 based on the bend angle and diameter of each structure. Details of the bend loss calculations are provided in Appendix A.

TABLE 2 Bend Loss Coefficients (Linsley and Franzini 1972)

Radius of Bend / Pipe Diameter	Deflection Angle of Bend		
	90°	45°	22.5°
1	0.50	0.37	0.25
2	0.30	0.22	0.15
4	0.25	0.19	0.12
6	0.15	0.11	0.08
8	0.15	0.11	0.08

MIKE 11 then applies the bend loss coefficients in the common head loss equation shown below to calculate head loss due to bends at each structure.

$$h = k\frac{v^2}{2g}$$

2.2.2 Roughness Parameters

The Manning's n values along each cross-section were assigned in accordance with TRCA standards as detailed in Table 3. Additionally, the following reaches are concrete-lined and therefore a Manning's n of 0.013 was applied to the low flow channel portion of MIKE 11:

- Channel 1 downstream of Dixie Road (chainage 3,432.9 to 4,767.01)
- Channel 2 upstream of Hillside Drive (chainage 0 to 169.63)

- Spring Creek Reach 1 upstream of Alfred Kuehne Boulevard (chainage 1,743.17 to 7,187.9)
- Dixie Tributary (chainage 1,234 to 5,346.16)

TABLE 3 Cross-Section Manning's n Values

Land Use	Description	Manning's n
Concrete-lined Channel	• Concrete lined low flow channel	0.013
Natural Watercourse/Channel	• Low flow channel • Extends typically from bank to bank	0.035
Floodplain – Urban Uses (Pervious)	• Municipal parks, playing fields, etc. • Typically located within valley and stream corridors • Assumes regular maintenance	0.050
Floodplain – Natural Areas	• Pasture, meadow, riparian vegetation, brush, and forest • Located within urban and/or rural land use setting • Not subject to regular maintenance • Assumes regeneration of open space type uses including pasture, meadow, and agricultural within floodplain areas	0.080

2.2.3 Boundary Conditions

Boundary conditions for the riverine model include inflows at the upstream end and at intermediate locations along the river reach and water level rating curves at the downstream end of the model. A summary of the boundary conditions is provided in Table 4. The boundary condition types available in MIKE 11 are described as follows:

- Inflow – Open: defined at the upstream end of the model to provide inflow to the 1D model
- Inflow – Distributed Source: defined along intermediate locations as input hydrographs to account for subcatchment discharge to segments of the river branch defined by the bounding chainage
- Q-h Rating Curve: defined at the downstream end of the model to control downstream water elevations (refer to Section 2.2.3.2)

TABLE 4 MIKE 11 Boundary Conditions

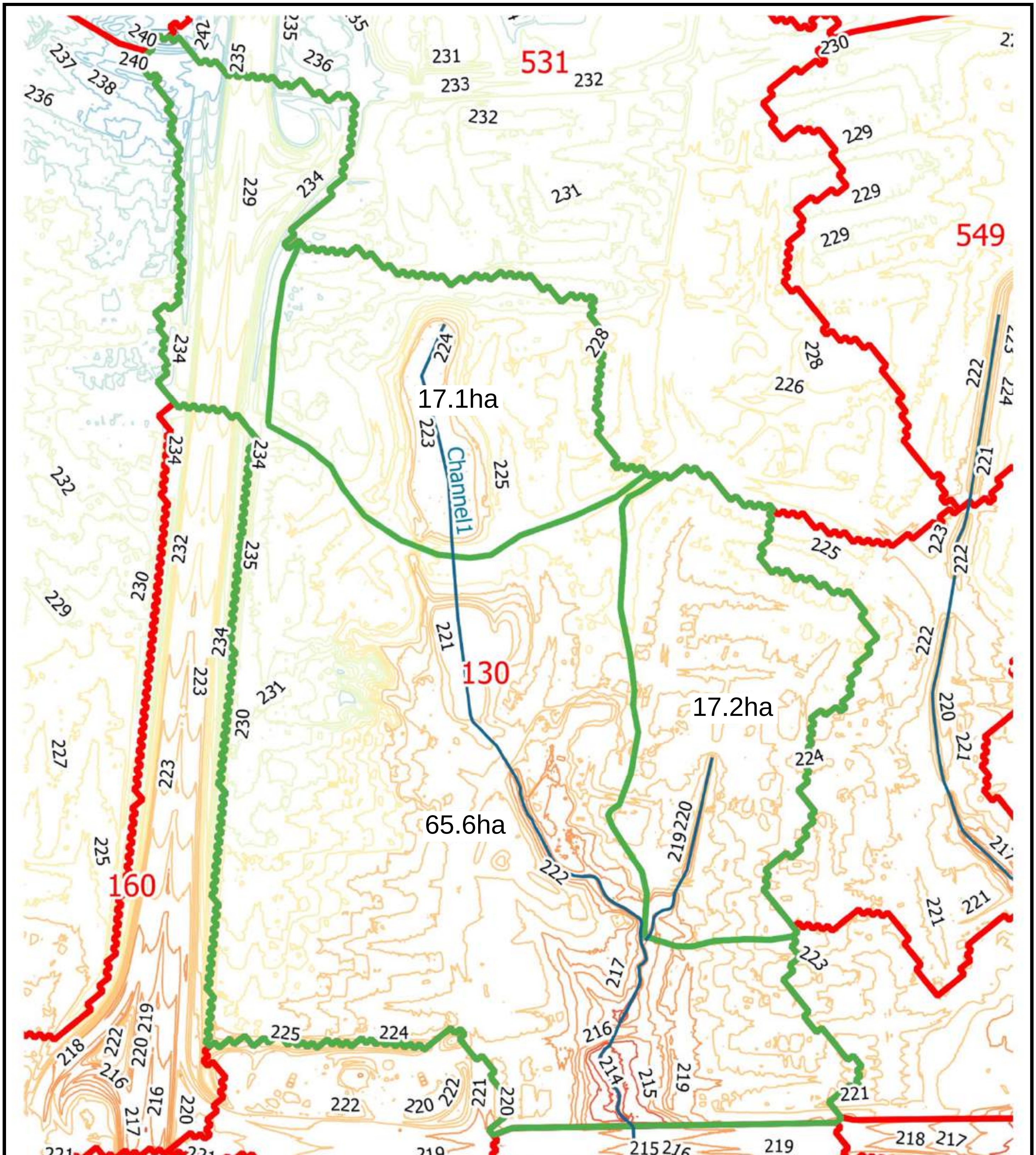
Reach Name	MIKE 11 Chainage (m)	Boundary Condition Type
Channel1	-70.775	Inflow - Open
Channel1	358.47 to 943.24	Inflow - Distributed Source
Channel1	959.495 to 3,088	Inflow - Distributed Source
Channel1	3,112 to 4,767	Inflow - Distributed Source
Channel2	1.012	Inflow - Open
Channel3	0	Inflow - Open
Channel3	180 to 1,588	Inflow - Distributed Source
Channel3	1,609 to 1,870	Inflow - Distributed Source
Channel4	0	Inflow - Open
Spring Creek Reach1	1,743.17	Inflow - Open
Spring Creek Reach1	1,743.17 to 3,519	Inflow - Distributed Source

Reach Name	MIKE 11 Chainage (m)	Boundary Condition Type
Spring Creek Reach1	3,519 to 4,843	Inflow - Distributed Source
Spring Creek Reach1	4,843 to 6,099	Inflow - Distributed Source
Spring Creek Reach1	6,099 to 6,731	Inflow - Distributed Source
Spring Creek Reach1	6,731 to 7,722	Inflow - Distributed Source
Spring Creek Reach1	7,722 to 8,552	Inflow - Distributed Source
Spring Creek Reach1	9,627	Q-h Rating Curve
Dixie Tributary	1,234	Inflow - Open
Dixie Tributary	1,234 to 2,283	Inflow - Distributed Source
Dixie Tributary	2,283 to 2,737	Inflow - Distributed Source
Dixie Tributary	2,737 to 4,178	Inflow - Distributed Source
Unknown Tributary	0	Inflow - Open

2.2.3.1 Inflow Hydrographs

The inflow hydrographs for the riverine model were developed using the VO model provided from the Etobicoke Creek Hydrology Study (MMM 2013) for the 2-year through 350-year design storms based on the 12-hour AES rainfall distribution, as this storm distribution provides the most conservative estimate of peak flows in the riverine system. To maintain consistency with the original Spring Creek study, the 2-year through 100-year flows were based on future conditions land use with stormwater management (SWM) facilities included, while the 350-year and Regional flows were based on future conditions land use with no SWM facilities. The MMM 2013 VO model was also used to develop hydrographs for the Regional storm event (Hurricane Hazel). The Regional storm event was run in both steady state and unsteady state conditions. Refer to Section 3.2 for further details. The peak flows for each storm event are provided in Table 5. The unsteady state hydrographs for the Regional storm event are provided in Appendix B.

The upstream ends of Channel 1 and Channel 2 originate in the same VO catchment and therefore flows from the VO model at NHYD 130 were divided between these two branches near Parr Lake North Park and Vodden Street (refer to Figure 9). The total catchment area of NHYD 130 is 99.9 ha. The flows were prorated based on catchment size; 17.2 ha drains to the upstream end of Channel 2 and 17.1 ha to the upstream end of Channel 1, and the remaining 65.6 ha is distributed along Channel 1 from river chainage 358.47 (top of south pond) to 943.24 (confluence with Channel 2). The portion of flow from NHYD 130 in the upstream portion Channel 1 was added to the peak flow from ADDHYD 2542. Using this approach, the peak flow was maintained, but redistributed.



Etobicoke Creek Catchments (MMM 2013)
Split Catchment 130
Watercourses

LiDAR Contours (1m)

206 - 211
211 - 215
215 - 220
220 - 224
224 - 229
229 - 233
233 - 238
238 - 242
242 - 247
247 - 251

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Spring Creek 2D Modelling Extension and Floodplain Mapping Update

Subdivided Catchment NHYD 130

Date:	Project:	Submitter:	Reviewer:
May 2013	22062	K. Molnar	K. Molnar

Figure 9

TABLE 5 Peak Flow Summary

Reach Name	MIKE 11 Chainage	Peak Flow (m^3/s)							
		2-year	**5-year**	**10-year**	**25-year**	**50-year**	**100-year**	**350-year**	**Regional**
Channel 1	-71.775	0.95	1.37	1.59	1.87	2.08	2.28	17.81	21.56
Channel 1	358.47-943.24	1.77	2.44	2.91	3.50	3.95	4.40	5.92	6.98
Channel 1	959- 3,088	2.36	3.27	3.99	4.90	5.57	6.29	6.80	9.79
Channel 1	3,112 - 4,767	3.51	4.59	5.32	6.23	6.90	7.58	9.82	10.10
Channel 2	1.012	0.46	0.64	0.76	0.92	1.04	1.15	1.55	1.83
Channel 3	0.00	7.21	9.68	11.38	13.53	15.14	16.76	22.16	25.23
Channel 3	180 - 1,588	6.25	8.43	10.00	12.21	13.91	15.50	20.62	22.40
Channel 3	1,609 - 1,870	0.55	0.72	0.84	0.98	1.08	1.19	1.54	1.57
Channel 4	0.00	1.30	1.74	2.04	2.42	2.70	2.98	3.92	4.15
Unknown Trib.	0.00	4.67	6.24	7.31	8.66	9.66	10.67	14.06	15.20
Spring Creek	1,743.17	6.47	10.01	15.41	21.10	23.76	26.44	101.87	155.07
Spring Creek	1,743.17 - 3,519	2.65	3.60	4.25	5.08	5.70	6.33	8.41	9.52
Spring Creek	3,519 - 4,843	1.29	1.78	2.12	2.55	2.87	3.20	4.28	4.87
Spring Creek	4,843 - 6,099	2.49	3.27	3.80	4.47	4.96	5.45	7.08	7.34
Spring Creek	6,099 - 6,731	2.47	3.28	3.82	4.51	5.02	5.54	7.25	7.72
Spring Creek	6,731 - 7,722	7.33	9.83	11.54	13.71	15.32	16.94	22.36	25.12
Spring Creek	7,722 - 8,552	0.97	1.37	1.66	2.03	2.31	2.59	3.57	4.51
Dixie Tributary	1,234	8.25	11.39	13.49	16.17	18.20	20.26	26.93	32.16
Dixie Tributary	1,234 - 2,283	1.67	2.27	2.68	3.20	3.58	3.96	5.24	5.65
Dixie Tributary	2,283 - 2,737	4.50	6.00	7.02	8.31	9.27	10.23	13.43	14.68
Dixie Tributary	2,737 - 4,178	2.44	3.28	3.86	4.59	5.13	5.67	7.50	8.27

2.2.3.2 Downstream Rating Curve

Consistent with the previous study, the downstream boundary condition used a rating curve extracted from the TRCA HEC-RAS model. The rating curve includes a flow and water level relationship from existing HEC-RAS river station 20.10, located downstream of Bramalea Road on the main branch of Spring Creek.

2.2.4 Simulation Settings

The simulation settings applied in the MIKE 11 model include the following:

- Initial Conditions: Water depth = 0.1 m; Discharge = 0.5 m^3/s
- Solver Settings: Default values
- Simulation Period: Variable (dependent on design storm being simulated)
- Time step: Fixed time step = 10 seconds
- Results: Storing frequency = 1 minute

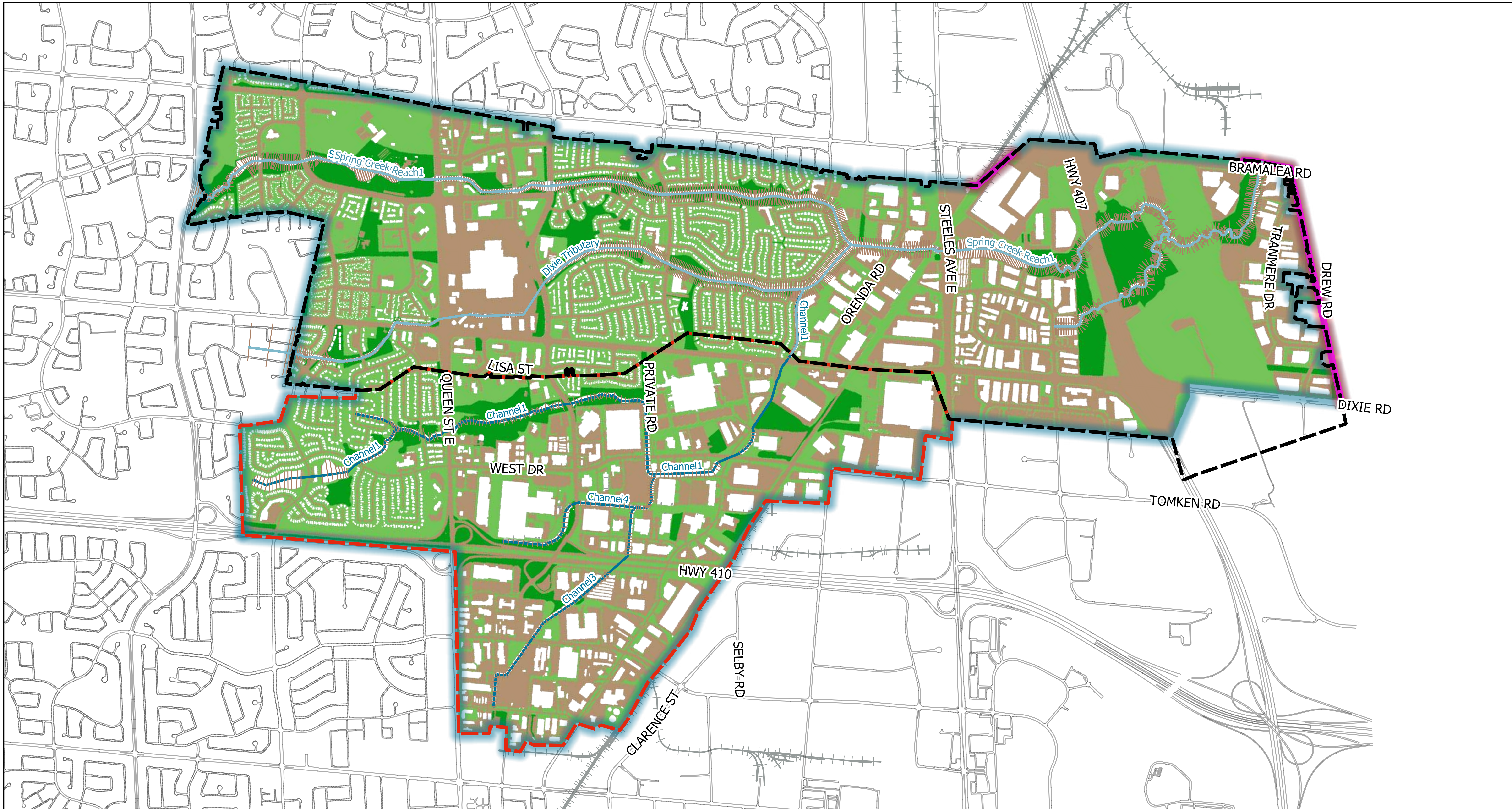
Following direction from TRCA, the riverine model was run using the MIKE 1D solver engine, a recent successor of the MIKE 11 engine. The original Spring Creek study used the MIKE 11 engine. We understand that the MIKE 1D engine includes a sink momentum correction which removes momentum of flow that exits the 1D model (i.e., a sink) but does not increase momentum accordingly for flow returning to the 1D model (i.e., a source). This calculation results in higher predicted water levels in the coupled 2D domain than those calculated using the MIKE 11 engine. While this is a more conservative approach, it is inconsistent as it does not apply momentum for source flows (from MIKE 21). The initialization file for the riverine model includes a feature which allows the user to turn the momentum correction off, which produces results that are similar to those developed from the MIKE 11 engine. This momentum correction factor was therefore turned off to ensure the current results are consistent with those in the original Spring Creek study area.

2.3 MIKE 21 2D Overland Flow Model

The development of the 2D overland model was completed in MIKE 21 and included the following:

- generate mesh geometry including obstructions (buildings), river block, and road breaklines/arcs
- sample mesh from topographic surface
- create 2D surface roughness file (Manning's M)
- assign boundary conditions

A schematic of the MIKE 21 model domain is provided in Figure 10 including the extent of the 2D domain, Manning's roughness, and boundary conditions. In order to ensure the boundary condition assumptions would not impact the results within the study area, the 2D domain was set sufficiently larger than the area of interest. The 2D domain is depicted in Figure 10.



Study Area (Original, MMM 2016)
StudyArea (Extended)
Watercourses (Original Study Area)
Watercourses (Extended Study Area)

Manning's M Surface Roughness
12.5 - Woods/Meadows/Cultivated Lands
20.0 - Lawns
40.0 - Impervious Areas
Model Domain - Closed Boundary
Model Domain - Open Boundary

0 250 500 750 1000 m

This drawing must be used in conjuction with the attached report, Spring Creek 2D Modelling Extension and Floodplain Mapping Update (April 2019) and is subject to the same limitations and conditions stated in the report.

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Spring Creek 2D Modelling Extension and Floodplain Mapping Update

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2D Overland Model Schematic

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Figure 10

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2.3.1 Mesh Generation

The boundary and geometry of the 2D mesh is consistent with that of the original Spring Creek study area with the addition of the extended area to the west. Buildings, roads, and river bank lines from the 1D trimmed cross-sections were loaded into the mesh for the extension area. Buildings and roads polygons were simplified to reduce the number of vertices in the mesh and prevent small angles. The building footprints and river block area were set to dry cells and excluded from the mesh. The road deck for most of the crossings was included in the 2D mesh especially at culverts to account for spills and circumventing flows. Some pedestrian bridges and smaller road crossings are only represented in the 1D model with a weir.

The mesh resolution in the extended study area is generally consistent with the original study area and includes the following four mesh zones. An example of the various mesh resolution is provided in Figure 11. A minimum angle of 25° was enforced to prevent instability from small mesh angles.

1. 10 m^2 on significant roadways

2. 25 m^2 in areas that are within the existing floodline extent

3. 50 m^2 for buffer zones between existing floodlines and areas not anticipated to be inundated

4. 100 m^2 for areas not anticipated to be inundated

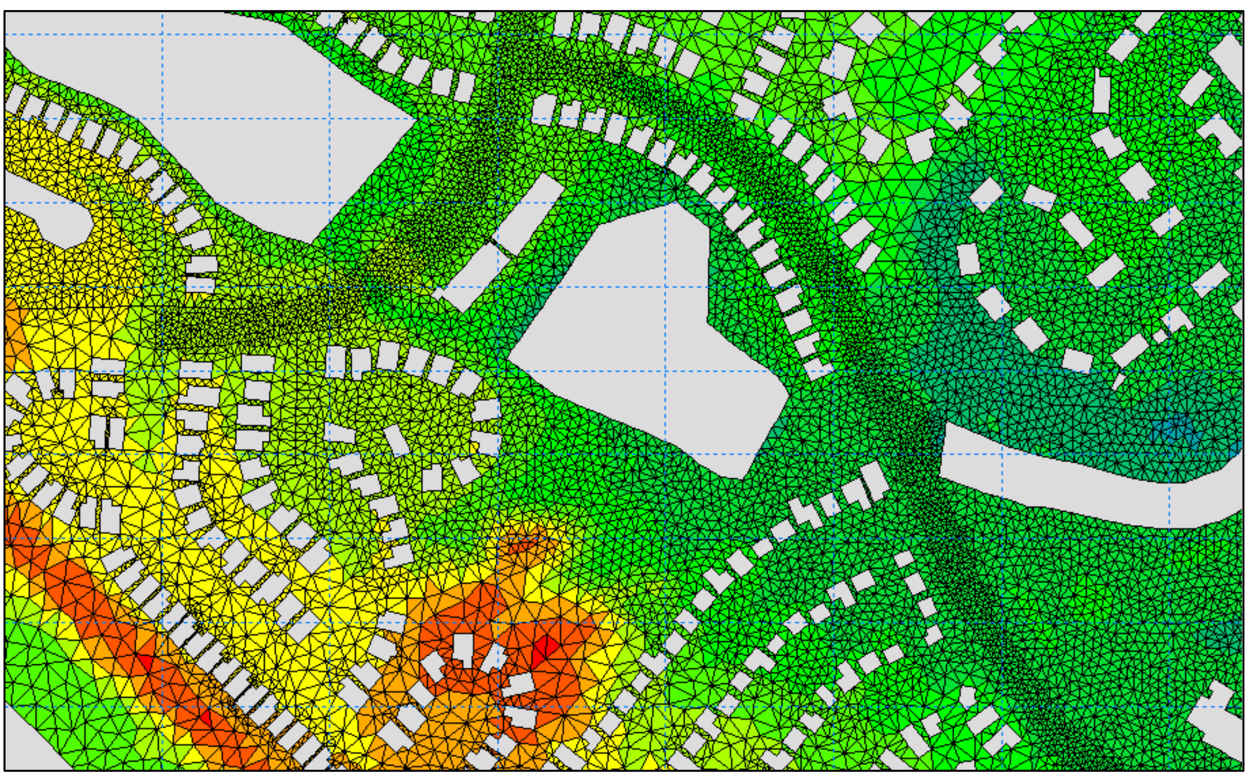


FIGURE 11 Example Mesh Resolution

2.3.2 Bathymetry Creation

The 2015 LiDAR was used in the extended study area to make use the most up to date information. To be consistent with the previous study, 2013 LiDAR was maintained over the original Spring Creek study area.

A few modifications were made to the LiDAR to ensure overland flow paths were appropriately represented. Most significantly:

- The Bramalea City Centre parking garage was cut out from the surface. There is a parking lot structure that was included in the buildings shapefile as an obstruction; however, the parking structure is open and therefore would allow flow conveyance.

- The Vodden Street pedestrian underpass was cut out as this would be the main spill path between the two ponds.

To create the 2D model bathymetry, the modified LiDAR was interpolated to the mesh nodes. The bathymetry was further modified along the model boundary to assign appropriate boundary conditions.

2.3.3 Surface Roughness

A spatially distributed map of Manning's n roughness values was created to reflect the various surface materials and vegetation throughout the 2D model domain. The Manning's n roughness map was developed based on the land use layer provided by TRCA. The Manning's n roughness file consists of square grid cells with a resolution of 2 m and covers the same extent as the 2D mesh.

Table 6 provides a summary of the TRCA Manning's roughness values used in the model. The methodology for applying roughness in MIKE FLOOD modelling is to use Manning's M (the inverse of Manning's n).

TABLE 6 Manning's Roughness Values

Land Use	Manning's n	Manning's M
Woods/Meadow/Cultivated Lands	0.08	12.5
Lawns	0.05	20
Impervious Areas	0.025	40

2.3.4 Boundary Conditions

The boundary conditions for the 2D model were assigned based on site conditions. The available options for assigning boundary conditions in MIKE 21 include either open or closed boundaries, wherein flow will be permitted to exit the system or be blocked, respectively. Since all inflows were included in the MIKE 11 model along each channel a closed boundary was used for the majority of the study area, with the exception of two locations within the existing Spring Creek model domain: at Steeles Avenue on the east side of the model domain; and at the southern end of the model domain. At these locations a constant elevation boundary condition was applied to allow water to leave the system instead of ponding at the edge of the model.

2.3.5 Simulation Settings

The MIKE 21 2D overland flow model provides a range of options for setting up and running the simulations. This section provides a listing of the settings used for this study.

- Solution Period
  - Time step: 0.2 seconds
  - Start time: Variable (dependent on design storm being simulated)
  - End time: Variable (dependent on design storm being simulated)
- Flood and Dry
  - Drying depth: 0.005 m
  - Flooding depth: 0.01 m
  - Wetting depth: 0.02 m
- Eddy Viscosity: 1 m^2/s
- Initial Conditions: Dry
- Results
  - Items: Surface Elevation, Total Water Depth, U Velocity, V Velocity, Current Speed
  - Storing frequency: 10 minutes

2.4 MIKE FLOOD 1D-2D Coupled Model

Once the MIKE 11 and MIKE 21 model components were constructed the remaining step was to couple the two components in MIKE FLOOD.

2.4.1 1D-2D Model Coupling

The 1D riverine model was coupled to the 2D overland model using the lateral weir coupling option. Using this option the flow exchange is calculated using a standard weir equation based on the elevation of either the 1D or 2D model at that location, whichever is higher. Lateral links were established on both banks of the creek to allow flow exchange to occur on either side. The lateral link locations are shown in Figure 12.

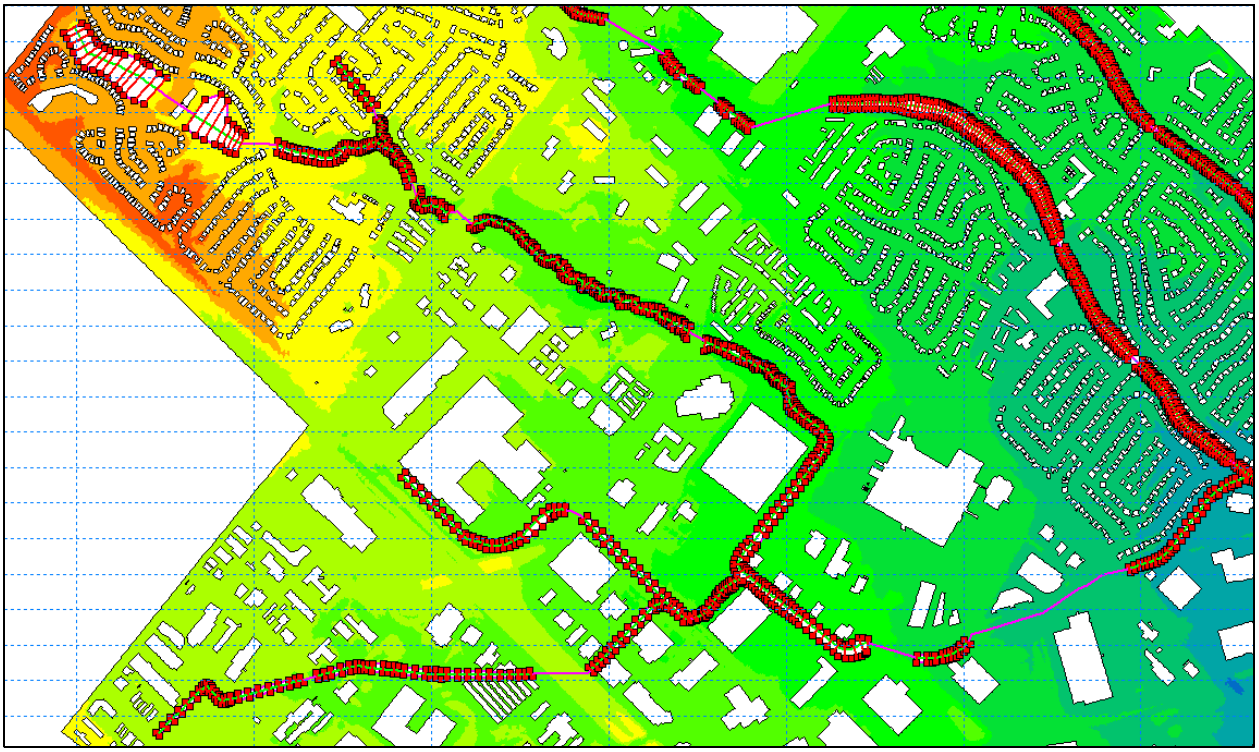


FIGURE 12 Lateral Link Locations

2.4.2 Simulation Parameters

The simulation parameters for the 1D-2D coupled model are consistent with those outlined in Section 2.3.5 for the MIKE 21 2D overland flow model.

2.4.3 Model Output

The following result parameters were stored at a frequency of 10 minutes: Water Surface Elevation, Total Water Depth, U Velocity, V Velocity, and Current Speed. Additional results from the 1D model are stored at a 1 minute frequency within the res1d file. This includes the Discharge and Water Level at each modelled cross-section.

3 FLOOD ASSESSMENT AND RESULTS

3.1 Model Run Scenarios

The 1D-2D coupled MIKE FLOOD model was run under a variety of unsteady and steady state flow scenarios to establish existing flood risk over a range of design storm events and the Regional storm, as summarized in Table 7. The run numbers are correlated with the model results which are displayed in Map Sets 1 to 9. In each map set Sheet 1 displays modelling depth, Sheet 2 displays modelled velocity, Sheet 3 displays resultant depth × velocity, and Sheet 4 displays overall flood risk.

TABLE 7 Model Run Scenarios

Run No.	Storm Event	Rainfall Distribution	Flow Condition	Land Use Condition
1	Regional	Hurricane Hazel	Steady	Future no SWM
2	Regional	Hurricane Hazel	Unsteady	Future no SWM
3	350-year	12-hour AES	Steady	Future no SWM
4	100-year	12-hour AES	Steady	Future with SWM
5	50-year	12-hour AES	Steady	Future with SWM
6	25-year	12-hour AES	Steady	Future with SWM
7	10-year	12-hour AES	Steady	Future with SWM
8	5-year	12-hour AES	Steady	Future with SWM
9	2-year	12-hour AES	Steady	Future with SWM

3.2 Selection of Input Hydrographs – Steady vs. Unsteady

The Regional storm event (Hurricane Hazel) was run in both steady state and unsteady state conditions; these are identified as run numbers 1 and 2, respectively. The unsteady state inflows include typical hydrographs with a rising limb, peak flow, and falling limb over the selected storm duration. These hydrographs were extracted from the VO model (MMM 2013) at appropriate flow nodes. The steady state inflows were prepared as 'quasi-steady' whereby the flow was gradually increased over a one hour period to achieve stability. The peak flow was then held constant for the remainder of the simulation time to achieve steady state throughout the study area. As summarized in Table 7, run numbers 3 to 9 were conducted using a 12-hour AES rainfall distribution applied to the riverine system. The 12-hour AES was selected because this storm distribution provides the most conservative estimate of peak flows in the riverine system (MMM 2013).

Traditionally, floodplain delineation in Ontario is completed using one-dimensional steady state (or quasi-steady state) hydraulic modelling to calculate flood elevations and the associated flood extents. This approach is consistent with recommendations in the Technical Guide – River and Stream Systems: Flooding Hazard Limit (MNR 2002). Steady state modelling is appropriate for watercourses with well-defined channels and for which a gradually varied flow assumption governs. Steady state (or quasi-steady state) modelling does not consider attenuation effects due to storage or reverse flow conditions. When delineating flood extents using quasi-steady flow input it is important to consider the total volume of observed flooding compared to the available volume of water in the system for a given storm event. This is particularly true in instances where storage effects are significant and therefore the use of steady state calculations without accounting for attenuation can be unrealistically conservative. Similarly, there may be some cases where flow spills from the channel and is conveyed downstream without returning to the watercourse. In these cases, the use of steady state inflows may result in having to "chase" the flooding in order to delineate the floodplain resulting in an unrealistically extensive floodplain. If the volume of water contained within the delineated floodplain is significantly greater than the available water in the system, then unsteady state modelling using inflow hydrographs would be required to more accurately reflect flood extents.

We compared the results of the Regional steady and unsteady state simulations and determined that the results are generally consistent. There are a few locations throughout the model domain where the Regional steady state results are more extensive than those from the unsteady run; however, these differences were considered to be minor. We did not observe any instances where spill flows did not reach steady state and therefore the Regional steady state results were used for Regulatory floodplain delineation.

3.2.1 Understanding MIKE FLOOD Results

The MIKE FLOOD model creates spatial outputs of both the 1D river and 2D overland results. The 1D results were output on a grid with 2 m resolution. The 2D overland results are generated for each mesh element. In some areas such as spill at road crossings, 1D and 2D results may overlap. In Maps Sets 1 to 9, the 1D results presented were clipped to remove any area already covered by the 2D mesh. This helps clarify instances where a channel is buried and when spill flow overtops a road.

For steady state results, the maximum depth and velocity were obtained from the last model time step. For unsteady results all depth, velocity, and the product of depth × velocity results were calculated using MIKE Zero tools to determine the maximum modelled value over the entire simulation period from the unsteady hydrograph output for each parameter.

3.3 Discussion of Results

3.3.1 Comparison to Original Spring Creek 2D MIKE FLOOD Results

The results of the Regional steady state simulation (see Map Set 1) were compared against the flood extent generated from the original Spring Creek model (MMM 2015). The extent of flooding within the original study area is generally consistent with the previous floodlines and this assessment served to verify the new model.

Minor exceptions to this were observed along the boundary of the original Spring Creek study area and are attributed to the extents of the previous model. In particular, results from the current study indicate that during large storm events (350-year and greater) flow spills from Channel 1 and is conveyed into the original Spring Creek study limit from the west, as shown in Figure 13 for the Regional steady state event. In particular, flow spills across Dixie Road into the original study area in four locations: 1) south of Private Drive and along Balmoral Drive; 2) around Brentwood Drive; 3) along Birchbank Drive; and 4) around the commercial buildings north and south of the CN rail. These differences are considered acceptable and therefore the results of the current study will be used to tie in the Regulatory floodlines in these areas.

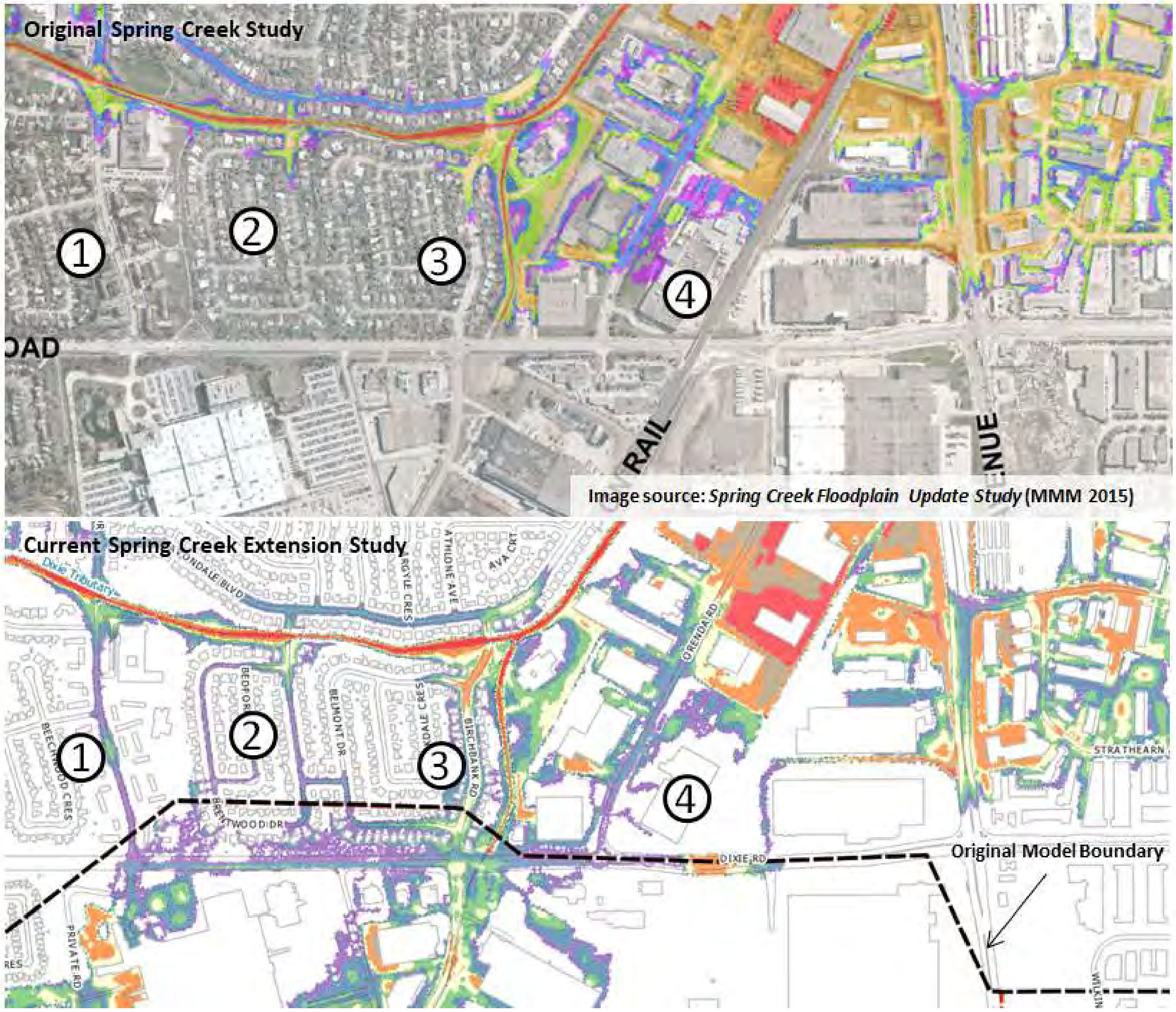
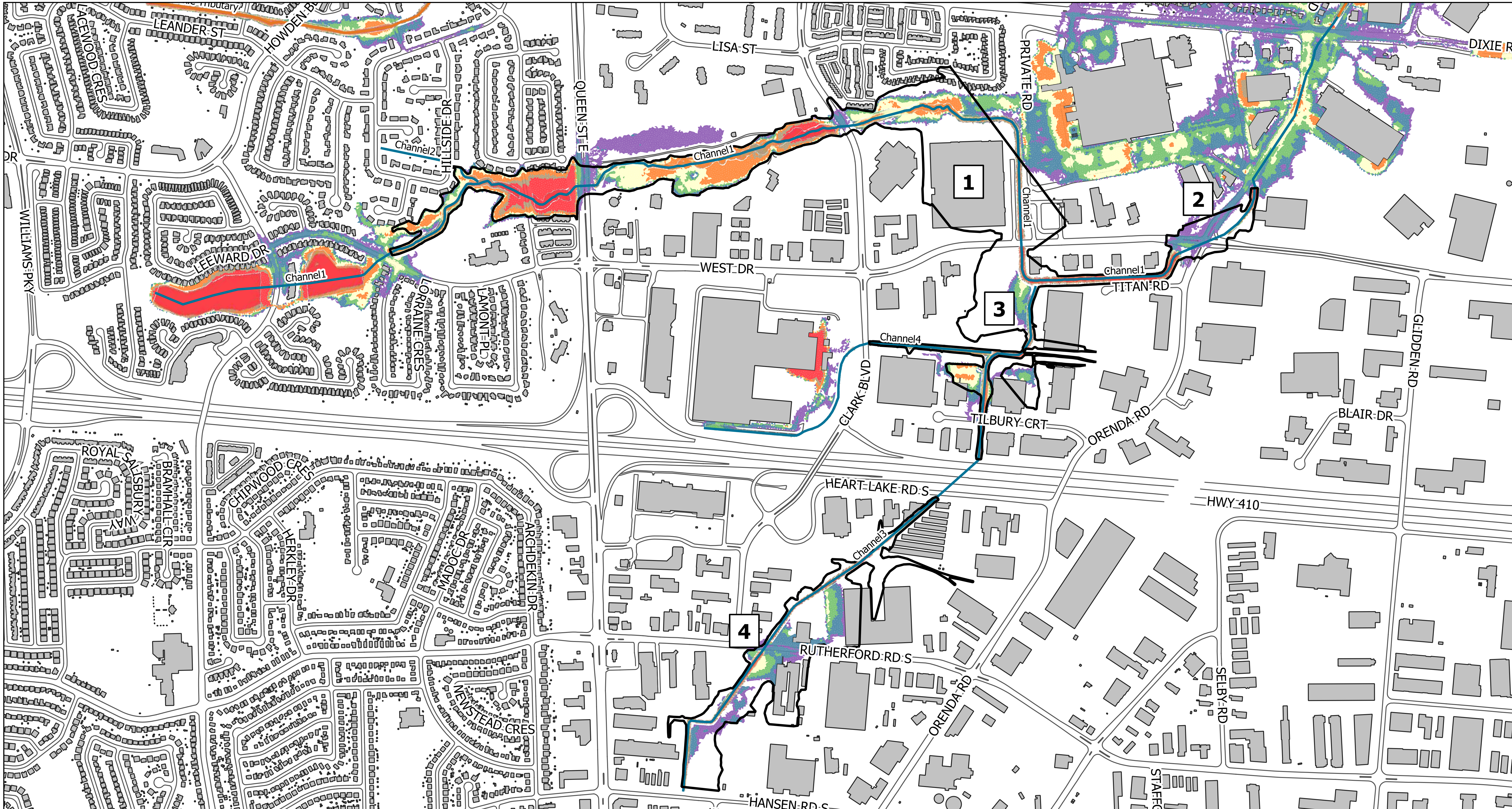


FIGURE 13 Comparison to Original Spring Creek 2D MIKE FLOOD Results

3.3.2 Comparison to Existing 1D HEC-RAS Results

Matrix also compared the results of the updated MIKE FLOOD modelling to the existing floodlines for the Spring Creek tributaries that were developed from HEC-RAS (Aquafor 2016). A comparison of the results from these two models is shown in Figure 14 including four areas where results are notably different. Primary reasons for variations in results are attributed to different modelling approach (1D HEC-RAS versus 2D MIKE FLOOD) and different topographic data. The Aquafor 2016 1D HEC-RAS model was developed using a DEM provided by TRCA based on 2005 and 2009 photogrammetry, while the Matrix 2D MIKE FLOOD was developed from 2015 LiDAR. The difference in modelling approach is particularly relevant where spill from Channel 1 occurs due to channel capacity issues near Private Drive (location 1) and structure capacity issues at Orenda Road (location 2). HEC-RAS results suggest spill at location 1 occurs at the 2-year event, while MIKE FLOOD shows spill not occurring below the 25-year event. The Aquafor 2016 study indicated that, based on topography, spill would continue into the developed area west of Dixie Road south of Private Drive; however, the 1D HEC-RAS modelling approach precluded the ability of this spill to be fully defined. Similarly, the difference in flood extents at location 3 is attributed to the fact that in the MIKE FLOOD model the spilled flow at location 1 diverts water from the Channel 1 and therefore backwater at the West Drive culvert and Channel 3 / Channel 1 confluence is reduced. In HEC-RAS, all flow is assumed to stay in the channel in this reach leading to a more extensive floodplain at location 3.



Roads

Buildings

Existing Floodline (Aquafor 2016)

MIKE FLOOD Depth, Regional Steady (m)

0.00 - 0.00

<= 0.10

0.10 - 0.30

0.30 - 0.50

0.50 - 0.80

0.80 - 1.50

1.50 - 2.00

> 2.00

0 250 500 750 1000 m

N

This drawing must be used in conjuction with the attached report, Spring Creek 2D Modelling Extension and Floodplain Mapping Update (April 2019) and is subject to the same limitations and conditions stated in the report.

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Spring Creek 2D Modelling Extension and Floodplain Mapping Update

Project #22062

Comparison to Existing 1D HEC-RAS Results

K. Molnar

Figure 14

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4 FLOODPLAIN MAPPING

The results of the Regional storm steady state runs, in combination with the existing LiDAR data, were used to delineate the Regional Floodline. The Regional Floodline was delineated by TRCA's GIS department using the Regional storm steady state results provided by Matrix. The resulting floodline was reviewed and stamped by Matrix. A draft version of the floodplain mapping displaying the Regional Floodline is provided in Appendix C.

5 CHARACTERIZATION OF EXISTING FLOOD RISK

As part of this study Matrix completed the characterization of existing flood risk in the new extension area using the results of the 1D-2D coupled MIKE FLOOD model. The following section summarizes the flood characterization including results of the design storm runs and identification of flood mechanisms, hydraulic deficiencies, and areas of high, medium, and low flood risk.

5.1 General Floodplain Characteristics

The general floodplain characteristics of the four reaches in the extension area are described below. Figure 15 is included for reference, which displays the reaches against aerial imagery and gives context to the level of development and floodplain restrictions. Each channel includes crossings (roads, rail, or pedestrian bridges) which may further constrict the floodplain. Hydraulic deficiencies are further discussed in Section 6.1. Each channel is described in detail in the following subsections.

FIGURE 15 Aerial Imagery of Study Area

5.1.1 Channel 1

Channel 1 originates at the Parr Lake pond north of Vodden Street East and extends through various parklands (Laurelcrest Park, Norton Place Park, and Carleton Park) and residential neighbourhoods. Channel 2 confluences with Channel 1 north of Lambeth Street within Laurelcrest Park. The floodplain of the upstream portion of Channel 1 is open and natural within the parklands (Figure 16). During the 350-year and Regional storm events some flooding is observed adjacent to residential buildings on Lancefield Crescent and Lombardy Crescent that back onto the floodplain.

FIGURE 16 Aerial Imagery of Channel 1 – Upstream

The floodplain characteristics of Channel 1 change downstream of Carleton Park, where the channel makes a 90° bend to the west toward West Drive, the floodplain is narrowed, and the surrounding land use changes to a highly impervious industrial and commercial area (Figure 17). Here the channel appears to have been realigned around the industrial development area and includes concrete-lined banks. The channel is straightened and has several 90° bends in this area. Model results indicate that the presence of these bends cause flow to spill from the channel as momentum carries flow forward along the path of least resistance. Channel 3 confluences with Channel 1 west of West Drive. Channel 1 is piped underground along Orenda Road from east (downstream) of West Drive to east (downstream) of Dixie Road. Downstream of Dixie Road the channel includes an open concrete channel cross-section with a trail and residential area on the left bank and a school and park on the right bank.

FIGURE 17 Aerial Imagery of Channel 1 – Downstream

5.1.2 Channel 2

Channel 2 is a short, concrete-lined ditch feature behind residential properties along Hillside Drive (Figure 18). Channel 2 originates at a 975 mm storm sewer outletting south of Lillington Street. Upstream of Hillside Drive the channel has well-defined banks which, according to model results, permits flow to stay in the channel for all storm events. Downstream of Hillside Drive Channel 2 has a low right bank near Esker Lake Trail behind Laurelcrest Park causing some spill into the floodplain.

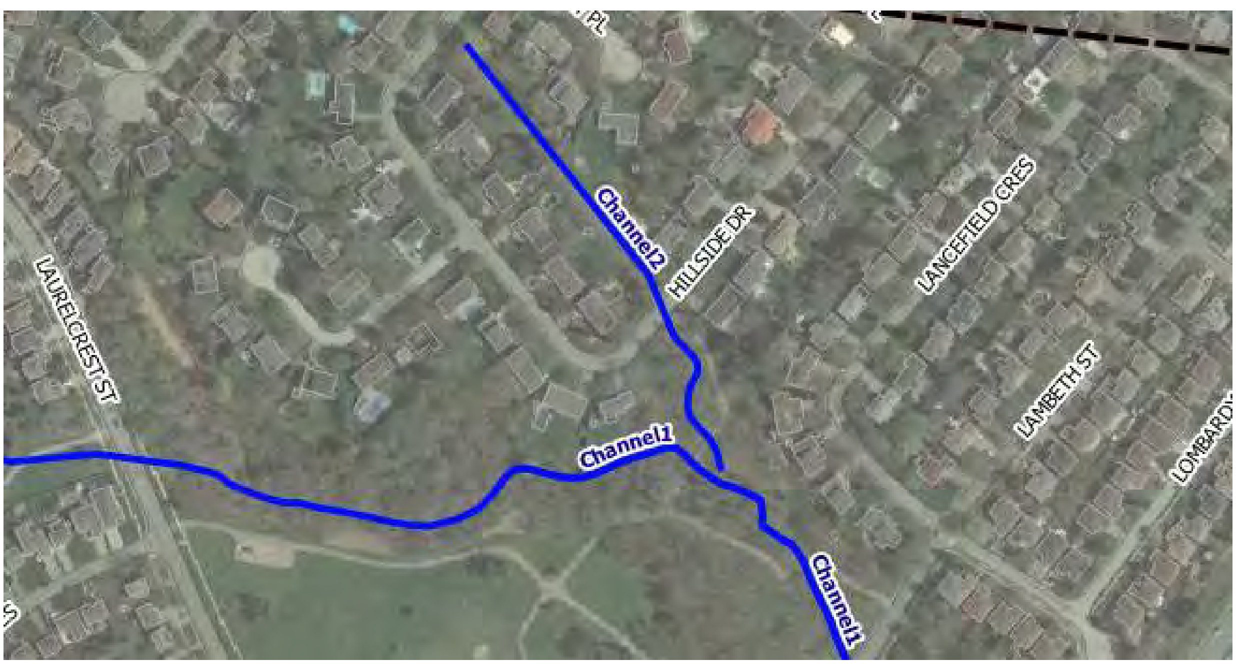

FIGURE 18 Aerial Imagery of Channel 2

5.1.3 Channel 3

Channel 3 is located in a highly impervious industrial and commercial area originating east of Hansen Road and has very little natural floodplain (Figure 19). The channel width is only about 10 m between developed land as several parking lots and buildings back onto the edge of the banks. Channel 3 has been straightened in the developed area. There are several severe bends along these channels which appear to have been reinforced by including concrete-lined sections.

FIGURE 19 Aerial Imagery of Channel 3

5.1.4 Channel 4

Channel 4, originating north of Clark Boulevard and east of Highway 410, is also located in a highly impervious industrial and commercial area and generally consists of a ditch along a railway spurline (Figure 20). The lack of defined left bank at the most upstream portion of Channel 4 causes flooding into the floodplain during the 2-year storm along the railway and onto an adjacent industrial property. Downstream of Clark Boulevard the channel has more defined banks and increased capacity.

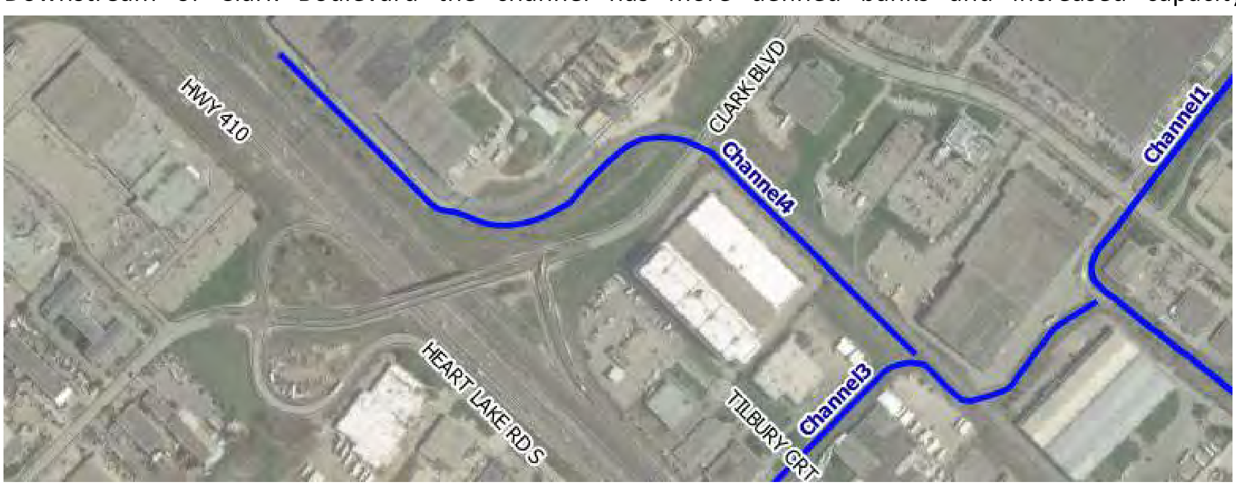

FIGURE 20 Aerial Imagery of Channel 4

5.2 Flood Risk Mapping

Flood risk characterization and mapping is typically undertaken with consideration of three risk factors: depth, velocity, and depth × velocity. The risk mapping criteria provided in Table 8 were based on current MNRF practices, adapted by TRCA. Low risk includes areas that are inundated but where vehicular and pedestrian access and egress are still feasible. Medium risk areas do not permit vehicular access and egress due to water depths, but pedestrian access and egress is possible. High risk areas do not facilitate safe access of any kind. These flood risk criteria were used to develop the flood risk mapping presented as Sheet 4 in each of Map Sets 1 through 9.

TABLE 8 Flood Risk Criteria

Risk Level	Low	Medium	High *
Depth	≤ 0.3 m	> 0.3 m and ≤0.8 m	> 0.8 m
Velocity	≤ 1.7 m/s		> 1.7 m/s
Depth × Velocity	≤ 0.37 m^2/s		> 0.37 m^2/s

* Exceedance of any one of the criteria results in high risk.

6 IDENITIFCATION OF HYRAULIC CONSTRAINTS

The 1D-2D coupled MIKE FLOOD model results were reviewed to assess flood conditions in the study area and identify areas at risk due to inadequate or underperforming infrastructure. This includes MIKE 11 results (longitudinal profiles and cross-sections) and MIKE 21 results (depth, velocity, and depth × velocity mapping and dynamic result files). The flood mechanisms resulting in high, medium, and low flood risk were identified throughout the study area. The analyses presented in this section are focussed on the Spring Creek tributaries only and do not revisit elements within the original Spring Creek study area.

6.1 Hydraulic Constraints

Riverine flooding occurs when water levels of rivers, streams, and creeks rise and overflow their banks, spilling onto adjacent areas. "Conservation Authorities are responsible for determining the hazard from riverine flooding" (TRCA 2019). Riverine flooding may be caused by a number of mechanisms including structure capacity (i.e., bridges and culverts), channel conveyance capacity, backwater conditions, and combinations thereof. During the review of results, the following potential sources and causes of riverine flooding were considered:

- structure capacity issues (bridges, culverts)
- channel capacity issues (i.e., areas with constrictions, low points in banks)
- backwater conditions
- overland flow path issues and topographic low points (on private or public lands)
- right-of-way conveyance capacity issues

Channel capacity restrictions may also lead to riverine flooding, in particular low banks which allow flow to spill from the main channel into the floodplain. Channel capacity restrictions are often linked to structure capacity issues. Some storm events cause spill into properties due to overland flow path issues and topographic low points (on private or public lands) or right-of-way conveyance capacity issues. We recognize that design and assessment of major overland flow paths fall within municipal responsibilities, not that of conservation authorities. However, it is important to acknowledge instances where riverine-derived flooding impacts components of the urban drainage system.

To determine potential sources of riverine flooding within the study area, the hydraulic constraints were reviewed and the following tables summarize the findings:

- Table 9 provides a summary of structure capacities, soffit elevations, and storm events leading to surcharge and overtopping.
- Table 10 provides a summary of channel capacity limitations or restrictions leading to spill from the main channel into the floodplain.
- Table 11 provides a summary of spill areas under each storm event.

TABLE 9 Structure Capacity

Structure Name	Reach Name	MIKE 11 Chainage	Dimensions [H × W or Diameter] (m)	Approx. Flow Area (m^2)	Soffit Elev. (m)	Storm Event Causing Surcharge	Storm Event Causing Overtopping
Vodden Street	Channel1	294	0.45	0.16	219.99	2-year	350-year
Laurelcrest Street	Channel1	570	0.5	0.20	219.72	2-year	350-year
Pedestrian Bridge No.16	Channel1	939	2.54 × 10	9.45	217.59	350-year	350-year
Pedestrian Bridge No.17	Channel1	1,029	1.62 × 7.3	5.59	216.11	50-year	350-year
Lambeth Street	Channel1	1,100	1.98 × 1.55	2.34	214.67	100-year	350-year
Queen Street East	Channel1	1,277	1.8 × 2.4	4.32	214.09	350-year	Regional SS*
Pedestrian Bridge No. 20	Channel1	1,934	1.86 × 1.2	1.71	210.16	350-year	350-year
Clark Boulevard	Channel1	2,132	2.25 × 1.75	3.0	209.47	50-year	350-year
West Drive	Channel1	2,975	1.2 × 6	7.2	204.8	2-year	N/A
Orenda Road / West Drive	Channel1	3,615	2.15 × 4.27	9.18	204.8	2-year	100-year
Orenda Road / Dixie Road	Channel1	4,093	1.83 × 3.66	6.70	199.27	2-year	10-year
Birchbank PS Driveway	Channel1	4,732	2.18 × 6.47	14.10	192.68	25-year	350-year
Hillside Drive	Channel2	186	2.24 × 1.83	3.16	219.87	N/A	N/A
Trail Bridge	Channel2	272	1.53 × 12.31	7.66	217.58	350-year	350-year
Rutherford Road South	Channel3	507	1.95 × 1.95	3.80	213.94	2-year	25-year
Heart Lake Road / Hwy 410	Channel3	1,234	3 × 6	18	212.33	N/A	N/A
Tilbury Court	Channel3	1,407	3 × 5.3	12.17	210.85	350-year	N/A
CN Rail	Channel3	1,689	3 × 7.6	22.8	210.27	N/A	N/A
Clark Boulevard	Channel4	2,132	3.5 × 2.58	7.02	212.13	N/A	N/A

* SS = steady state

TABLE 10 Channel Capacity Limitations

Reach Name	Location	Storm Event Causing Spill from Channel
Channel1	Parr Lakes to Carleton Park	10-year
Channel1	Downstream of Carleton Park to West Drive	25-year
Channel1	Orenda Road at West Drive	100-year
Channel1	Orenda Road (West Drive to Dixie Road)	10-year
Channel1	Downstream of Dixie Road	10-year
Channel2	Trail (Downstream of Hillside Drive to Channel 1)	350-year
Channel3	Upstream of Rutherford	350-year
Channel3	Rutherford Road South	10-year
Channel3	Tilbury Court to Channel 4	100-year
Channel3	Between Channel 4 and Channel 1 confluence	5-year
Channel4	Upstream of Clark Boulevard	2-year

6.2 Flood Frequency

Table 11 presents a summary of the spill areas under each storm event. A description of the spill area and flow path and the associated risk areas (low, medium, and high) are also presented. Note that only spills originating from the extended study area are commented on. Areas of low, medium, and high risk are shown only for the 2D overland and do not include areas within the 1D river channel. Some spill from the extended study area spills into the original study domain (refer to Section 3.3). It may be difficult to separate out the entire flooding area due to spill from Channel 1 and spill from Dixie Tributary. Therefore, the flood risks areas are summarized for the full model domain in addition to the flood risk areas within the extended study area. Note also that risk area quantities will not match those in Table 3.4 of the *Spring Creek Flood Characterization Report* (MMM 2016) due to differences in model domain and updates to flood risk definitions since completion of that study.

TABLE 11 Flood Frequency

Return Period	Spill Description (Extended Study Area)	Domain	Area of Flooding (ha) [1]		
			Low Risk	Medium Risk	High Risk
2-year	Spill occurs along rail from Channel 4 upstream of Clark Boulevard around property. Spill from Channel 1 is contained within parks located in the floodplain.	Full Domain	8.83	6.78	3.43
		Extended Area	2.71	0.32	0.58
5-year	Spill from the channels starts to occur in a few places although no new significant impacts to properties. Spill upstream of Rutherford Road caused by undersized crossing. Spill occurs at Channel 3 where it confluences with Channel 1.	Full Domain	10.02	6.6	8.65
		Extended Area	3.18	0.57	0.59
10-year	Spill travels overland along Orenda Road and Birchbank Road and along Dixie Road as the culvert capacity in piped section under Orenda Road is exceeded. Spill flow	Full Domain	19.32	7.82	13.73
		Extended Area	6.64	1.04	0.69

Return Period	Spill Description (Extended Study Area)	Domain	Area of Flooding (ha) [1]		
			Low Risk	Medium Risk	High Risk
	upstream of Rutherford crosses Rutherford and renters Channel 3.				
25-year	Spill from Channel 1 downstream of Carleton Park travels south toward Orenda Road through industrial area along private roads and private properties.	Full Domain	38.84	12.97	17.51
		Extended Area	13.83	1.99	1.04
50-year	The spill from Channel 1 downstream of Carleton Park expands and travels along a new flow path east to Balmoral Drive and then south on Dixie Road toward Orenda Road and Birchbank Road.	Full Domain	48.08	17.28	19.93
		Extended Area	17.37	3.46	1.43
100-year	Minor spill downstream of Tilbury Court. Spill from Par Lake South starts to back onto properties along Laurelcrest Street and Lorraine Crescent.	Full Domain	53.32	20.81	22.7
		Extended Area	18.63	4.67	1.91
350-year	Spill from Parr Lake north pond travels through Vodden Street underpass and along Leeward Drive. Flow overtops Laurelcrest Street spilling into properties backing onto Laurelcrest Park. Minor spill occurs along the upstream extent of Channel 3. Spill from Channel 1 creates a new flow path along Balmoral Drive, Belmont Drive, Brentwood Drive. Spill at Orenda Road and West Drive overtops intersection and runs along Orenda Road. Additional spill around Birchbank Public School and south of Orenda Road between West Drive and Dixie Road. There is a large increase in medium and high risk areas.	Full Domain	64.78	87.77	40.87
		Extended Area	12.02	23.32	10.56
Regional Storm (Steady)	Additional spill flow on properties downstream of Tilbury Court, upstream of Rutherford and along Channel 1 over the trail into the pond south of Queen Street. There is an increase in high risk areas.	Full Domain	101.45	52.5	93.46
		Extended Area	27.69	10.76	15.88

[1] Areas are reported for spill outside of the channel (2D overland only)

6.3 Flood Zones

Matrix reviewed the MIKE FLOOD results in detail across the study area to identify high risk flood zones for each modelled storm event based on the TRCA risk criteria (adapted from MNRF standards). To define an area as high risk, each wetted cell in the model results was compared against the risk criteria provided in Table 8 in Section 5.2. Through this process, the following high risk flood zones were identified (refer to Figure 21) and are discussed in detail throughout this section:

1. Laurelcrest Drive south of Vodden Street (Channel 1)

2. Upstream of Queen Street (Channel 1)

3. Norton Place Park (Channel 1)

4. Downstream of Carleton Park (Channel 1)

    a. Private Road (Channel 1)
    b. Orenda Road at West Drive (Channel 1)

5. Tilbury Court (Channel 3)

6. Rutherford Road (Channel 3)

Roads

Buildings

MIKE FLOOD Depth, Regional Steady (m)

0.00 - 0.00

<= 0.10

0.10 - 0.30

0.30 - 0.50

0.50 - 0.80

0.80 - 1.50

1.50 - 2.00

> 2.00

0 250 500 750 1000 m

This drawing must be used in conjuction with the attached report, Spring Creek 2D Modelling Extension and Floodplain Mapping Update (May 2019) and is subject to the same limitations and conditions stated in the report.

Matrix Solutions Inc.
ENVIRONMENT & ENGINEERING

Spring Creek 2D Modelling Extension and Floodplain Mapping Update

Project #22062

Flood Zones

K. Molnar

Figure 21

T:\22062-162714 Spring Creek 2D Update\05 Analysis\GIS\22062-162714_RegFloodlineReview.qgs

6.3.1 Zone 1 – Laurelcrest Drive South of Vodden Street (Channel 1)

Zone 1 primarily includes Laurelcrest Drive from Vodden Street to Lorraine Crescent. High risk flooding in this area is generally limited to open park lands; however, flooding on Laurelcrest Drive also occurs, becoming high risk (immediately at the culvert) at the 350-year storm event. During the Regional event, the flooding on Laurelcrest Drive just south of Vodden Street becomes high risk. The primary flood mechanisms contributing to flooding in this area are structure capacity as well as channel capacity. The high risk flooding at the Laurelcrest Drive culvert is primarily attributed to depth × velocity values exceeding the 0.37 m^2/s threshold, while high risk flooding south of Vodden Street is due to a combination of depth and depth × velocity exceedances.

The Vodden Street culvert, located between the two Parr Lake ponds, is surcharged for all events. Overtopping occurs at the 350-year event. The culverts outletting the two Parr Lake ponds are small (0.16 m^2 and 0.20 m^2 flow area at the Vodden Street and Laurelcrest Street culverts, respectively) which allow the ponds to store water.

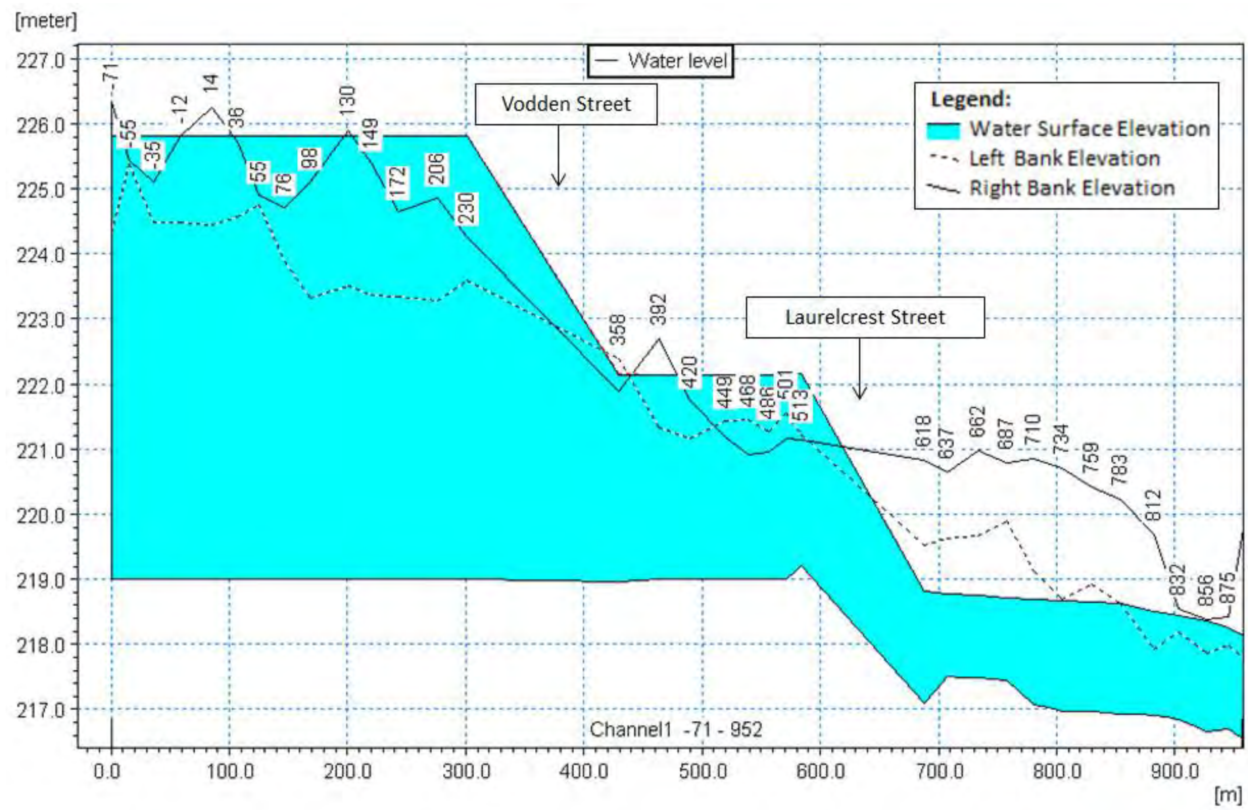

FIGURE 22 Channel 1 Profile near Parr Lake Ponds – 350-year Storm

During the 350-year storm, flow passes through the Vodden Street underpass (high risk) and along Vodden Street and Laurelcrest Street (low risk; Figure 23). Some of the spill overtops Vodden Street and runs behind properties on Laurelcrest Street (low risk). An overland flow path, characterized as high risk, is observed over Laurelcrest Street and along the rear yards of homes on Hawthorn Crescent before it rejoins the channel in Laurelcrest Park.

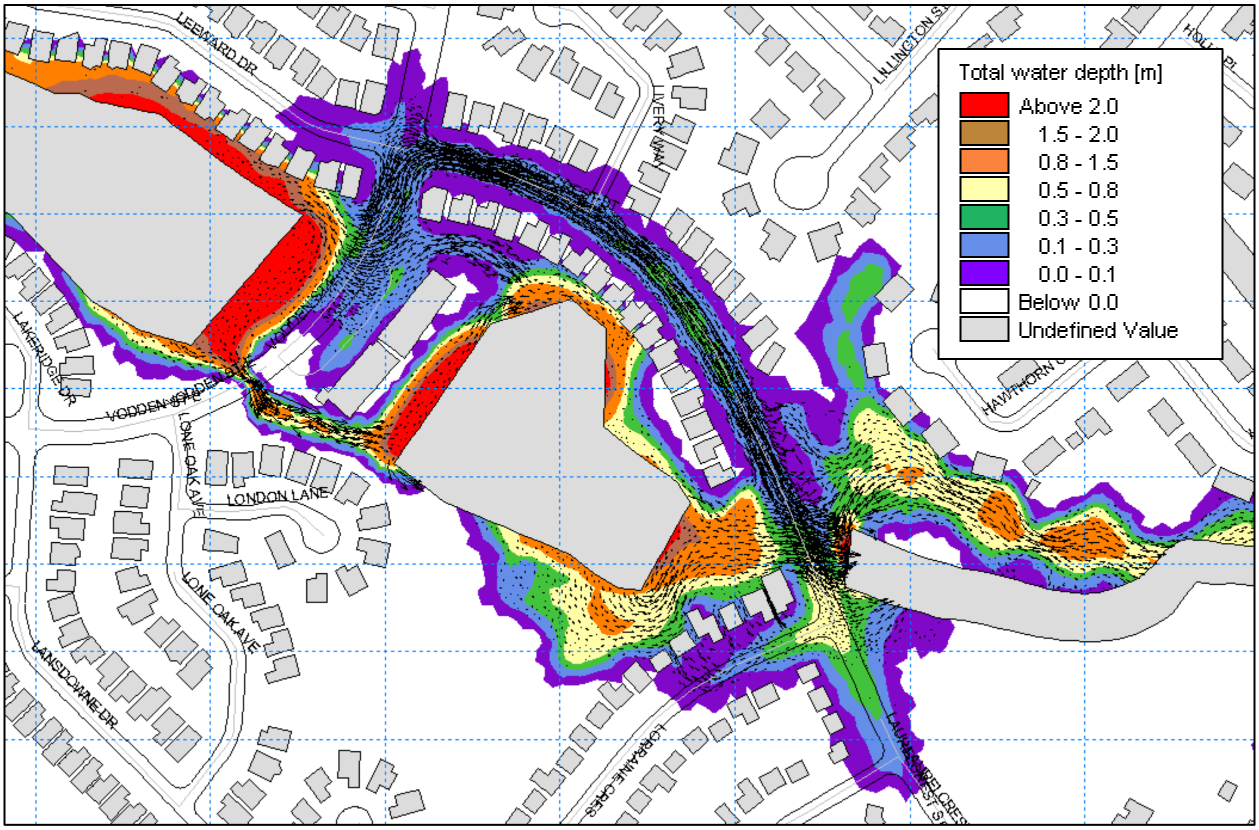

FIGURE 23 Channel 1 Parr Lake to Laurelcrest Street – Regional Storm

6.3.2 Zone 2 – Upstream of Queen Street (Channel 1)

Zone 2 includes the area upstream of Queen Street in Laurelcrest Park (Figure 24). Spill into properties upstream of Queen Street (at Laurelcrest Park) occurs at the 350-year storm. Flooding in this area is generally limited to open park lands; however, flooding does back onto properties on Lancewood Crescent, and Lombardy Crescent at the 350-year and Regional storm event. The area is classified as high risk for these larger storms.

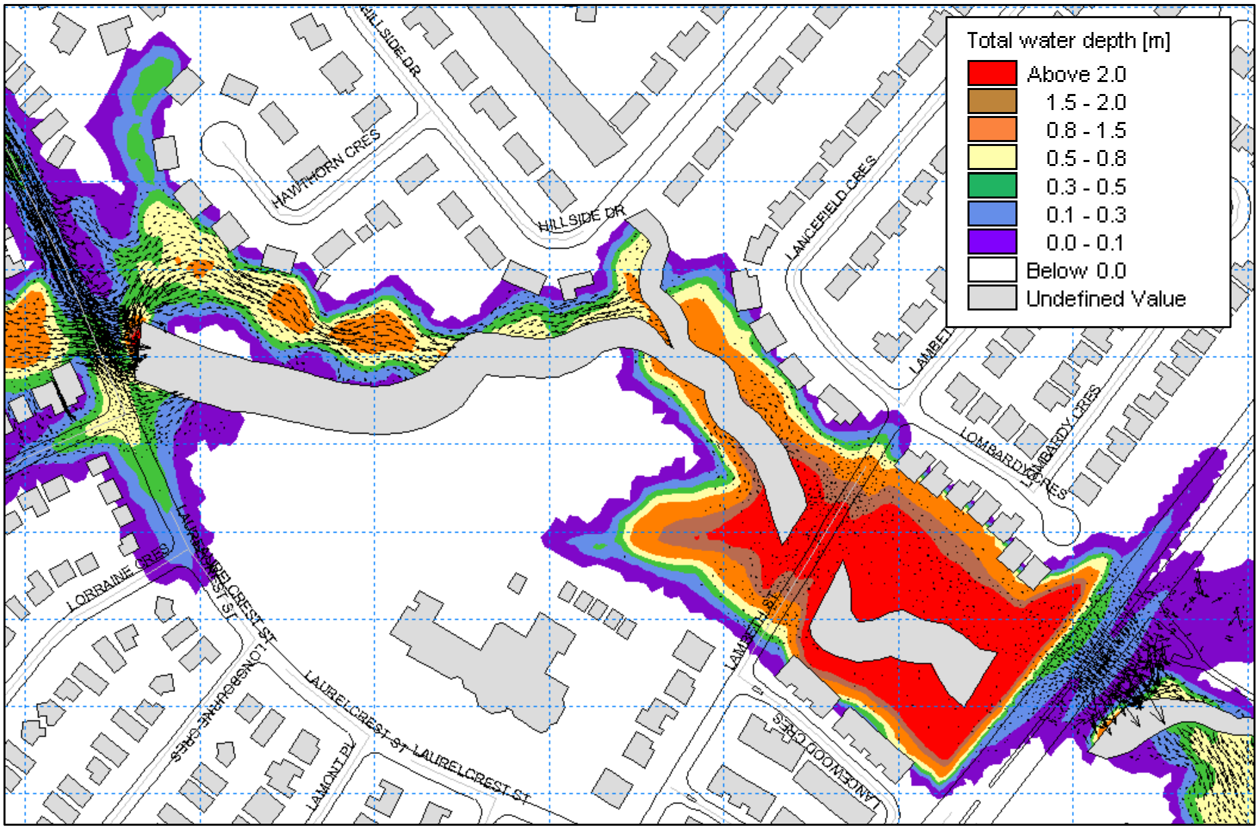

FIGURE 24 Channel 1 Laurelcrest Street to Queen Street – Regional Storm

The flood risk in this zone is primarily driven by structure capacity. While Pedestrian Bridge 17 and Lambeth Street are at capacity for a 50-year and 100-year storm respectively, no structures in this zone are overtopped until the 350-year storm. Backwater originating at Queen Street during the 350-year storm creates a high risk area upstream of the crossing, impacting the rear yards of properties on Lancefield Crescent and Lancewood Crescent. Similar flooding extent is observed for the Regional event in this area, with some areas having a higher classification of risk for the Regional steady state event. The Queen Street road deck elevation is 4 m higher than the soffit elevation. This causes a significant backwater behind Queen Street (Figure 25). Depths in this area exceed the criteria for high risk, while velocity and depth x velocity remain low as water is held behind the road.

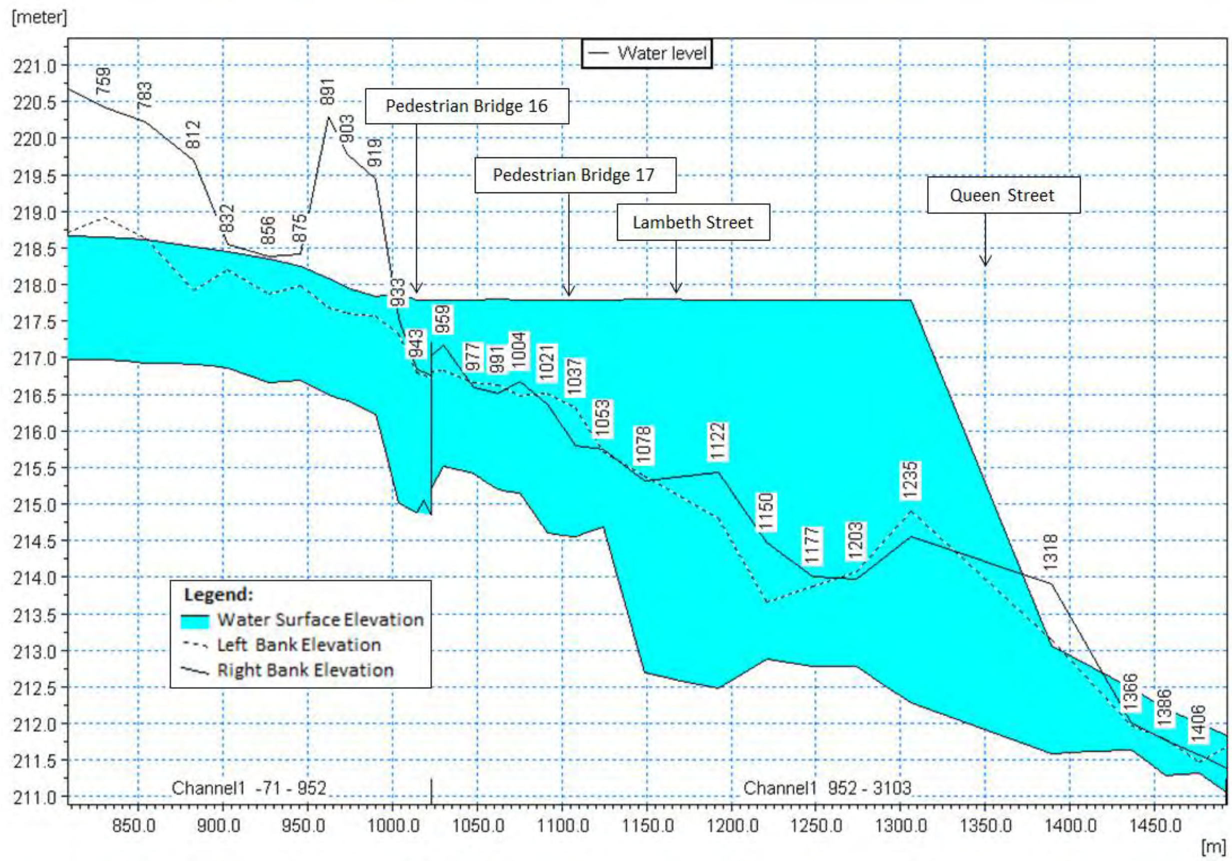

FIGURE 25 Channel 1 Profile upstream of Queen Street – 350-year Storm

6.3.3 Zone 3 – Norton Place Park (Channel 1)

Norton Place Park is located along Channel 1 between Queen Street and Clark Boulevard. Flooding in this zone is generally contained to parkland and has minimal impact on private property. High flood risk starts to occur outside of the channel in the 10-year event between the pedestrian bridge and Clark Boulevard, although it is still contained within the park until the 350-year event. Backwater from Clark Boulevard results in increased depths and risk classification upstream of Clark Boulevard for the higher return periods. An additional overland flow constraint occurs for the regional storm (Figure 26), where flow overtopping Queen Street results in spill from Channel 1 crossing trail into an adjacent pond.

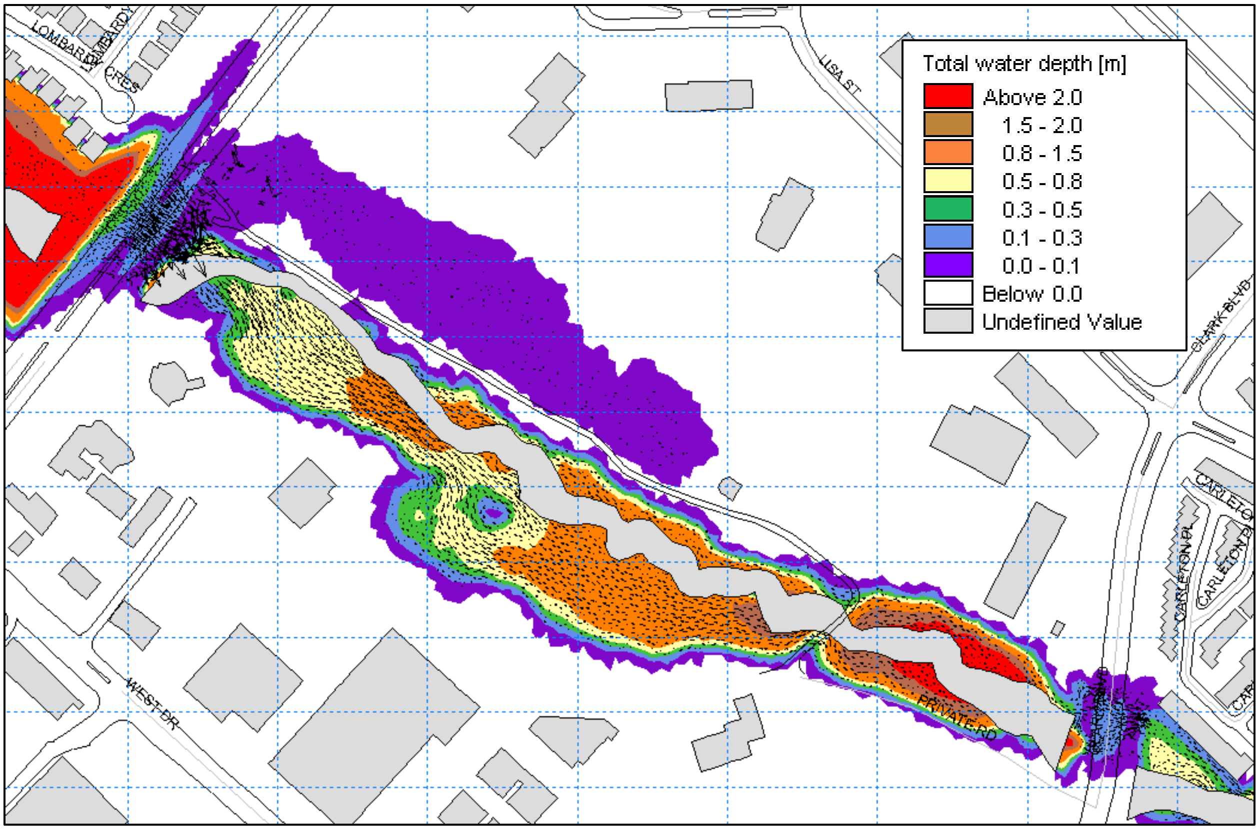

FIGURE 26 Channel 1 Norton Place Park – Regional Storm

The backwater behind Clark Boulevard contributes to higher depths immediately upstream of the road and results in classification of high flood risk. The Clark Boulevard culvert is surcharged during the 50-year storm (Figure 27). Backwater caused by Clark Boulevard but does not result in any spill onto the road or private properties until the 350-year storm.

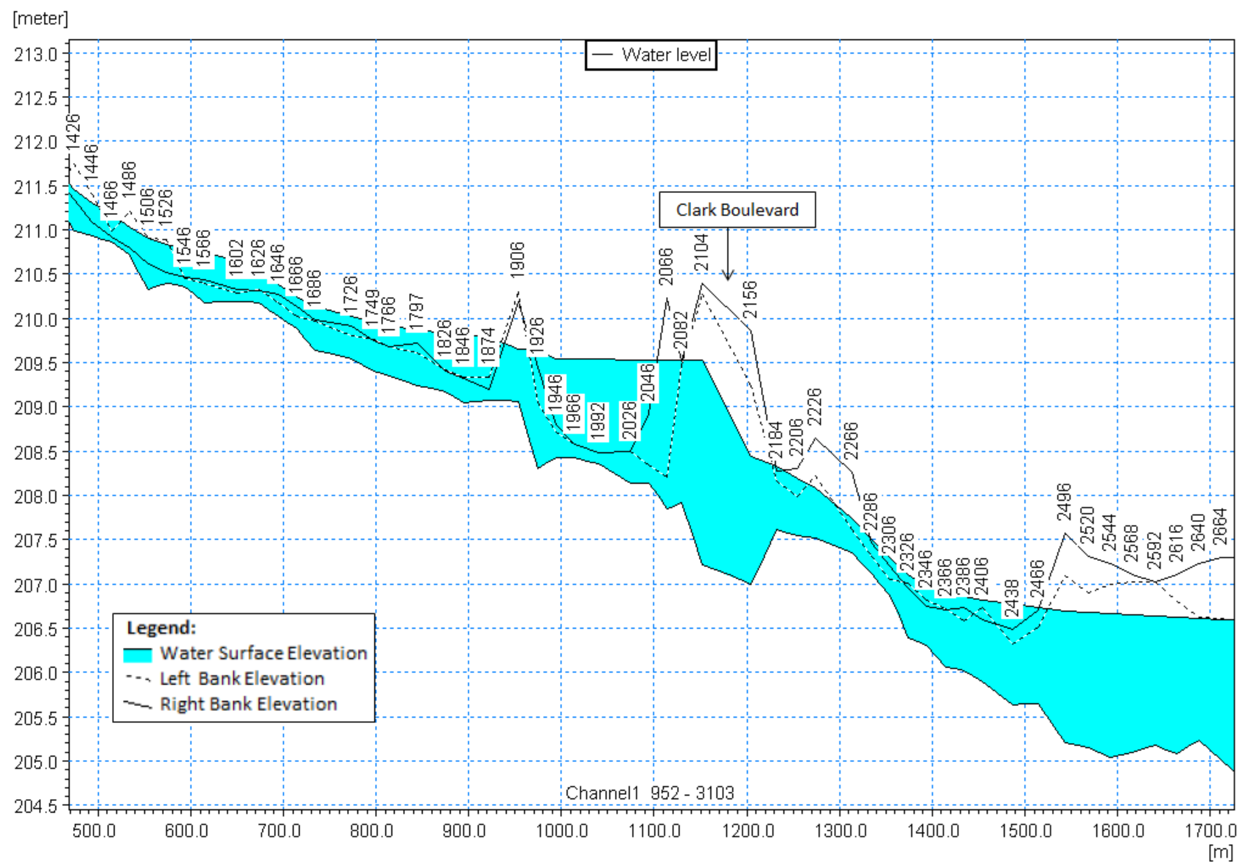

FIGURE 27 Channel 1 Profile near Clark Boulevard – 50-year Storm

6.3.4 Zone 4 – Downstream of Carleton Park (Channel 1)

The extensive overland flooding shown in Figure 28 for the Regional storm event results from a combination of spill locations and issues but is interconnected. Capacity issues with the buried section of Channel 1 beneath Orenda Road result in spill along Orenda Road and Dixie Road at the 10-year storm. The channel banks just downstream of Dixie Road are also overtopped during the 10-year storm which further contributes to spilling on properties in this area. Spill from Channel 1 at the bend downstream of Carleton Park occurs at the 25-year storm and connects with the spill on Orenda Road and Birchbank Road. Spill across the West Drive and Orenda Road intersection occurs at the 350-year storm. During large events the spill from Channel 1 connects with spill from Dixie Tributary.

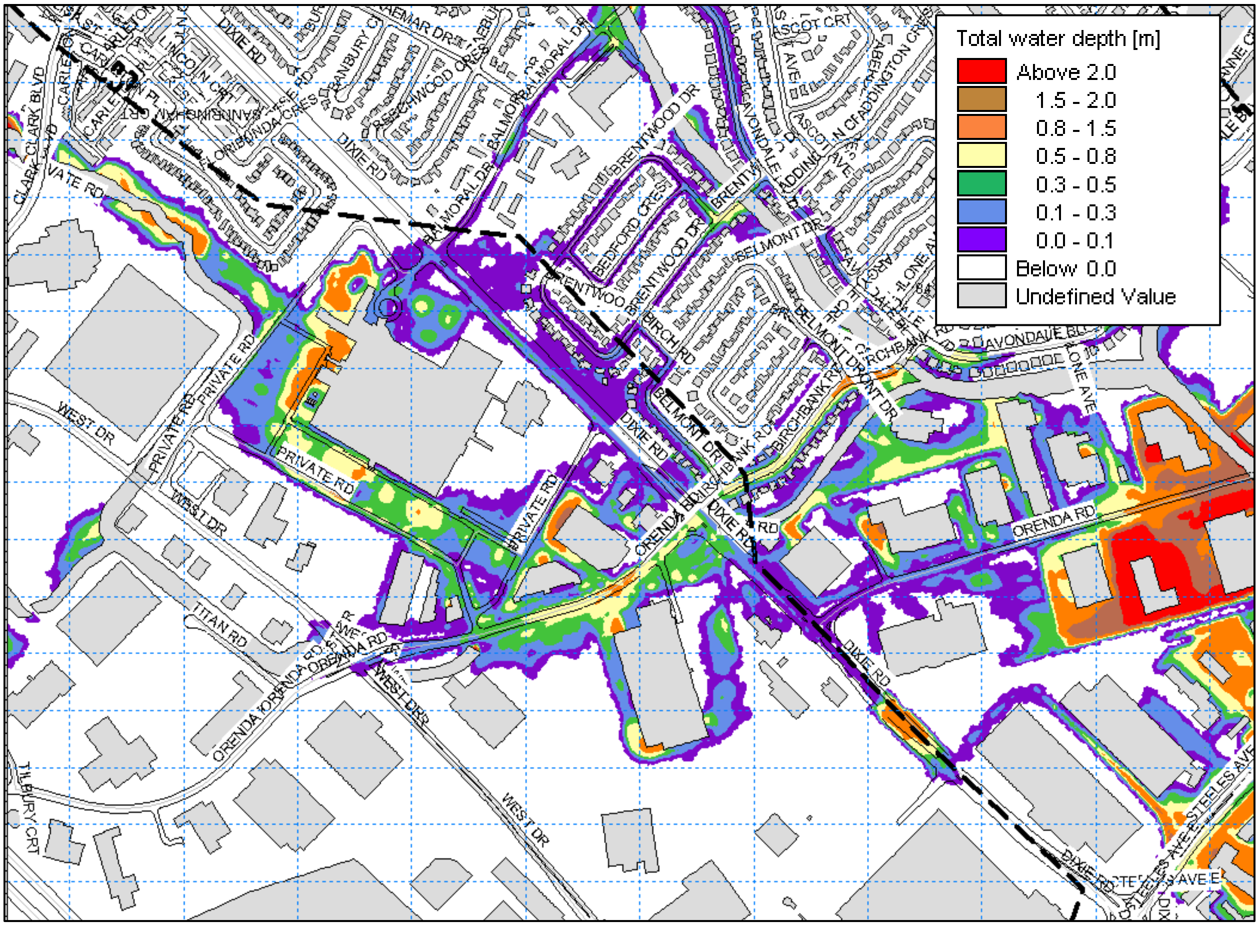

FIGURE 28 Channel 1 Spill Area – Regional Storm (Steady)

During the Regional event several properties are shown to be impacted by flooding, and much of which is shown is characterized as high risk. The spill south of Carleton Park originating at the bend does not enter a major roadway or channel until Orenda Road or Dixie Road. It follows a flow path along private roads and around private properties within the industrial area. Additional properties south of Orenda Road and east of Dixie Road are impacted as spill exceeds the roadway capacity of Orenda Road. Residential neighbourhoods and Birchbank Public School are also impacted within this spill area. The spill from Channel 1 therefore impacts areas downstream and as such has been presented as Zones 4a and 4b to discuss these two areas separately.

6.3.4.1 Zone 4a: Private Road

At the 25-year storm, the left bank of Channel 1 is overtopped downstream of Carleton Park/upstream of West Drive. This is also where the channel bends sharply to the west and the spill flow takes a more direct flow path to the south. The limited channel capacity and the more direct overland flow path result in spill along the private road and parking lot flowing toward Channel 1 at Orenda Road (Figure 29.) The spill occurring from the 25-year – 100-year is generally low risk with some medium risk areas. The 350-year and Regional storm events result in a high risk classification, primarily driven by the high depth × velocity.

During the 50-year storm, an additional spill occurs at the Channel 1 bend with some spill heading to Dixie Road. The spill paths and depths for the Regional storm for this flood zone are illustrated in Figure 29.

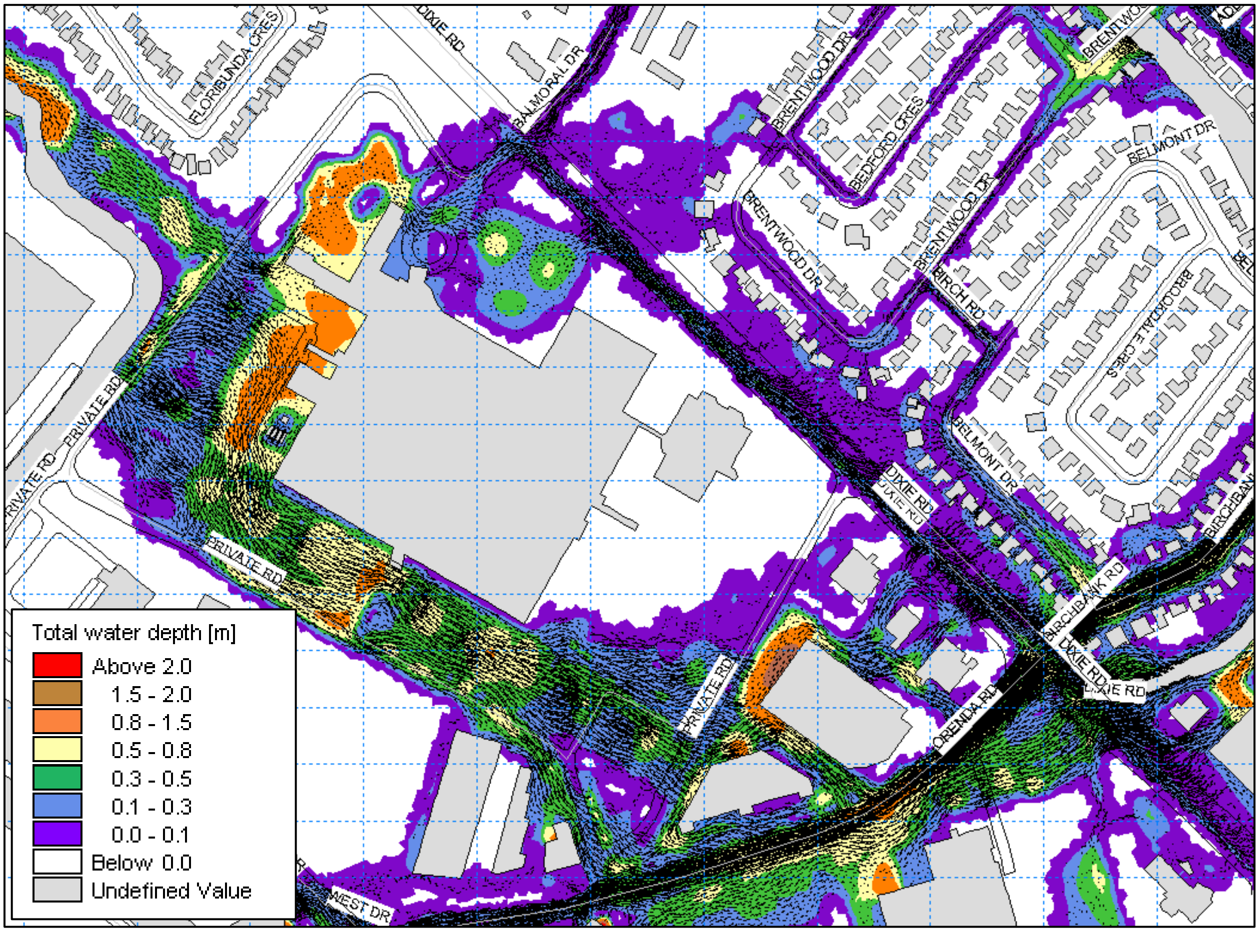

FIGURE 29 Channel 1 Spill along Private Road – Regional Storm

The channel capacity issue at the bend is also connected to structure capacity issues further downstream on Channel 1 at West Drive, Orenda Road and West Drive intersection, and the buried section under Orenda Road between West Drive and Dixie Road, all of which are surcharged during the 2-year event, resulting in some backwater. The West Drive deck elevation is much higher than the soffit, resulting in no overtopping of the structure.

6.3.4.2 Zone 4b: Orenda Road at West Drive

Zone 4b includes Orenda Road at West Drive down to Dixie Road where Channel 1 is buried under Orenda Road. High risk along Orenda Road is a result of high depth x velocity product, and high risk areas first start to appear at the 50-year event. High risk flooding in this area is generally contained to Orenda Road, but all risk levels extend to adjacent private properties along Orenda Road for the Regional event (Figure 30).

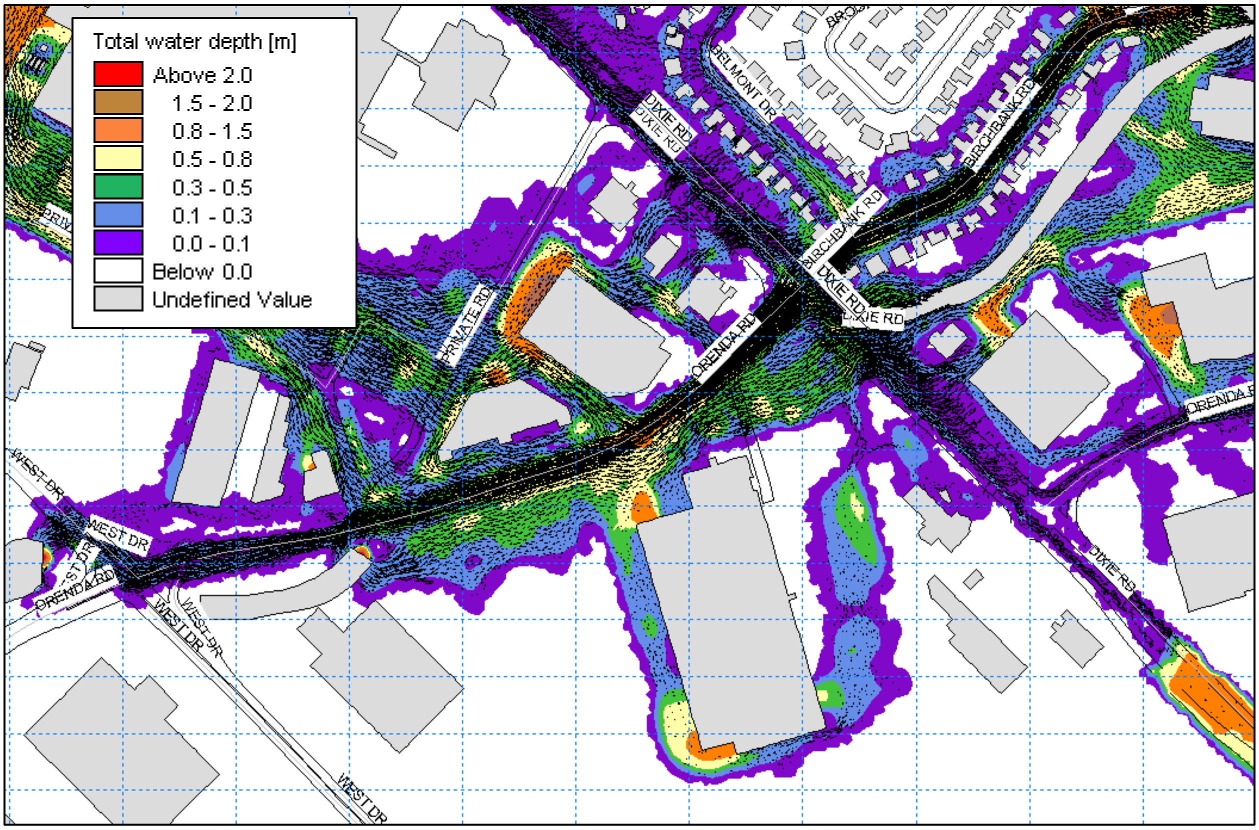

FIGURE 30 Channel 1 West Drive to Dixie Tributary – Regional Storm

Model results indicate that the downstream portion of Channel 1 has capacity issues at several structures. In particular, the Orenda Road / West Drive and Orenda Road / Dixie Road culverts are both surcharged during the 2-year storm. Flooding along Orenda Road occurs at the 10-year storm, while flooding across the Orenda Road and West Drive intersection occurs at the 350-year storm. Figure 31 shows a profile of this area for the 10-year storm. The profile also highlights backwater caused by the Birchbank Public School driveway (chainage 4,741), which is within the original Spring Creek study area.

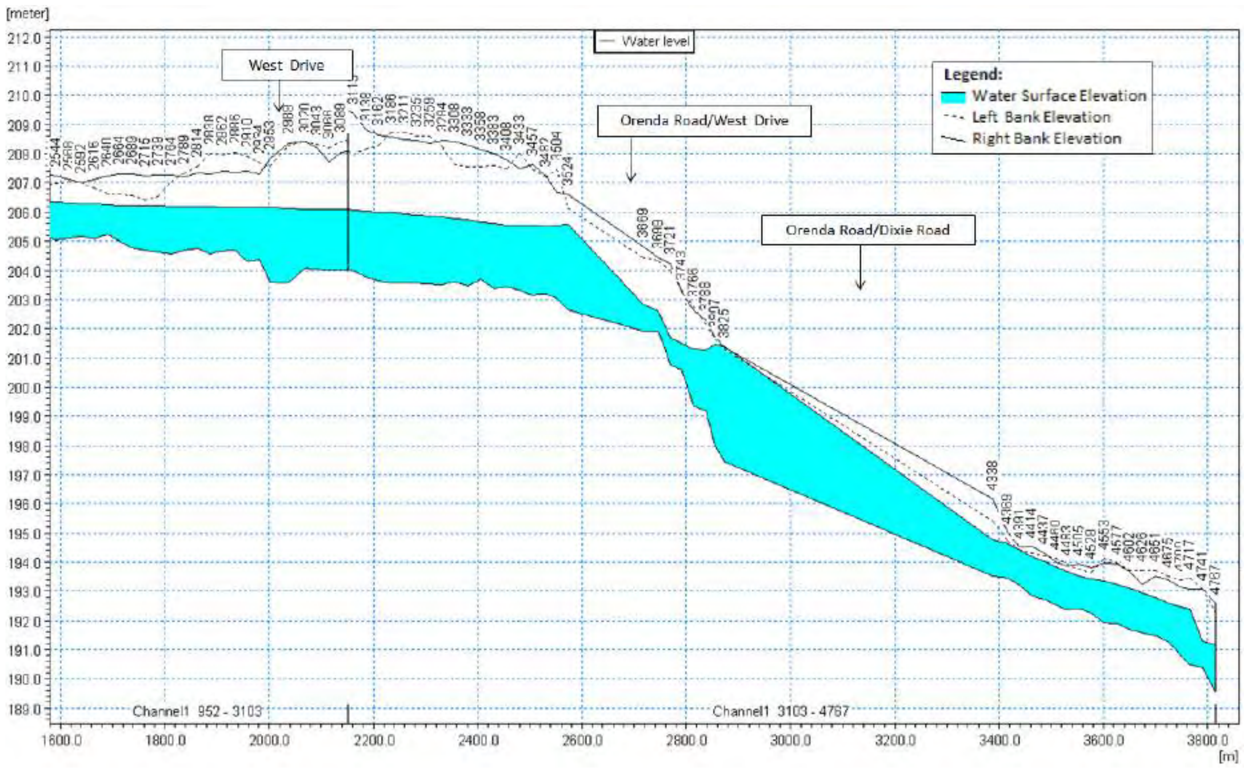

FIGURE 31 Channel 1 Profile near Orenda Road – 10-year Storm

The buried section under Orenda Road results in spill at the 10-year storm. This results in flooding along Orenda Road, Birchbank Road, and Dixie Road and leads to spilling onto properties south of Channel 1 and east of Dixie Road. The channel banks just downstream of Dixie Road are overtopped during the 10-year storm which further contributes to spilling on properties in this area.

6.3.5 Zone 5 – Tilbury Court (Channel 3)

Zone 5 is located on Channel 3 near Tilbury Court (Figure 32). Flooding along Channel 3 downstream of Tilbury Court and upstream of Channel 4 is due to channel capacity issues and results in spill onto adjacent properties for the 350-year and Regional storm events. The Tilbury Court crossing is surcharged at the 350-year storm. Spill areas in this zone are a mix of high, medium, and low risk, with the medium and high risk classified due to depths.

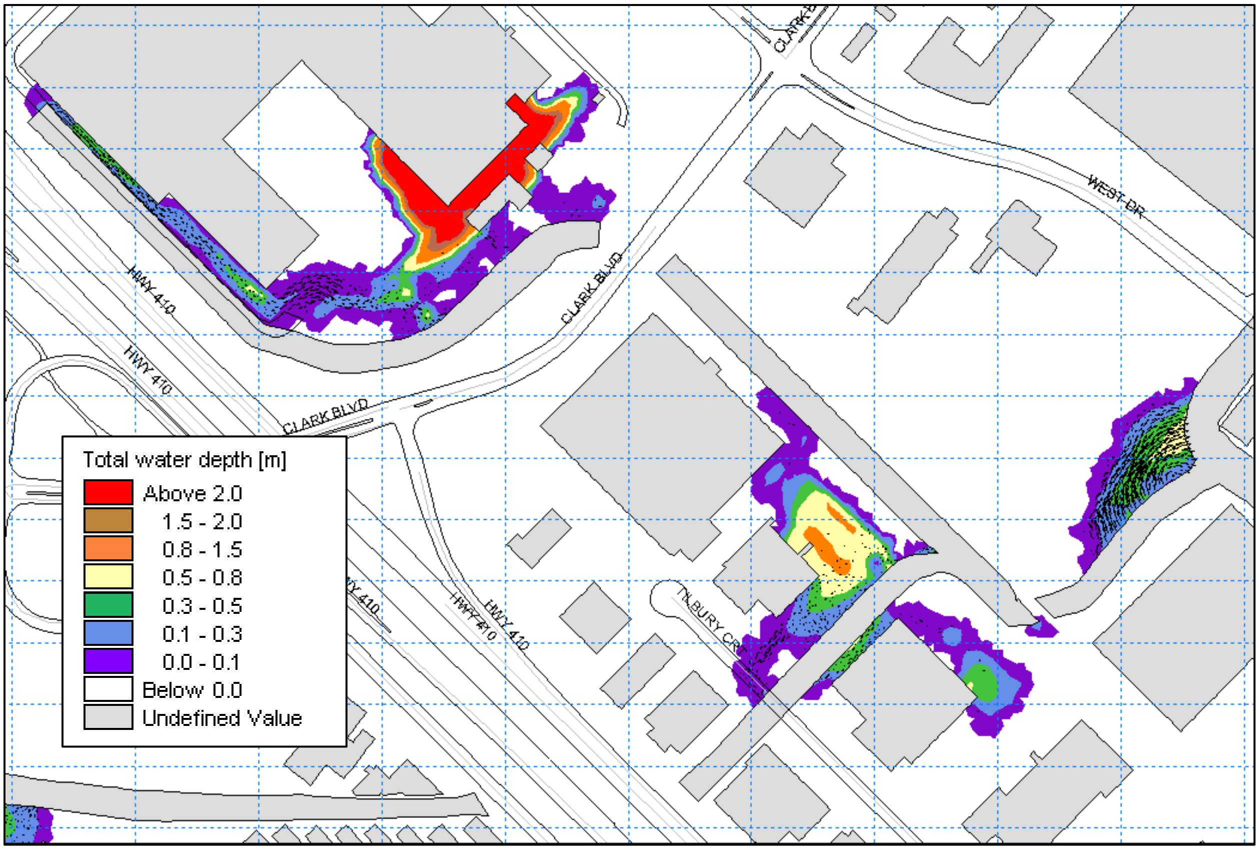

FIGURE 32 Channel 3 at Tilbury and Channel 4 – Regional Storm

Also shown in Figure 33, the left bank is overtopped at the most upstream extent of Channel 4 at the 2-year storm. This results in high risk flooding along an adjacent property due to high depths for all storms.

6.3.6 Zone 6 – Rutherford Road (Channel 3)

Flood Zone 6 is located along Channel 3 near Rutherford Road. This area floods at the 2-year event but is not classified as high risk for any of the storms. Medium risk areas are located upstream and downstream of Rutherford Road where depths exceed 0.3 m. The flooding is generally related to structure capacity constraints.

Rutherford Road South is surcharged at the 2-year storm. Figure 33 shows a profile of Channel 3 in this area and the backwater caused by the crossing starting at the 2-year storm. The remaining crossings downstream on Channel 3 have a much larger flow area than that on Rutherford Road and therefore do not have surcharging or overtopping issues (with the exception of Tilbury Court which is surcharged at the 350-year storm).

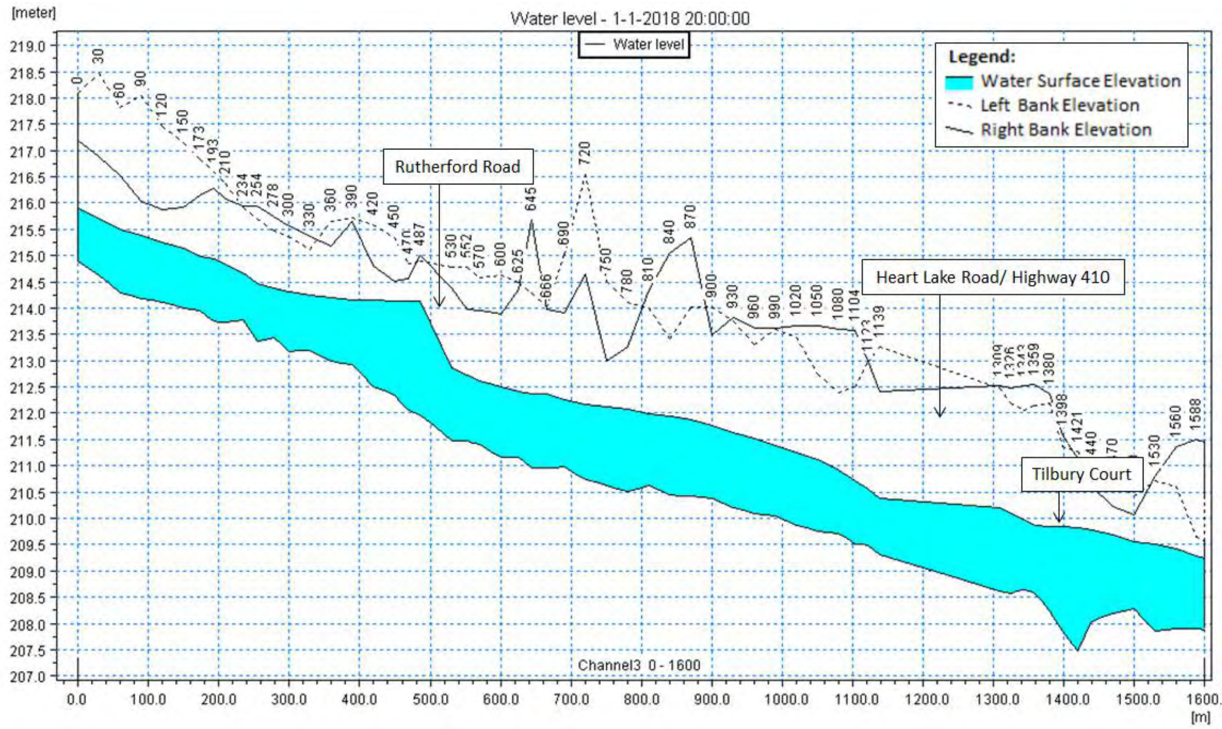

FIGURE 32 Channel 3 Profile near Rutherford Road – 2-year Storm

Channel 3 banks are overtopped at the 10-year storm due to backwater from an undersized crossing at Rutherford Road (Figure 33). Additional spill occurs at the upstream extent of Channel 3 at the 350-year and Regional storm event due to a low right bank which does not appear to be impacted by the backwater from Rutherford Road. The spill around and upstream of Rutherford Road enters properties which back onto the channel.

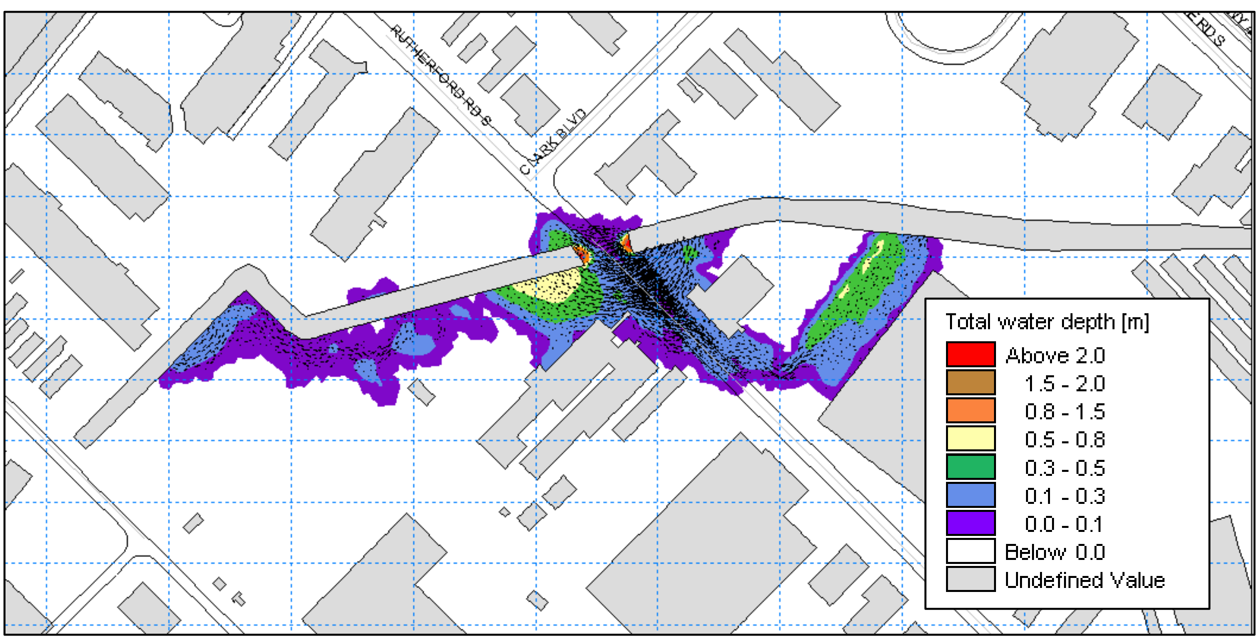

FIGURE 33 Channel 3 at Rutherford – Regional Storm

6.4 Spill Assessment

A spill assessment was completed to quantify spill from Channel 1 near Private Drive. To determine these peak flows, dynamic unsteady results for the Regional Storm were reviewed. The output file from the dynamic modelling includes a time series of flooding in the 2D domain as well as along the modelled cross-sections. Three spill cross-section lines were generated in GIS to define locations of interest; these are shown on Figure 34 along with the Regional unsteady state depth and velocity vector output.

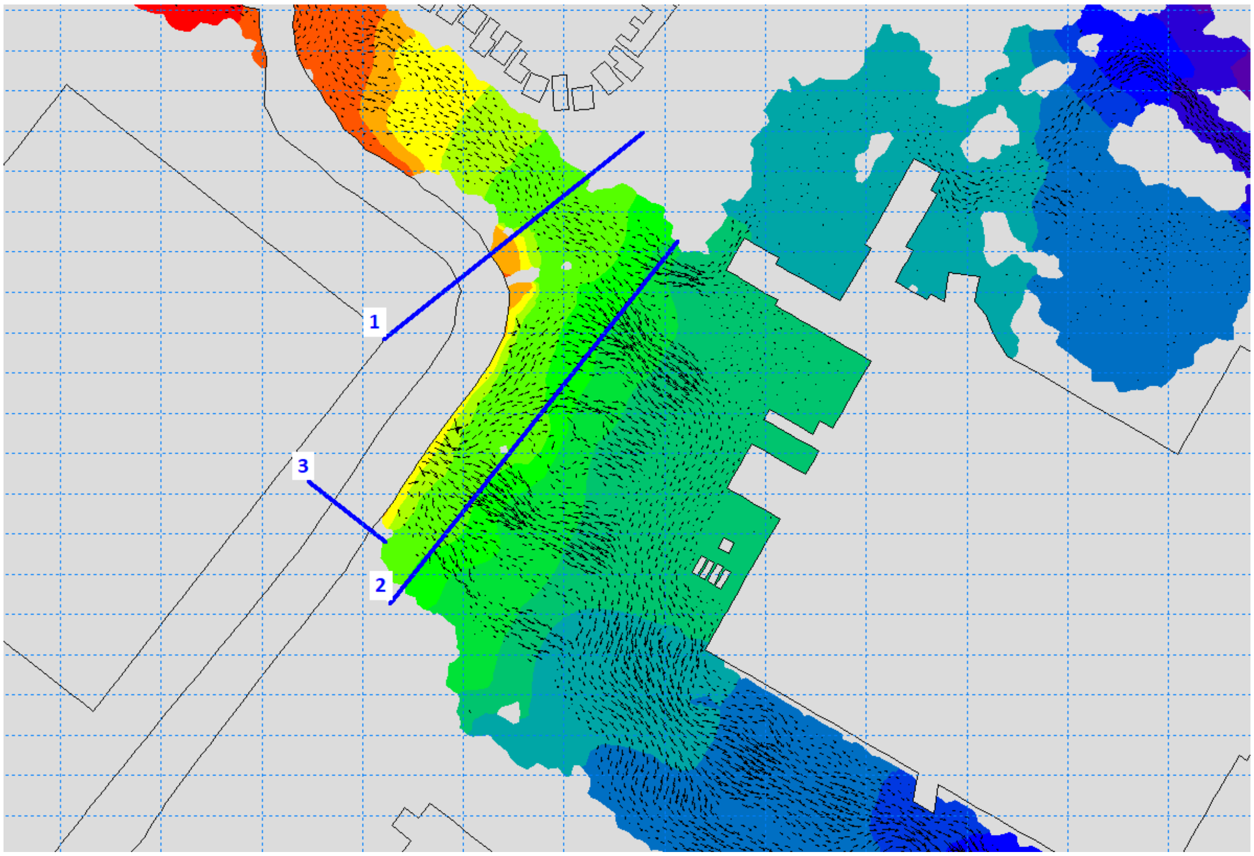

FIGURE 35 Channel 1 Spill Assessment Locations

Using a post-processing tool in MIKE Zero, a time series of discharge values was generated from the 1D and 2D result files along these cross-sections and the results are summarized in Table 12.

TABLE 12 Channel 1 Spill Assessment (Regional Unsteady State)

Spill Location	Flow (m^3/s)
1	27.3
2	32.0
3	16.4

Based on the locations of the cross-sections identified in Figure 35, it was anticipated that the spill assessment would indicate: $Q_1 = Q_2 + Q_3$

However, the reach of Channel 1 shown in Figure 35 has a distributed inflow applied along its length, meaning at each cross-section, the flow is incrementally increased. This means that the total inflow at spill location 1 is less than the total inflow where spill occurs along location 2. Furthermore, reverse flow conditions were observed at location 3 which contributes to additional spill in location 2. These conditions as described complicate the evaluation of spill from the channel and therefore a flow balance was not possible.

7 CONCLUSION AND RECOMMENDATIONS

This study was undertaken on behalf of TRCA to update and extend an existing MIKE FLOOD hydraulic model of the Spring Creek watershed with the ultimate goal of delineating Regulatory floodlines for the small tributaries to Spring Creek located west of the original study area. Floodlines were previously delineated in this area based on 1D HEC-RAS modelling (Aquafor 2016) and 1D-2D MIKE FLOOD (MMM 2015). Due to a number of significant spills identified within the study area and the complex flow paths through urban developments, a coupled 1D-2D approach was required to assess the extent of spill and delineate floodlines. To complete the project objective, updates to the original MIKE FLOOD hydraulic model (MMM 2015) were required to append the additional tributaries, generate water surface elevations, and subsequently produce Regulatory floodplain maps. The updated floodplain maps allow TRCA to identify areas of flood risk for the purpose of protecting people and property from riverine flood hazards.

The model domain for the current Spring Creek extension includes the entire extent of the original model in addition to the tributaries to the west. These tributaries, labelled as Channels 1 to 4 in the model, are small watercourses that primarily receive runoff from highly impervious commercial and industrial development lands. The channels appear to have been straightened and include multiple sharp bends which lead to spill from the channel during large storm events.

Matrix completed model simulations for nine storm events including the 2-year through 350-year storms and the Regional storm event (unsteady and steady state). Floodplain mapping was produced using the results of the Regional steady state event, consistent with MNRF standards. The remaining storms were used to characterize flood risk in the study area, identify flood mechanisms, and classify risk.

Review of results revealed a number of hydraulic constraints leading to riverine flooding including structure capacity issues, channel capacity issues, and overland flow constraints. Surcharge was noted at 15 of the 19 structures along the Spring Creek tributaries. Many of these do not spill until the 25-year storm event so it is likely that they meet the anticipated design capacity of the structures. However, 5 structures were shown to surcharge during the 2-year storm. Spill from the channel banks was observed at many locations throughout the model domain. Much of the spilled flow is contained within the floodplain. There are a few exceptions caused by severe bends in the channel where flow continues moving forward along the path of least resistance. Some areas of high risk flooding are noted around industrial buildings; however, the depths and velocities of flooding in these areas are low enough such that the properties have safe access during major storm events.

Recommendations stemming from this study generally include assessing and implementing mitigation measures to reduce high risk flooding. This could include:

1. Upgrade culverts that have been identified as undersized. Initial iterations can be completed using MIKE 11 or HEC-RAS to reduce required simulation time. High priority areas can be completed first such as Flood Zone 4 (around long culverts on West Drive and Orenda Road). Continue upgrading culvert sizes in an upstream direction from these high priority locations. Conduct final comprehensive modelling using 1D/2D integrated MIKE FLOOD model to assess overall impacts and benefits.

2. Investigate whether channel capacity works are still required after upgrading culvert sizes. Incorporate bank improvement works as required using the systematic approach outlined above.

8 REFERENCES

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APPENDIX A
Bend Loss Calculations

Orenda Road / West Drive Culvert Characteristics

Width	Height	Area	Wetted Perimeter	Hydr. Radius	Eq. Pipe Dia.	Slope
(m)	(m)	(m^2)	(m)	(m)	(m)	(%)
4.27	2.15	9.18	12.84	0.71	3.42	0.53

Bend Characteristics

Bend	Bend Radius (m)	Defl. Angle (deg)	Radius / dia.	k
Bend 1	25.0	25	1.00	0.26

h_b=k x (V^2/2g)
k=radius of bend/Eq. pipe dia.and deflection angle coefficient

d. Bends

(Values of K_L in $h_{L_m} = K_L \frac{V^2}{2g}$, the head loss in excess of that in a straight pipe of equal length)

Radius of bend / *Pipe diameter*	*Deflection angle of bend*		
	90°	45°	22.5°
1	0.50	0.37	0.25
2	0.30	0.22	0.15
4	0.25	0.19	0.12
6	0.15	0.11	0.08
8	0.15	0.11	0.08

Source: Table 11-2-Water Resources Engineering 2nd Edition (Linsley and Franzini)

k coefficients

Radius/Dia	Deflection Angle			
	90	45	22.5	25
1	0.50	0.37	0.25	0.26
2	0.30	0.22	0.15	0.16
4	0.25	0.19	0.12	0.13
6	0.15	0.11	0.08	0.08
8	0.15	0.11	0.08	0.08

Orenda Road / Dixie Road Culvert Characteristics

Width (m)	Height (m)	Area (m^2)	Wetted Perimeter (m)	Hydr. Radius (m)	Eq. Pipe Dia. (m)	Slope (%)
3.66	1.83	6.70	10.98	0.61	2.92	0.86

Bend Characteristics

Bend	Bend Radius (m)	Defl. Angle (deg)	Radius / dia.	k
Bend 1	17.2	39	0.44	0.41
Bend 2	87.0	12	7.25	0.07
Bend 3	63.3	11	5.76	0.07
				0.55

$h_b = k \times (V^2/2g)$

k=radius of bend/Eq. pipe dia.and deflection angle coefficient

d. Bends

(Values of K_L in $h_{L_m} = K_L \frac{V^2}{2g}$, the head loss in excess of that in a straight pipe of equal length)

Radius of bend / Pipe diameter	*Deflection angle of bend* 90°	45°	22.5°
1	0.50	0.37	0.25
2	0.30	0.22	0.15
4	0.25	0.19	0.12
6	0.15	0.11	0.08
8	0.15	0.11	0.08

Source: Table 11-2-Water Resources Engineering 2nd Edition (Linsley and Franzini)

k coefficients

Radius/Dia	Deflection Angle 90	45	22.5	39	12	11
1	0.50	0.37	0.25	0.34	0.19	0.19
2	0.30	0.22	0.15	0.20	0.12	0.11
4	0.25	0.19	0.12	0.17	0.09	0.08
6	0.15	0.11	0.08	0.10	0.07	0.06
8	0.15	0.11	0.08	0.10	0.07	0.06
0.44				0.41		
7.25					0.07	
5.76						0.07

APPENDIX B
Regional Storm Inflows Hydrographs

	Reach	Spring Creek	Spring Creek	Spring Creek	Spring Creek	Spring Creek	Spring Creek	Spring Creek	Dixie Tributary	Dixie Tributary	Dixie Tributary	Dixie Tributary	Unknown Trib.	Channel1	Channel 1	Channel1	Channel1	Channel2	Channel3	Channel3	Channel3	Channel4
	Chainage	1743.17	1743.17 - 3519	3519 - 4843	4843 - 6099	6099 - 6731	6731 - 7722	7722 - 8552	1234	1234 - 2283	2283 - 2737	2737 - 4178	0	-70.775	358-943	959.495- 3088	3112 - 4767	1.012	0	180 - 1588	1609 - 1870	0
Time	**Peak Flow**	158.17	9.52	4.87	7.34	7.72	25.12	4.51	32.16	5.65	14.68	8.27	15.20	21.56	6.98	13.18	10.10	1.83	25.23	23.65	1.57	4.15
01/01/2018 10:00		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
01/01/2018 10:15		0.17	0.16	0.07	0.19	0.18	0.42	0.05	0.19	0.09	0.28	0.15	0.32	0.27	0.10	0.00	0.26	0.03	0.41	0.00	0.05	0.09
01/01/2018 10:30		0.62	0.51	0.23	0.60	0.58	1.39	0.17	0.85	0.30	0.91	0.48	1.03	0.85	0.32	0.00	0.83	0.08	1.37	0.00	0.14	0.29
01/01/2018 10:45		0.96	0.60	0.26	0.69	0.66	1.71	0.18	1.55	0.34	1.11	0.57	1.20	0.93	0.37	0.00	0.97	0.10	1.69	0.00	0.15	0.32
01/01/2018 11:00		1.43	0.63	0.28	0.71	0.68	1.85	0.19	1.92	0.36	1.18	0.60	1.25	0.99	0.39	0.02	1.01	0.10	1.82	0.71	0.16	0.32
01/01/2018 11:15		2.01	0.50	0.22	0.53	0.51	1.52	0.15	1.83	0.30	0.94	0.48	0.97	0.80	0.31	0.35	0.77	0.08	1.48	1.60	0.11	0.24
01/01/2018 11:30		2.98	0.49	0.23	0.50	0.49	1.46	0.15	1.63	0.31	0.89	0.46	0.92	0.84	0.32	0.39	0.72	0.08	1.41	1.77	0.11	0.24
01/01/2018 11:45		4.15	0.52	0.25	0.51	0.49	1.48	0.17	1.62	0.34	0.90	0.48	0.93	0.91	0.34	0.40	0.72	0.09	1.45	1.67	0.11	0.25
01/01/2018 12:00		5.32	0.56	0.27	0.52	0.51	1.54	0.18	1.71	0.36	0.94	0.51	0.96	0.98	0.37	0.43	0.73	0.10	1.53	1.58	0.11	0.26
01/01/2018 12:15		6.59	0.76	0.37	0.72	0.70	2.06	0.25	2.06	0.48	1.27	0.70	1.33	1.36	0.51	0.27	1.00	0.13	2.04	1.42	0.16	0.37
01/01/2018 12:30		7.75	0.85	0.42	0.78	0.76	2.31	0.29	2.54	0.53	1.41	0.78	1.46	1.54	0.57	0.35	1.08	0.15	2.29	1.68	0.17	0.39
01/01/2018 12:45		9.07	0.91	0.46	0.80	0.80	2.48	0.32	2.86	0.58	1.49	0.83	1.54	1.69	0.62	0.46	1.11	0.16	2.47	2.04	0.17	0.42
01/01/2018 13:00		10.55	0.98	0.50	0.83	0.82	2.62	0.35	3.09	0.62	1.57	0.88	1.60	1.82	0.68	0.59	1.14	0.18	2.63	2.26	0.18	0.43
01/01/2018 13:15		13.13	1.62	0.81	1.51	1.49	4.29	0.59	4.24	1.00	2.64	1.47	2.82	3.10	1.10	0.09	2.06	0.29	4.29	1.86	0.35	0.79
01/01/2018 13:30		16.18	1.88	0.93	1.68	1.67	5.07	0.70	5.88	1.15	3.06	1.70	3.23	3.69	1.28	0.54	2.32	0.34	5.02	2.73	0.37	0.87
01/01/2018 13:45		19.20	2.05	1.04	1.75	1.76	5.53	0.81	6.68	1.28	3.30	1.84	3.44	4.16	1.43	1.07	2.42	0.37	5.49	3.91	0.38	0.94
01/01/2018 14:00		22.16	2.24	1.15	1.80	1.85	5.88	0.90	7.12	1.38	3.50	1.98	3.61	4.54	1.59	1.47	2.48	0.42	5.90	4.73	0.38	0.99
01/01/2018 14:15		26.08	2.72	1.40	2.22	2.28	7.09	1.10	8.32	1.65	4.28	2.43	4.43	5.55	1.94	1.44	3.04	0.51	7.20	4.97	0.48	1.22
01/01/2018 14:30		30.49	2.97	1.53	2.35	2.43	7.78	1.23	9.63	1.78	4.65	2.65	4.77	6.12	2.13	2.00	3.22	0.56	7.91	5.83	0.50	1.29
01/01/2018 14:45		34.97	3.15	1.64	2.41	2.51	8.25	1.34	10.43	1.89	4.91	2.81	4.98	6.57	2.28	2.58	3.29	0.60	8.43	6.74	0.51	1.34
01/01/2018 15:00		39.43	3.33	1.74	2.46	2.59	8.62	1.44	11.05	1.97	5.12	2.96	5.14	6.93	2.44	3.07	3.35	0.64	8.88	7.39	0.51	1.38
01/01/2018 15:15		43.39	3.13	1.66	2.11	2.27	8.05	1.39	11.00	1.82	4.75	2.79	4.61	6.50	2.34	3.82	2.87	0.61	8.45	8.02	0.42	1.21
01/01/2018 15:30		46.83	3.12	1.67	2.05	2.23	7.96	1.39	10.71	1.79	4.71	2.80	4.52	6.40	2.36	3.91	2.76	0.62	8.47	7.82	0.40	1.19
01/01/2018 15:45		49.43	3.14	1.67	2.04	2.22	8.00	1.38	10.79	1.76	4.74	2.83	4.51	6.33	2.37	3.90	2.74	0.62	8.57	7.49	0.40	1.17
01/01/2018 16:00		51.13	3.12	1.65	2.02	2.21	8.06	1.37	10.86	1.74	4.76	2.84	4.52	6.29	2.36	3.88	2.72	0.62	8.65	7.39	0.40	1.16
01/01/2018 16:15		53.77	3.96	2.04	2.97	3.12	10.34	1.68	12.43	2.24	6.19	3.61	6.19	8.05	2.89	2.96	4.01	0.76	10.83	6.89	0.64	1.64
01/01/2018 16:30		56.93	4.26	2.17	3.19	3.35	11.34	1.83	14.41	2.42	6.71	3.87	6.71	8.87	3.10	3.42	4.35	0.81	11.72	8.34	0.67	1.75
01/01/2018 16:45		60.92	4.46	2.28	3.27	3.46	11.89	2.00	15.19	2.58	6.98	4.02	6.96	9.50	3.26	3.98	4.48	0.86	12.25	9.98	0.68	1.84
01/01/2018 17:00		65.70	4.68	2.42	3.34	3.56	12.29	2.13	15.87	2.69	7.20	4.17	7.15	9.97	3.46	4.48	4.55	0.91	12.73	10.87	0.69	1.89
01/01/2018 17:15		69.10	4.01	2.13	2.44	2.71	10.40	1.90	14.97	2.25	6.02	3.57	5.65	8.54	3.07	5.80	3.31	0.80	11.10	11.64	0.45	1.43
01/01/2018 17:30		71.29	3.85	2.07	2.25	2.53	9.76	1.82	13.61	2.13	5.70	3.44	5.26	7.96	2.98	5.65	3.00	0.78	10.65	10.42	0.42	1.35
01/01/2018 17:45		71.93	3.75	2.01	2.19	2.46	9.52	1.71	13.33	2.01	5.60	3.40	5.12	7.53	2.90	5.37	2.91	0.76	10.49	9.22	0.41	1.28
01/01/2018 18:00		71.31	3.61	1.91	2.14	2.39	9.38	1.63	13.00	1.93	5.50	3.34	5.02	7.21	2.77	5.14	2.85	0.73	10.32	8.74	0.40	1.24
01/01/2018 18:15		69.94	3.51	1.83	2.11	2.35	9.26	1.57	12.60	1.87	5.37	3.24	4.91	6.98	2.68	4.89	2.82	0.70	10.06	8.60	0.40	1.21
01/01/2018 18:30		68.23	3.43	1.78	2.08	2.31	9.09	1.53	12.28	1.82	5.26	3.16	4.83	6.81	2.60	4.64	2.80	0.68	9.85	8.44	0.40	1.19
01/01/2018 18:45		66.56	3.37	1.74	2.06	2.28	8.97	1.50	12.02	1.79	5.18	3.10	4.77	6.69	2.55	4.44	2.78	0.67	9.69	8.27	0.40	1.17
01/01/2018 19:00		65.03	3.32	1.71	2.05	2.26	8.87	1.48	11.83	1.77	5.11	3.05	4.72	6.61	2.50	4.28	2.76	0.66	9.55	8.13	0.40	1.16
01/01/2018 19:15		70.12	6.64	3.28	5.83	5.94	17.74	2.72	18.13	3.81	10.77	6.08	11.39	13.74	4.65	0.57	7.91	1.22	18.07	6.16	1.36	3.14
01/01/2018 19:30		79.09	7.82	3.82	6.72	6.87	21.62	3.33	26.26	4.54	12.78	7.11	13.49	17.12	5.47	2.89	9.30	1.43	21.47	13.04	1.50	3.58
01/01/2018 19:45		92.66	8.63	4.29	7.06	7.31	23.68	4.02	28.82	5.20	13.81	7.70	14.47	19.66	6.14	5.87	9.79	1.61	23.45	20.01	1.54	3.93
01/01/2018 20:00		110.40	9.52	4.87	7.34	7.72	25.12	4.51	31.63	5.65	14.68	8.27	15.20	21.56	6.94	8.18	10.10	1.82	25.23	22.23	1.57	4.15
01/01/2018 20:15		127.18	8.93	4.70	6.11	6.63	23.02	4.40	31.83	5.21	13.49	7.79	13.41	20.24	6.72	11.19	8.37	1.76	23.98	23.65	1.22	3.57
01/01/2018 20:30		141.43	9.01	4.81	5.92	6.50	22.82	4.43	31.10	5.17	13.47	7.93	13.15	19.97	6.87	11.52	8.00	1.80	24.27	22.43	1.18	3.51
01/01/2018 20:45		151.57	9.11	4.87	5.90	6.50	23.07	4.36	31.90	5.10	13.68	8.12	13.20	19.74	6.98	11.49	7.94	1.83	24.80	21.33	1.17	3.45
01/01/2018 21:00		158.17	9.11	4.84	5.88	6.47	23.36	4.32	32.16	5.07	13.84	8.24	13.26	19.55	6.96	11.47	7.91	1.82	25.19	21.31	1.16	3.42
01/01/2018 21:15		157.76	7.01	3.81	3.50	4.15	17.99	3.50	27.81	3.76	10.30	6.34	9.05	14.90	5.58	13.18	4.68	1.46	19.92	22.32	0.56	2.16
01/01/2018 21:30		152.46	6.26	3.44	2.93	3.55	15.62	3.09	23.11	3.27	9.06	5.69	7.71	12.64	5.04	11.30	3.81	1.32	17.87	18.07	0.47	1.87
01/01/2018 21:45		143.39	5.75	3.13	2.71	3.26	14.39	2.64	21.45	2.84	8.43	5.32	7.09	10.94	4.60	9.72	3.50	1.21	16.69	14.26	0.44	1.63
01/01/2018 22:00		132.30	5.19	2.75	2.53	3.00	13.56	2.31	19.63	2.55	7.90	4.96	6.62	9.68	4.09	8.64	3.30	1.07	15.63	12.74	0.43	1.48
01/01/2018 22:15		118.63	3.67	1.95	1.18	1.61	9.92	1.67	15.61	1.66	5.45	3.54	3.99	6.42	3.00	8.66	1.49	0.79	11.63	12.38	0.10	0.74
01/01/2018 22:30		104.52	2.94	1.56	0.79	1.15	7.89	1.30	11.91	1.26	4.32	2.86	2.95	4.64	2.42	7.14	0.94	0.64	9.53	9.67	0.05	0.52
01/01/2018 22:45		90.67	2.40	1.24	0.60	0.90	6.60	0.94	9.87	0.92	3.60	2.40	2.36	3.32	1.96	5.78	0.70	0.52	8.08	7.35	0.03	0.36
01/01/2018 23:00		77.64	1.90	0.93	0.46	0.68	5.63	0.69	8.10	0.68	3.01	1.99	1.90	2.36	1.52	4.74	0.54	0.40	6.83	6.06	0.02	0.25
01/01/2018 23:15		66.06	1.51	0.70	0.35	0.52	4.80	0.50	6.52	0.51	2.44	1.60	1.50	1.67	1.18	3.90	0.42	0.31	5.64	5.26	0.01	0.17
01/01/2018 23:30		55.95	1.20	0.53	0.27	0.40	4.03	0.37	5.20	0.38	1.99	1.28	1.19	1.18	0.92	3.13	0.33	0.24	4.66	4.49	0.01	0.12
01/01/2018 23:45		47.38	0.95	0.40	0.21	0.30	3.40	0.27	4.17	0.28	1.62	1.03	0.94	0.82	0.71	2.49	0.26	0.19	3.86	3.83	0.01	0.08
01/02/2018 0:00		40.11	0.76	0.30	0.16	0.23	2.88	0.20	3.42	0.21	1.32	0.83	0.75	0.58	0.55	1.98	0.21	0.15	3.20	3.24	0.00	0.06
01/02/2018 0:15		33.80	0.60	0.23	0.12	0.18	2.44	0.14	2.76	0.16	1.08	0.66	0.60	0.40	0.43	1.61	0.17	0.11	2.65	2.72	0.00	0.04
01/02/2018 0:30		27.85	0.48	0.17	0.10	0.14	2.07	0.11	2.22	0.12	0.88	0.53	0.48	0.28	0.33	1.36	0.13	0.09	2.19	2.29	0.00	0.03
01/02/2018 0:45		22.49	0.38	0.13	0.07	0.10	1.76	0.08	1.82	0.09	0.72	0.43	0.38	0.20	0.26	1.16	0.11	0.07	1.82	1.90	0.00	0.02
01/02/2018 1:00		18.24	0.30	0.10	0.06	0.08	1.49	0.06	1.50	0.07	0.59	0.34	0.31	0.14	0.20	0.99	0.08	0.05	1.51	1.53	0.00	0.01
01/02/2018 1:15		14.50	0.24	0.07	0.04	0.06	1.27	0.04	1.23	0.05	0.48	0.28	0.25	0.10	0.16	0.85	0.07	0.04	1.25	1.26	0.00	0.01
01/02/2018 1:30		11.28	0.19	0.05	0.03	0.05	1.08	0.03	1.01	0.04	0.39	0.22	0.20	0.07	0.12	0.73	0.05	0.03	1.03	1.08	0.00	0.01
01/02/2018 1:45		9.07	0.15	0.04	0.03	0.04	0.92	0.02	0.83	0.03	0.32	0.18	0.16	0.05	0.10	0.61	0.04	0.03	0.86	0.95	0.00	0.01
01/02/2018 2:00		7.59	0.12	0.03	0.02	0.03	0.78	0.02	0.69	0.02	0.26	0.14	0.13	0.04	0.07	0.51	0.03	0.02	0.71	0.81	0.00	0.00

APPENDIX C
Regulatory Floodplain Mapping

Spring Creek 2D Modelling Extension and Flood Plain Map Update

Regional Storm Flood Event

Hydraulic Engineering Consultant:

Matrix Solutions Inc.
ENVIRONMENT & ENGINEERING

LICENSED PROFESSIONAL ENGINEER
2019-05-08
K. L. MOLNAR
100162568
PROVINCE OF ONTARIO

The Professional Engineer's Seal verifies the location of the floodline and associated water surface elevations. For additional information Please see CFN 57480 for the final report : Spring Creek 2D Modelling Extension and Flood Plain Mapping Update.

AIRBORNE IMAGING
A Clean Harbors Company

Mapping Note:

The elevation data on this map was produced by TRCA from a DEM with 0.5 m grid resolution. The DEM was created using bare earth mass points with a vertical accuracy tolerance of +/- 0.10m RMSE on hard flat surfaces. The mass points were collected using LiDAR flown in 2015 by Airborne Imaging.

The spot elevations shown on this map were produced by TRCA using the DEM mentioned above. The contour lines were produced by TRCA from a smoothed surface grid. This data set is provided as reference only.

The planimetric data on this map was acquired from a number of sources with different collection dates and may not match with the elevation data set and is for reference only. The building footprints were acquired from the City of Brampton in 2018.

The vertical datum is mean sea level as established by the Geodetic Survey of Canada CGVD 1928:1978 Ontario Adjusted Version.
The horizontal datum is North American Datum of 1983, UTM 6° projection Zone 17, Central Meridian 81° W.

Grid interval 100 m.

LEGEND

Contour - 5m		Bridge/Culvert	
Contour - 1m		Railway	
Contour - 0.5m		Water feature and Drainage	
Spot Elevation	170.79	Regulatory Flood Line	
Building		Regulatory Flood Water Surface Elevation	158.43
Road			

N

SCALE

0 100 200 300 400 m

1:4000

Toronto and Region Conservation Authority

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(416)-661-6600, info@trca.on.ca

Drawn by : MDT	Checked by : QIY

SHEET :

01 of 01