Matrix Solutions Inc.
ENVIRONMENT & ENGINEERING

LITTLE ETOBICOKE CREEK FLOOD EVALUATION STUDY
MODELLING FOR FLOOD CHARACTERIZATION AND ANALYSIS
PROGRESS REPORT NO. 2

Prepared for:
CITY OF MISSISSAUGA

Prepared by:
MATRIX SOLUTIONS INC.

Version 2.0
November 2020
Guelph, Ontario

Unit 7B, 650 Woodlawn Rd. W
Guelph, ON, Canada N1K 1B8
T 519.772.3777 F 226.314.1908
www.matrix-solutions.com

LITTLE ETOBICOKE CREEK FLOOD EVALUATION STUDY

MODELLING FOR FLOOD CHARACTERIZATION AND ANALYSIS

PROGRESS REPORT NO. 2

Prepared for City of Mississauga, November 2020

Amanda McKay, P.Eng.
Water Resources Engineer

reviewed by
Kelly Molnar, P.Eng.
Water Resources Engineer

CONTRIBUTORS

Name	Job Title	Role
Amanda McKay, P.Eng.	Water Resources Engineer	Primary Author
Kelly Molnar, P.Eng.	Water Resources Engineer	Reviewer
Karen Hofbauer, M.A.Sc., P.Eng.	Senior Water Resources Engineer	Reviewer

VERSION CONTROL

Version	Date	Issue Type	Filename	Description
V0.1	09-Jul-2018	Draft	24603-531 LittleEtobicokeCr PR#2 2018-07-09 draft.docx	Issued to client for review
V1.0	28-Sep-2018	Final	24603-531 LEC Progress Report 2 2018-09-28 final V1.0.docx	Issued to client
V2.0	27-Nov-2020	Revised Final	24603-531 LEC Progress Report 2 R 2020-11-27 final V2.0.docx	Issued to client

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

APPENDICES

1 INTRODUCTION

The Little Etobicoke Creek watershed in the City of Mississauga (the City) has experienced flooding and erosion concerns recorded back to at least the 1970s. The recent large flood event on July 8, 2013, which corresponded approximately to a 350-year storm (MMM 2015), resulted in many reports of flooding-related incidents and damage, particularly in the Dixie Road and Dundas Street area. The focus of this flood evaluation study is to characterize flooding within the Little Etobicoke Creek watershed, identify preliminary flood cluster areas, and to develop flood remediation alternatives.

The Little Etobicoke Creek Flood Evaluation Study is being conducted in two phases as part of a final Master Plan for the City. Phase 1 was completed in January 2018 and expanded on previous studies of the overland spill from Little Etobicoke Creek, particularly focused on the Dixie-Dundas Special Policy Area, where flood flows spill from Toronto and Region Conservation Authority (TRCA) jurisdiction lands into Credit Valley Conservation jurisdiction lands. Phase 2 of the study is currently ongoing and is the subject of this report. Phase 2 of the study is focused on the Little Etobicoke Creek watershed as a whole and includes characterization of overland urban flood risk as well as development, assessment, and recommendations for flood remediation measures. Figure 1 shows the study area, including the 2,260 ha Little Etobicoke Creek watershed.

1.1 Progress Report Purpose

This progress report summarizes the Phase 2 PCSWMM hydraulic model development methodology for the Little Etobicoke Creek watershed area and presents preliminary results. To accurately assess flooding in the Little Etobicoke Creek watershed, a detailed urban drainage model is required. The PCSWMM model developed for this purpose includes both the creek and the major overland drainage system modelled in two dimensions (2D). Ideally, this model would include the creek geometry in one dimension; however, due to program instabilities, a full two-dimensional (2D) approach was adopted. The model would also ideally include the minor drainage system; however, a full dual drainage model is not within the scope of this study. The minor drainage system will be added to sections of the model where flood clusters are identified during the full 2D assessment.

The PCSWMM 2D model is used as a screening tool to identify areas of concern related to flooding. Once the flood cluster areas have been identified, Matrix will then split the model into appropriately sized segments and incorporate the minor system component to allow for a more detailed analysis of the flood mechanisms and potential remediation measures. This will be done in a subsequent stage of the project.

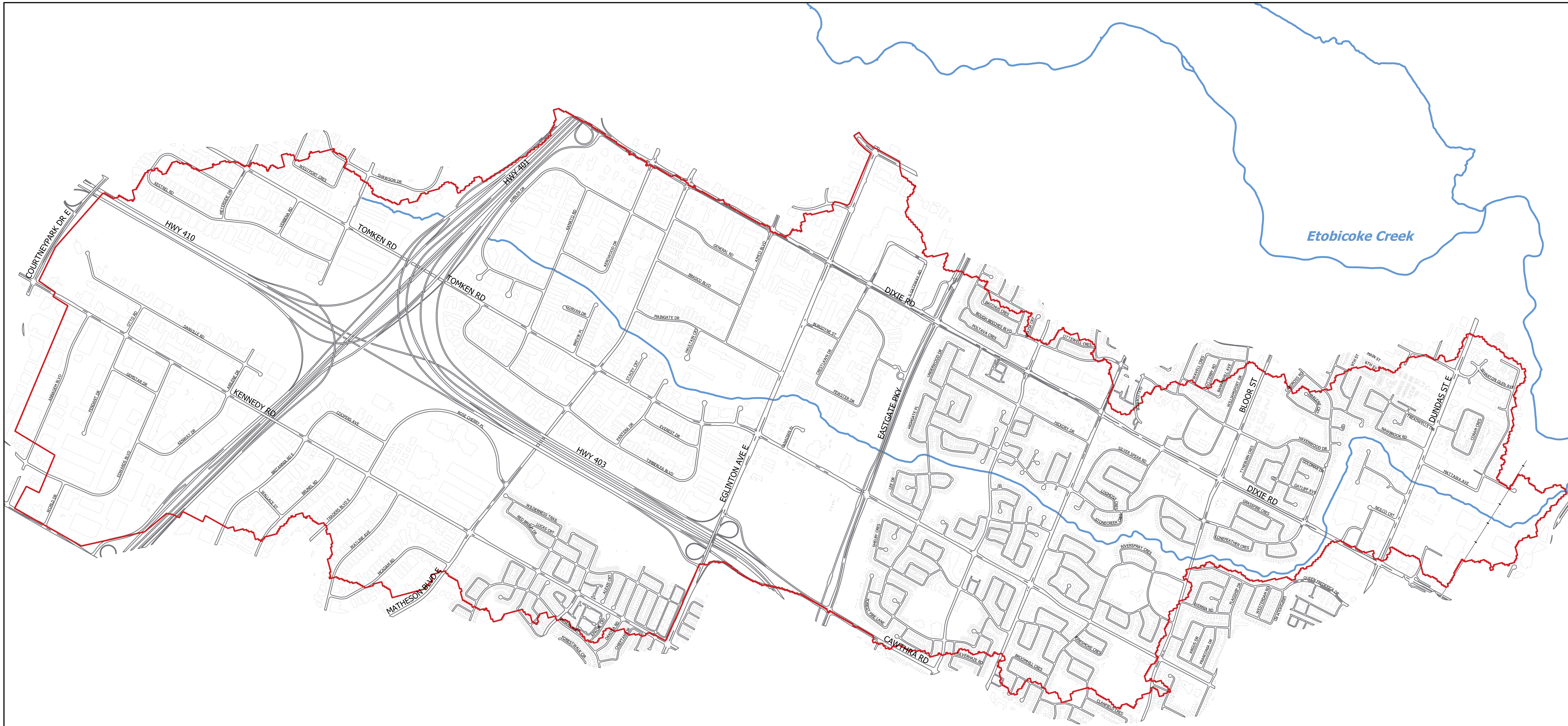


Figure Date: July 3, 2018

Little Etobicoke Catchment
Roads
Watercourse
Railway
Buildings

This drawing must be used in conjuction with the attached report, Little Etobicoke Creek Phase 2 Modelling for Flood Characterization and Analysis - Flood Evaluation Study, (June 2018) and is subject to the same limitations and conditions stated in the report.

N

0 250 500 750 1000 m

1:25,000

Matrix Solutions Inc.
ENVIRONMENT & ENGINEERING

Little Etobicoke Creek Phase 2
Flood Evaluation Study

Project #24603

Phase 2 Study Limit

Disclaimer: The information contained herein may be compiled from numerous third party materials that are subject to periodic change without prior notification. While every effort has been made by Matrix Solutions Inc. to ensure the accuracy of the information presented at the time of publication, Matrix Solutions Inc. assumes no liability for any errors, omissions, or inaccuracies in the third party material.

A. MacKay
K. Hofbauer

Figure 1

T:\24603 - Little EtobicokeCr_Flood\531\05 Analysis\GIS\Phase 2

The PCSWMM 2D model was run for the Regional storm event, the July 8, 2013 event, and the following design storms:

- 100-year 4-hour Chicago event
- 50-year 4-hour Chicago event
- 25-year 4-hour Chicago event
- 10-year 4-hour Chicago event
- 5-year 4-hour Chicago event
- 2-year 4-hour Chicago event

After discussions with TRCA and the City, two additional model simulations were added to the 2D modelling runs. The additional sensitivity runs were variations of the 100-year 4-hour Chicago event and include:

- 100-year 4-hour Chicago event, with minor system abstraction modification, to assess the sensitivity of the system to the assumed minor system capacity
- 100-year 4-hour Chicago event, climate change assessment

Further details about these events are discussed in Section 4.3.

The storm assessment aims to identify areas that may be at risk to overland flooding and determines at what event the flood risk may be classified as low, medium, or high risk (in accordance with the Ontario Ministry of Natural Resources and Forestry [MNRF] risk classification).

This progress report summarizes the model approach and development details of the PCSWMM model for existing conditions. Results of the model simulations are also presented in this progress report. Flood risk characterization, assessment of flood mechanisms, and identification of flood cluster areas will be provided in the subsequent Progress Report 3.

Table 1 provides a summary list of the previous progress reports and content.

TABLE 1 Summary of Progress Reports

Progress Report No.	Topic	Content
1	Floodplain Spill Assessment (Matrix 2018a)	• background review • Phase 1
2	Modelling for Flood Characterization and Analysis (current)	• details of two-dimensional (2D) PCSWMM model development • 2D model validation • flood risk results

2 BACKGROUND REVIEW

A detailed background review of previous studies was completed during Phase 1 and is summarized in Progress Report 1 (Matrix 2018a).

2.1 Data Acquisition

The following data received from the City and the TRCA were compiled and reviewed for the Phase 2 assessment:

- GIS base mapping, including land use, roads, buildings, watercourse lines, etc.
- topographic information (digital elevation model [DEM] from light detection and ranging [LiDAR] data)
- reporting and modelling from previously completed studies
- meteorological and streamflow data
- flooding locations for the July 8, 2013 event
- storm sewer data
- select property easements

2.2 Data Preparation

The following modifications and refinements were made to the provided data before developing the PCSWMM model:

- DEM modifications were made in three areas where the LiDAR data picked up anomalies in the surface from ongoing construction. Aerial imagery review and site visits were conducted to confirm the manual edits at the following locations:
  - Eastgate Parkway: on the southwest side of the road near the Little Etobicoke Creek crossing where the LiDAR picked up ongoing tunnelling construction.
  - Dixie Road Crossing: southwest corner of Dixie Road and Golden Orchard Drive intersection.
  - Dixie Road near Rockwood Mall: depression in Dixie Road west of the Rockwood Mall.
- Land use mapping was provided by TRCA; however, land use data was provided by the City outside of the TRCA jurisdiction. Assumptions and manual modifications were made to the City's data to match the land uses mapped by TRCA (e.g., connecting adjacent road segments, defining parkland etc.).
- Hourly rainfall data from the Toronto Pearson International Airport was disaggregated to 5-minute intervals to match the frequency of the City's rainfall data collection.

3 EXISTING CONDITION MODEL DEVELOPMENT

Originally a one-dimensional (1D)/2D riverine approach was pursued for the Little Etobicoke Creek model; however, model instability was encountered using this approach surrounding the 1D/2D connections. Matrix communicated the instability issues with the City and contacted both Computational Hydraulics International (CHI; the developers of PCSWMM) and TRCA for technical support. Both CHI and TRCA suggested that a full 2D approach would likely be more stable, while still producing results that are suitable for the flood characterization and screening of flood cluster areas. Therefore, the existing condition model was developed using a full 2D approach. Due to the size of the study area, the PCSWMM 2D model was developed in two halves as described in the next section.

The following input data were required to develop the 2D model in PCSWMM in order to simulate the interactions between the overland flows, floodplain, and the channel:

- hydrology layers:
  - study area subcatchment characteristics
  - inflows from the Upper Model into the Lower Model (further details in Section 3.1)
- 1D layers:
  - HEC-RAS cross-section geometry to define the low-flow channel not picked up by LiDAR
  - crossing structure details
- 2D layers:
  - bounding layer including separate polygons for areas with different surface roughness (Manning's n) and different mesh type (directional mesh applied along rivers, hexagonal mesh applied elsewhere)
  - river centreline layer (for directional mesh alignment along river)
  - obstructions layer (buildings or walls which influence overland flow paths on the 2D surface)
  - edge layer to ensure that locations with significant changes in elevation are identified (e.g., curb lines to separate roadway from sidewalk or curb)
  - DEM layer based on LiDAR data provided by TRCA

The PCSWMM model was prepared using data obtained from TRCA and the City, which included:

- bare-earth DEM developed from LiDAR data
- Visual OTTHYMO v.4 (VO4) hydrology model with associated GIS data and report
- HEC-RAS hydraulic model with associated GIS data and report

The details of model development are provided in the following subsections.

3.1 Model Domain

The Little Etobicoke Creek model was initially developed as a single PCSWMM 2D model domain including the entire 2,260 ha watershed of the creek from the headwaters to the confluence with Etobicoke Creek. However, after generating a portion of the 2D mesh, it was realized that the number of nodes in the model domain (over 800,000) would result in over 1.5 million conduits. This number of nodes and conduits, according to CHI, greatly exceeds the recommended size of a PCSWMM model. Due to these software limitations, the model was split into two segments: the Upper Model (1,730 ha), from the headwaters of the Little Etobicoke Creek watershed to Eastgate Parkway, and the Lower Model (960 ha), from Eastgate Parkway to the confluence with Etobicoke Creek.

A review of the topography, existing VO4 model, and HEC-RAS model was completed to determine a suitable location for separating the model into segments. Based on this review it was found that Eastgate Parkway was the most suitable location to split the model into the Upper and Lower segments due to the following considerations:

- Eastgate Parkway is at a higher elevation than its surroundings and no flow was shown to spill over this road in the existing HEC-RAS model during the Regional storm.
- Due to the road topography, if flow did spill over Eastgate Parkway, it would stay within the river valley (i.e., the low point is at the creek crossing; therefore, flow would spill over the roadway and back into the creek as opposed to travelling down the road).
- The VO4 catchment delineation considers Eastgate Parkway as a local topographic divide; therefore, splitting catchments would not be required.
- Separation at this location would divide the study area into roughly equal portions (60% Upper and 40% Lower).
- Eastgate Parkway represents the approximate boundary between commercial and residential land uses within the Little Etobicoke Creek watershed, which simplifies the model development in terms of cell size, roughness, etc. An exception to this is the residential neighbourhood on the west side of the Upper Model domain between Matheson Boulevard and Eglington Avenue.

Riverine flows from the Upper Model were input to the Lower Model as a point source boundary condition. No significant overland flows were found between the two models. An overview of the Upper Model and Lower Model domains is provided in Figure 2.

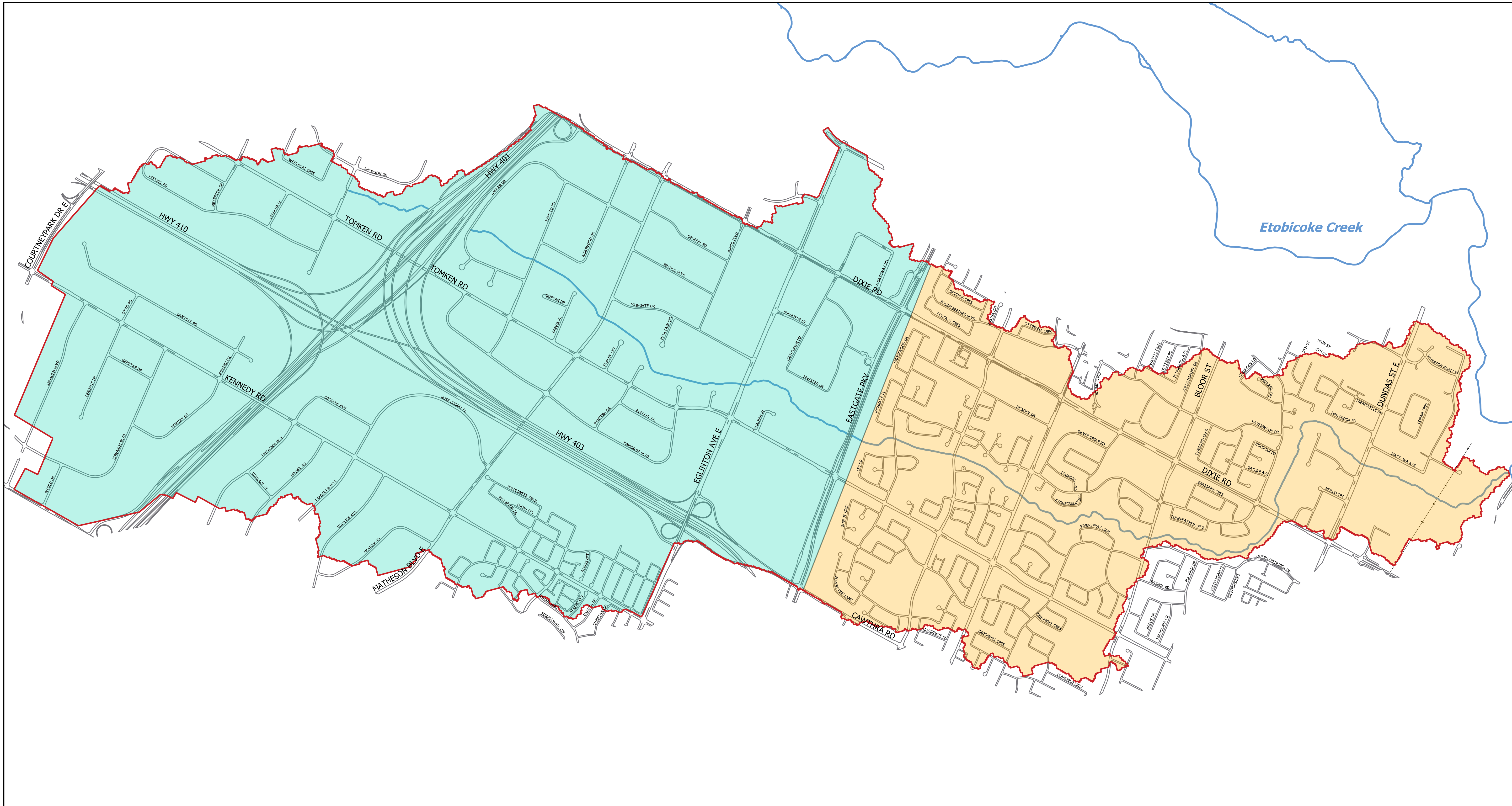


Figure Date: July 3, 2018

- Little Etobicoke Catchment
- Upper Model Domain
- Lower Model Domain
- Roads
- Watercourse
- Railway

N

0 250 500 750 1000 m

1:25,000

This drawing must be used in conjuction with the attached report, Little Etobicoke Creek Phase 2 Modelling for Flood Characterization and Analysis - Flood Evaluation Study, (June 2018) and is subject to the same limitations and conditions stated in the report.

Matrix Solutions Inc.
ENVIRONMENT & ENGINEERING

Little Etobicoke Creek Phase 2
Flood Evaluation Study

Project #24603

Upper and Lower Model Domains

Disclaimer: The information contained herein may be compiled from numerous third party materials that are subject to periodic change without prior notification. While every effort has been made by Matrix Solutions Inc. to ensure the accuracy of the information presented at the time of publication, Matrix Solutions Inc. assumes no liability for any errors, omissions, or inaccuracies in the third party material.

A. MacKay
K. Hofbauer

Figure 2

T:\24603 - Little EtobicokeCr_Flood\531\05 Analysis\GIS\Phase 2

3.2 Hydrology Layers

3.2.1 Riverine Inflows

As the PCSWMM model was developed for the entire Little Etobicoke Creek watershed, no riverine inflows were required to the Upper Model. The Upper Model outflow was extracted for each storm simulation and input to the Lower Model as an inflow boundary condition (point source).

3.2.2 Study Area Subcatchments

Catchments within the study area were delineated at a catch-basin-scale based on a procedure described by the Massachusetts Metropolitan Area Planning Council (MAPC 2015). The procedure uses a LiDAR DEM surface and a set of hydrologic analysis tools in ArcGIS to delineate catchment areas. Each catch basin was associated with the outfall feature where it contributes flow. The DEM was then enhanced using the street centreline and curb lines at the edge of the roads. This enhancement ensured that modelled runoff would flow toward the street gutters and also refines local drainage patterns that the raw DEM may not have precisely captured on its own. Since the catch basin locations provided in the GIS data were schematic only, the catch basins were relocated to the curbs to ensure they were adequately capturing flow in the gutter. The flow captured by catch basins was conveyed to the creek through the methods described in Section 3.2.3.1.

A catchment for each catch basin in the study area was created using the enhanced DEM. Flow accumulation lines were generated, allowing catch basins to be connected to grid cells with high accumulated flows acting as the “pour points” for the catchments. Catchments were then created for each pour point. Where necessary, manual adjustments were made to the catchment boundaries to refine the automated process when warranted by other site-specific knowledge. Catchments were also delineated to various natural drainage locations within the creek corridor. Figure 3 shows the delineated catchments for Little Etobicoke Creek.

The hydrologic parameters associated with the subcatchments including catchment area, length, slope, percent impervious, and surface roughness were calculated based on available background data that were organized and extracted using spatial analysis tools. The Curve Numbers (CN) assigned to the catchments are discussed in the following subsections.

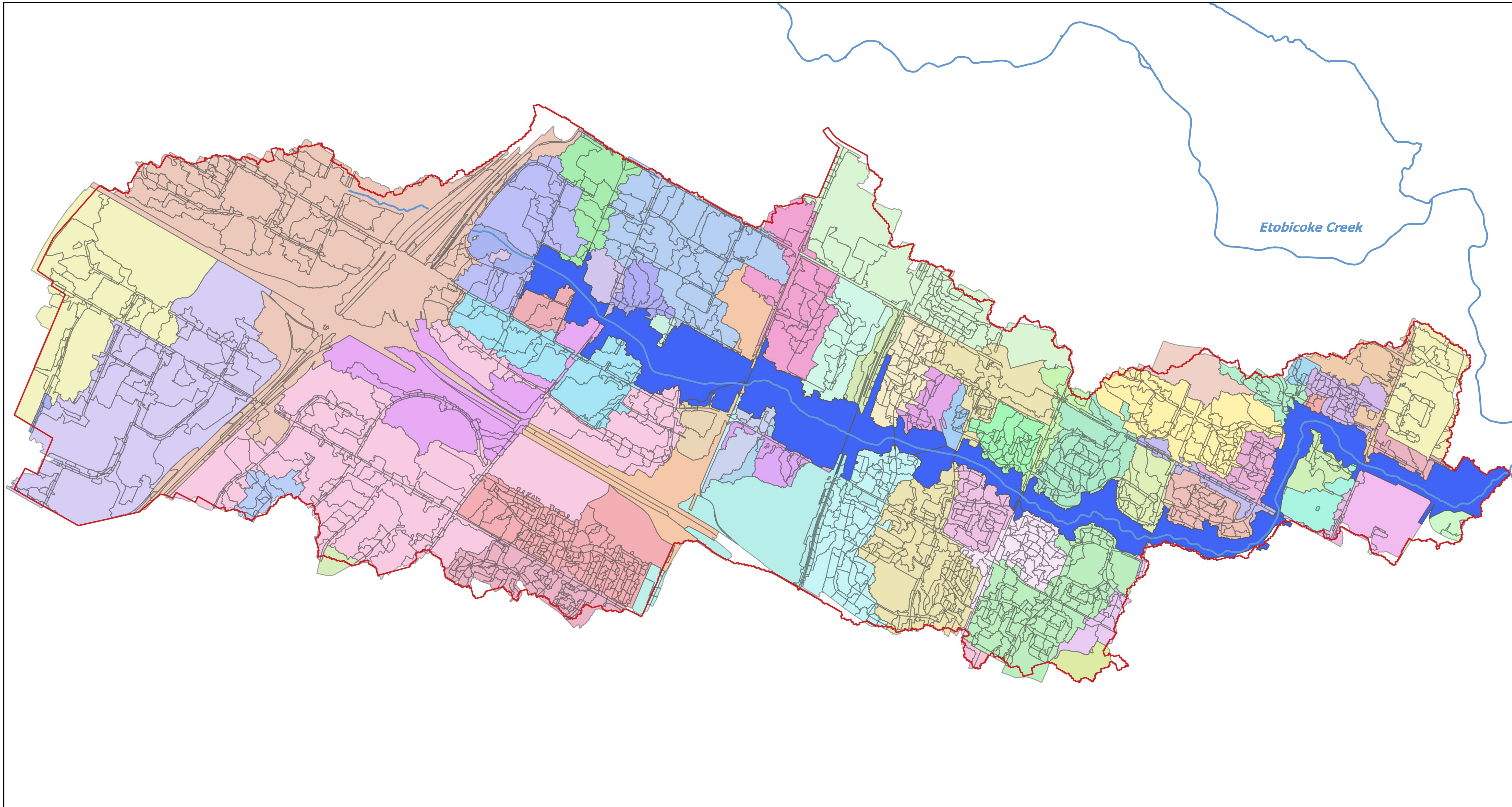


Figure Date: July 3, 2018

Little Etobicoke Catchment

Watercourse

Urban Catchments

Drain to River

Drain to Storm Sewer Outlet or Overland Outlet (multicolour)

This drawing must be used in conjuction with the attached report, Little Etobicoke Creek Phase 2 Modelling for Flood Characterization and Analysis - Flood Evaluation Study, (June 2018) and is subject to the same limitations and conditions stated in the report.

N

0 250 500 750 1000 m

1:25,000

Matrix Solutions Inc.
ENVIRONMENT & ENGINEERING

Little Etobicoke Creek Phase 2
Flood Evaluation Study

Project #24603

Urban Catchment Delineation

A. MacKay
K. Hofbauer

Figure 3

T:\24603 - Little EtobicokeCr_Flood\531\05 Analysis\GIS\Phase 2

3.2.3 Major and Minor System Subcatchments

Using the methods described in Section 3.2.2 the drainage area contributing to each catch basin was determined. Using this setup, the model is inherently ready to incorporate storm sewers in the flood cluster areas during the next stage of this study. To accurately assess the overland drainage system without specifically modelling the minor sewer system in PCSWMM, the flow expected to be conveyed by the minor system was separated from the total runoff hydrographs for each rainfall event.

The hydrograph portions to be assigned and conveyed to the minor system were based on best estimates of the existing storm sewer capacities. To estimate the capacity of the minor system, the age of the surrounding development was assessed. Based on a review of historical imagery from 1954, 1970, and 1984 (Appendix A), the residential communities surrounding Little Etobicoke Creek were built largely in the 1960s and 1970s. Drainage infrastructure of this era was typically designed to convey flows from a higher-frequency and lower-intensity storms than the City's current design standards.

Given the age of the infrastructure, it was assumed that the minor system was designed to convey peak flows relative to the 2-year event. This assumption was also used in the previous flood analysis study in the historic Village of Malton (Matrix 2018b). In this previous study, Matrix validated the minor system capacity assumptions by adding the minor system into a neighbourhood in the Village of Malton. Flow hydrographs for a number of pipes within the minor system area were exported from the model results. The contributing catchment areas to each pipe segment were determined and were used to calculate the peak intensity in the pipes. The previous analysis (detailed in Appendix B) confirmed the assumed peak intensity of 19 mm/hour was appropriate for hyetograph abstraction.

The conservative 2-year peak rainfall intensity of 19 mm/hour was assumed to be the minor system capacity for the Little Etobicoke Creek. This minor system intensity was subtracted from the rainfall hyetographs for each storm event. The resulting hyetographs were applied to each of the small urban catchments to generate the runoff hydrographs representing overland flow (the green portion of the hyetograph; Figure 4). Figure 4 shows the STN 6 hyetograph used for the July 8, 2013 storm event. The remaining July 8, 2013 and design storm hyetographs are provided in Appendix C.

While the minor system flow was abstracted from the urban overland flow model, these flows still need to be accounted for in the riverine portion of the model. As such, lumped sewershed catchments were included to represent the minor system outflows to the creek at each outlet; these are illustrated as the large colour coded areas on Figure 3. Instead of being connected to catch basins, these minor system catchments were connected directly to the sewer outlets. The portion of the hyetograph that was subtracted from the overland catchments was applied to these sewershed catchments (the blue portion of the hyetograph; Figure 4).

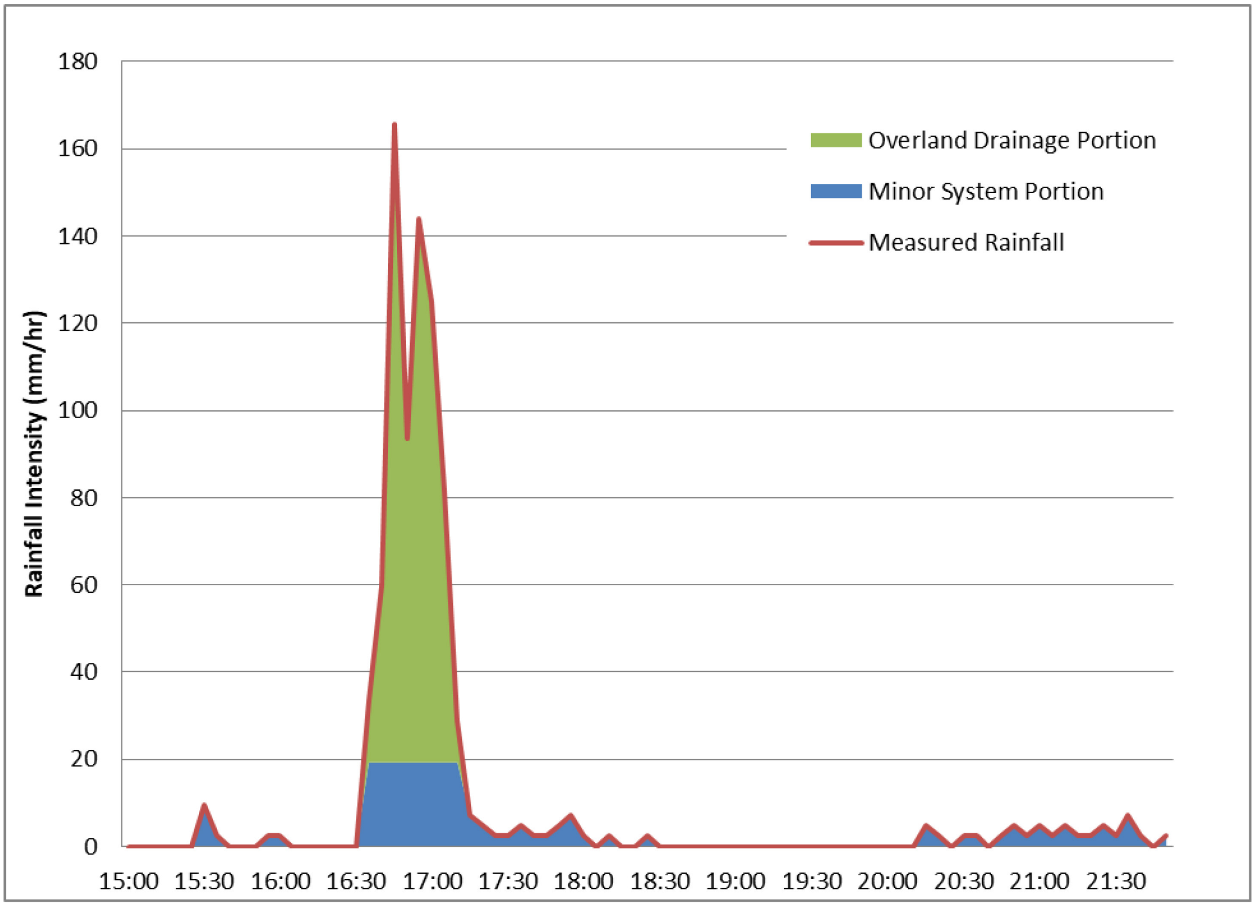


FIGURE 4 STN 6 - July 8, 2013 Hyetographs

The combination of inputs to the discretized urban catchments and the lumped sewershed catchments represent the complete event hyetograph within the study area (the red line of the hyetograph, Figure 4). An example of this division is provided in Figure 4 for the July 8, 2013 event (for STN 6 rain gauge near the study area).

This methodology could be adjusted to abstract other flows to explore the effect that a different design capacity would have on the model results. An alternative abstraction intensity was explored as a sensitivity analysis for the Little Etobicoke Creek study, based on the City's storm sewer information and design standards (further details on this additional assessment are provided in Section 4.3). However, given information of system performance combined with the known age of infrastructure, the 2-year flow abstraction is considered conservative and appears reasonable for the overland flow assessment at this time. Changes in the amount of flow accounted for in the minor system will not have a significant impact on the riverine water levels; however, some changes would be expected in surface flows within the urban areas.

3.2.3.1 Infiltration in Split Catchments

Modelling separate catchments for the major and minor systems requires special consideration for infiltration characteristics. To ensure that infiltration is accurately accounted for, it was assumed that infiltration will occur only in the minor system catchments (lumped sewershed catchments). Using the described method, the lumped sewershed catchments receive the initial portion of each rainfall event. As such, the sewershed catchments include CN values that align with the appropriate land use. Due to differences in topographic data used for delineation, as well as the catchment discretization, the sewershed catchments delineated for the Little Etobicoke Creek watershed did not align directly with the existing VO4 model. The CN values for each minor system catchment were developed based on pro-rating values from the existing calibrated VO4 hydrologic model for Etobicoke Creek (MMM 2013).

The major system catchments (small urban catchments) have been assigned CN values of 100. Assigning a value of 100 ensures that additional infiltration is not occurring through the major catchments; all infiltration is assumed to occur in the 2-year flow abstraction to the minor system.

3.2.4 River Subcatchments

For areas within the creek corridor, subcatchments are not associated with a catch basin since the area will drain directly into the creek. For the river subcatchments, the entire hyetograph was applied to the subcatchment as no minor system was present in these locations. A breakdown of minor, major, and river subcatchments for each Upper Model and Lower Model is provided in Table 2.

TABLE 2 Number of Subcatchments in the Upper and Lower Models

Subcatchment Type	Upper Model	Lower Model
Major	1,647	1,458
Minor	26	31
River	6	7

3.3 One-dimensional Layers

As discussed previously, the combined 1D/2D riverine approach for the Little Etobicoke Creek model was considered unstable after the initial runs; therefore, the river portion is currently represented using 2D cells as opposed to 1D conduits.

To adequately simulate riverine flow, road crossings within the study area needed to be included in PCSWMM. Culverts and bridge openings have been included as closed conduits in the 1D riverine model to simulate the culvert/bridge openings below the bridge deck. These 1D conduits are connected to the appropriate 2D conduits immediately upstream and downstream of the crossings. Overflow in excess of the crossing capacity spills to the 2D portion of the model along roadways and/or overland flow paths as dictated by topography. The 1D connections within the model were reviewed to ensure the inverts of the openings align with the 2D surface and that there was a proper connection to the road for potential overtopping.

Downstream of the Upper Model 2D domain, a portion of the 1D channel was included to allow for establishing a downstream boundary condition. The 1D channel extends for approximately 200 m downstream of the 2D domain. Cross-section geometry was extracted from the HEC-RAS model for this portion of the model. After review of preliminary results, it was determined that at the downstream edge of the Lower Model 2D domain, backwater from downstream, was minimal and therefore no 1D channel was included downstream of the 2D domain (refer to Section 3.5.2 for details of the boundary condition).

3.4 Two-dimensional Layers

The 2D portion of the PCSWMM model was developed with a particular focus on the overland drainage system. Elevations in the model were based on the LiDAR data provided by TRCA. The following subsections detail the processes used to develop the 2D model.

3.4.1 Surface Bounding Layer

Creating a 2D model in PCSWMM requires a "bounding layer" to define the extent of the 2D model domain. The bounding layer is typically subdivided into areas with different mesh type and/or surface roughness. For the purpose of this study, the bounding layer includes the following four subareas using Manning's n values consistent with standard TRCA practice:

- Urban Pervious with a hexagonal mesh of 5 m resolution and Manning's n of 0.05
- Urban Residential Impervious with a hexagonal mesh of 5 m resolution and Manning's n of 0.025
- Urban Commercial Impervious with a hexagonal mesh of 10 m resolution and Manning's n of 0.025
- Natural Areas with a hexagonal mesh of 5 m resolution and Manning's n of 0.08
- Channel Watercourse Area with a directional mesh of 3 m resolution and Manning's n of 0.035

3.4.2 River Centreline Layer

The river centreline layer was exported from HEC-RAS and used in PCSWMM as an alignment for the directional mesh of the 2D area along the river. The exported centreline was compared with the LiDAR surface to ensure the alignment generally matched that of the creek corridor and did not cross channel banks, etc.

3.4.3 Obstructions Layer

A shapefile of building polygons was provided by TRCA. This layer was used in PCSWMM as an obstructions layer to simulate structures or other features that influence the direction of overland flow.

3.4.4 Edge Layer

An "edge layer" is a line layer that identifies locations with notable changes in elevation to be accounted for in the mesh. This layer is optional and not required for 2D models; however, it is recommended in cases where roadways should be separated from a curb or sidewalk. Incorporating the edge layer splits the mesh along the line feature to allow the vertical face of the curb to be accurately represented. Without the edge layer, the mesh generation would interpolate between topographic data points, creating steep slopes instead of two areas separated by a vertical face. The edge layer used for this project included the curb edge of the roads.

3.4.5 Digital Elevation Model Layer

The DEM layer was based on the bare-earth LiDAR supplied by TRCA with slight manual modifications as summarized in Section 2.2. As a full 2D approach was pursued for the modelling, the low-flow channel from the HEC-RAS model was burned into the DEM to provide the 2D nodes with elevations that would represent the channel bed. To complete this, a surface of the channel between the left and right banks stations was created using the RAS Mapper tool in HEC-RAS. Road segments were cut from the channel surface to maintain the road elevations and then the complete channel surface was overlaid with the DEM. Figure 5 shows a comparison of a portion of the original DEM and the modified DEM used in the PCSWMM model.

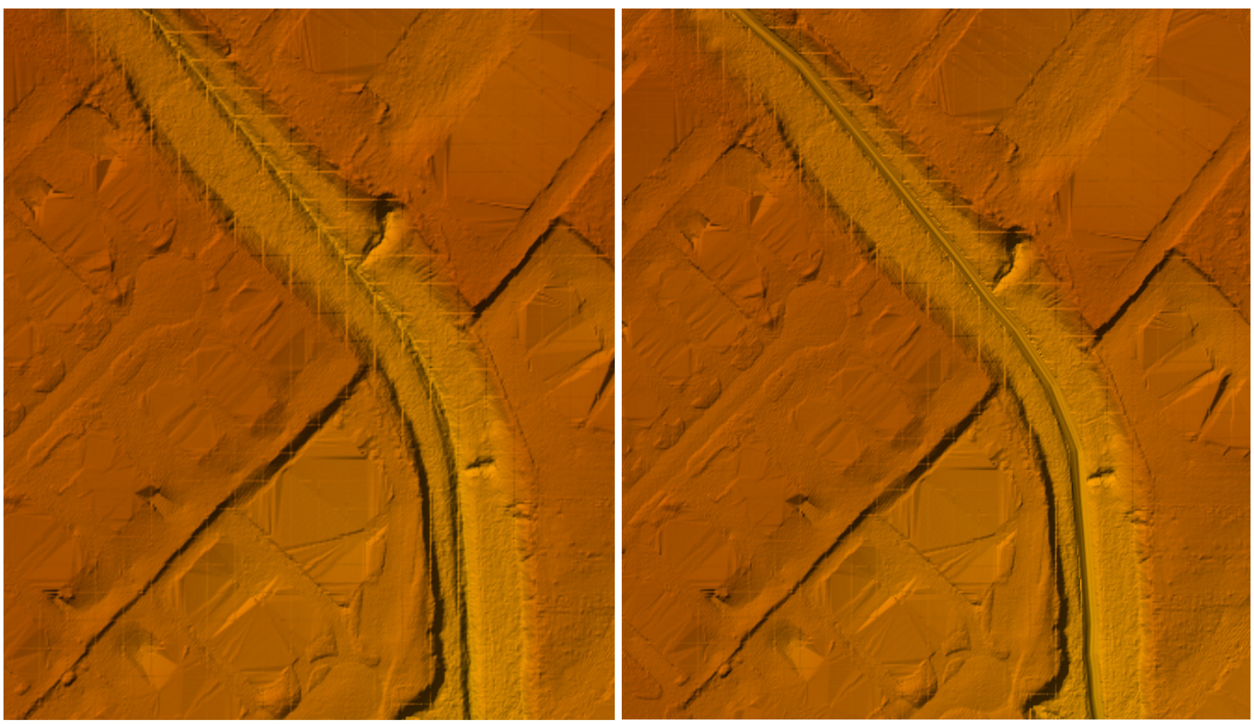


FIGURE 5 Original Digital Elevation Model (Left) and Modified Digital Elevation Model for PCSWMM (Right)

3.4.6 Two-dimensional Mesh Generation

In PCSWMM, the first step in developing the 2D mesh is to generate 2D nodes. The 2D nodes were generated based on the attributes of the 2D layers defined previously, such as bounding layer (for mesh type and Manning's n), obstructions, edge layer, river centreline layer (for directional mesh only), and DEM layer. The 2D nodes layer uses elevation data extracted from the DEM.

In the model setup, 1D conduits in the model account for the flow through bridges and culverts at each creek road crossing. Each 1D conduit was connected to the 2D mesh using the built-in connection tool in PCSWMM to directly connect the 1D and 2D junctions (refer to Section 3.6). Each crossing was reviewed to ensure that flow was not artificially obstructed upstream or downstream of the 1D conduit and that the mesh provided a suitable connection for water to overtop the roads. Figure 6 shows a sample area of 1D/2D mesh at a road crossing.

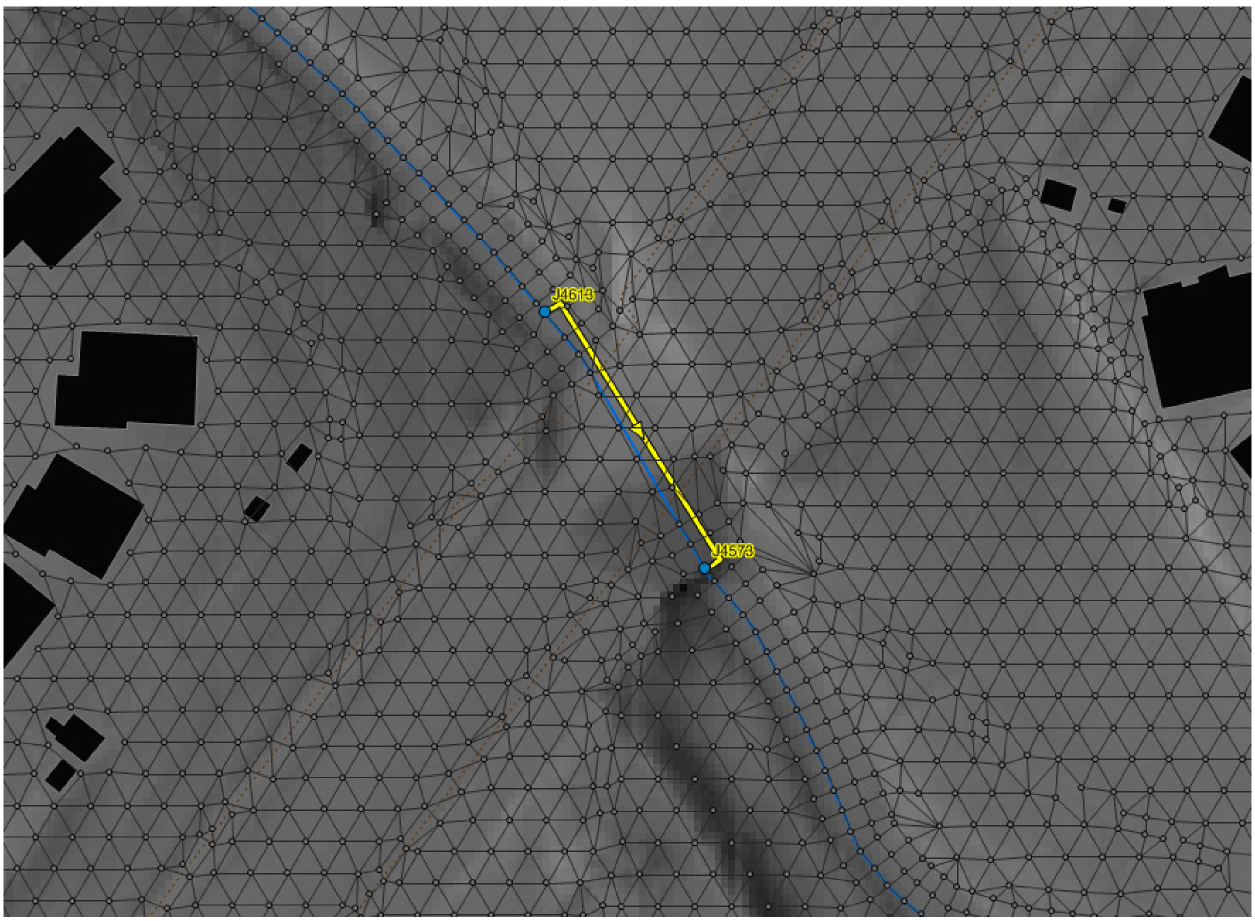


FIGURE 6 Mesh Example at Road Crossing

3.5 Boundary Conditions

3.5.1 Precipitation Input

Precipitation input for the July 8, 2013 rainfall event was incorporated through the use of nearby rainfall gauges based on proximity to the Little Etobicoke Creek watershed. Rainfall data from the City's STN 6, STN 5, and STN 10 and Environment Canada's Toronto Pearson International Airport Station rainfall records were applied to the appropriate subcatchments based on Thiessen Polygons. Figure 7 outlines the precipitation gauges assigned to each of the major subcatchments, and Figure 8 shows the distribution of rainfall depths applied to the major and minor catchments, as well as the overall station volumes.

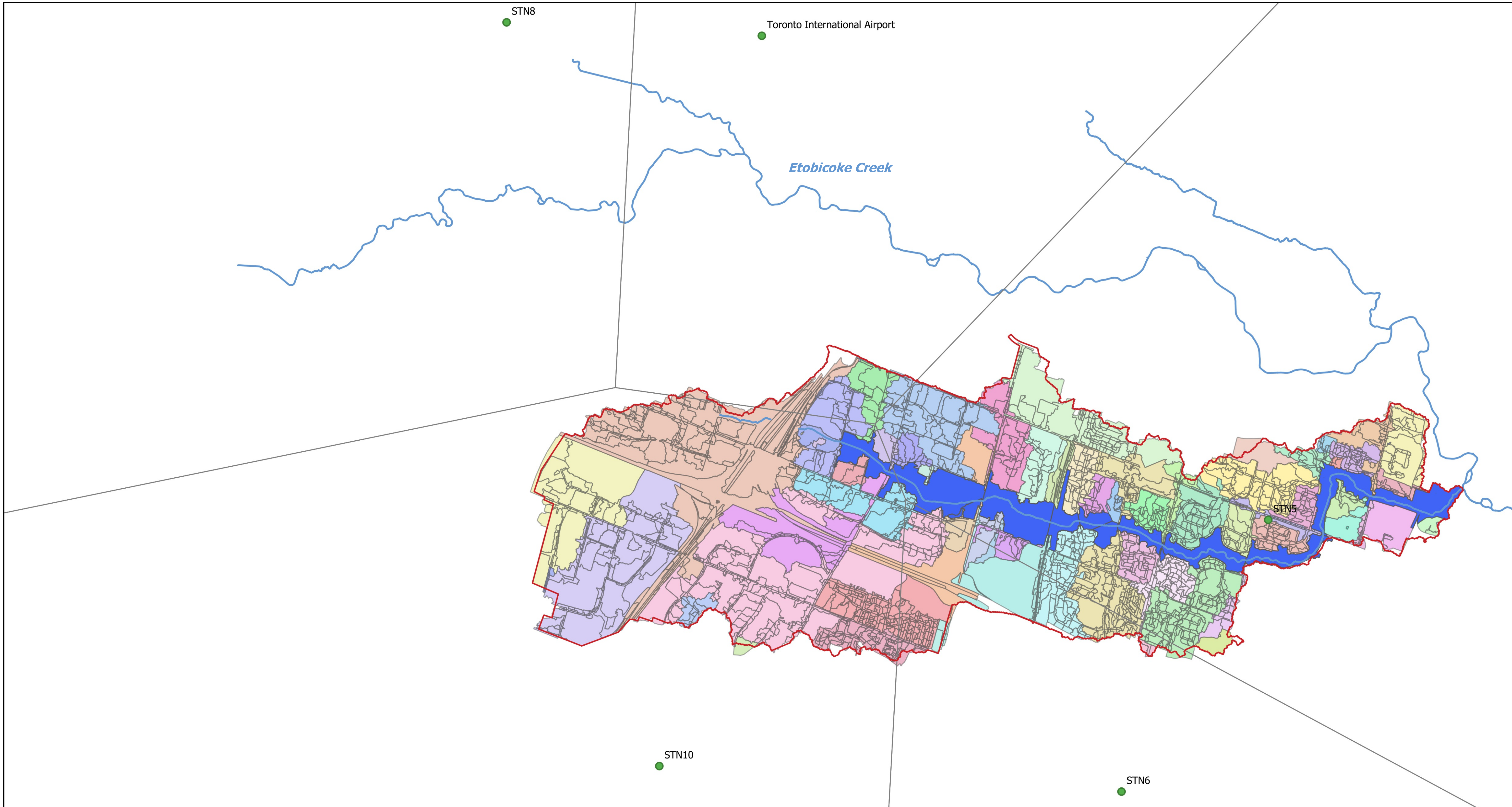


Figure Date: July 3, 2018

Little Etobicoke Catchment
Model Climate Station Coverage Area
Watercourse
Model Climate Stations

Urban Catchments
Drain to River
Drain to Storm Sewer Outlet or Overland Outlet (multicolour)

0 500 1000 m
1:40,000

This drawing must be used in conjuction with the attached report, Little Etobicoke Creek Phase 2 Modelling for Flood Characterization and Analysis - Flood Evaluation Study, (June 2018) and is subject to the same limitations and conditions stated in the report.

Matrix Solutions Inc.
ENVIRONMENT & ENGINEERING

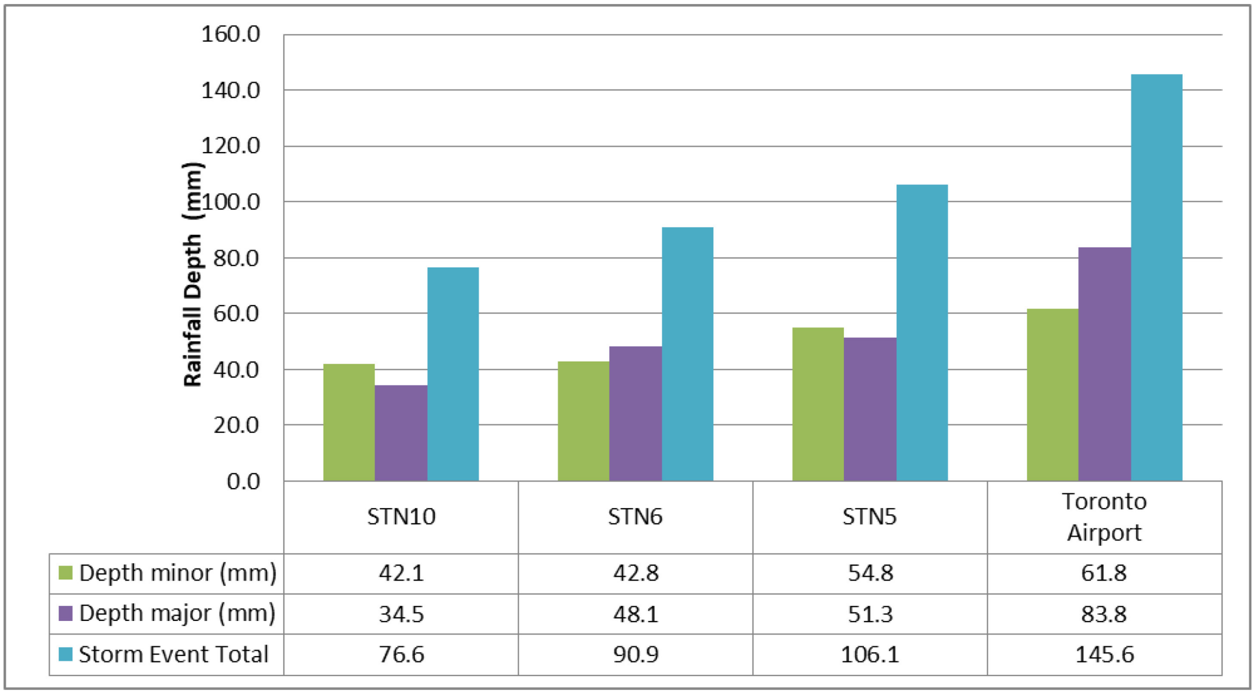
Little Etobicoke Creek Phase 2
Flood Evaluation Study

Project #24603

July 8, 2013 Rainfall Gauges Assigned to Major Urban Subcatchments

A. MacKay
K. Hofbauer

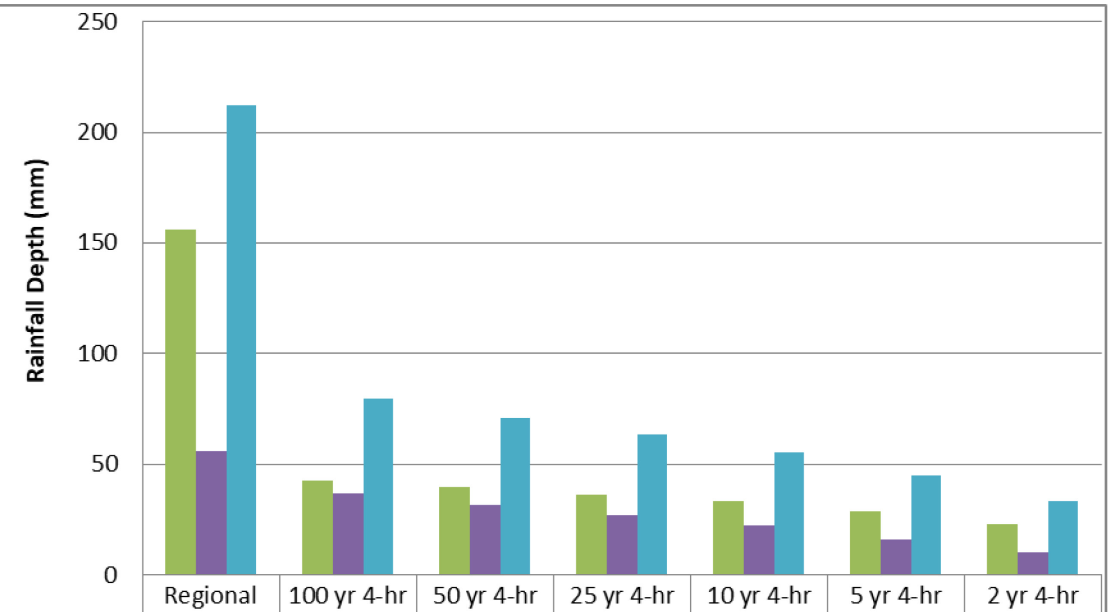
Figure 7



	STN10	STN6	STN5	Toronto Airport
Depth minor (mm)	42.1	42.8	54.8	61.8
Depth major (mm)	34.5	48.1	51.3	83.8
Storm Event Total	76.6	90.9	106.1	145.6

FIGURE 8 July 8, 2013 Rainfall Station Summary

Typically, the Chicago storm rainfall distribution is used to generate peak flows in urban areas where the peak flows are largely influenced by rainfall intensity as opposed to total rainfall depth. The Chicago storm distribution provides much higher peak intensities compared to the Atmospheric Environment Services distribution and therefore, tends to produce more conservative flooding results in the urban system. Therefore a 4-hour Chicago storm distribution was used in the urban catchments for each of the design storm simulations. The Chicago storm hyetographs were developed based on the City's intensity duration frequency data and are shown in Appendix C. A summary of the rainfall depths applied to the major and minor catchments for each of the design storms is provided in Figure 9. The minor system volumes vary between each storm event as an intensity of 19 mm/hour was removed from each 5-minute time interval as opposed to a specific volume.



	Regional	100 yr 4-hr	50 yr 4-hr	25 yr 4-hr	10 yr 4-hr	5 yr 4-hr	2 yr 4-hr
Depth minor (mm)	155.96	42.4	39.5	36.5	33.2	28.8	23.2
Depth major (mm)	56.04	37.0	31.8	27.1	22.2	16.2	10.3
Storm Event Total	212.0	79.4	71.3	63.6	55.4	45.0	33.4

FIGURE 9 Design Storms - Rainfall Summary

3.5.2 One-dimensional Boundary Condition

A boundary condition was required for the 1D portion of the Upper Model to govern water levels at the downstream end of the model. The fixed water level option was selected as it was determined to be the most appropriate for this application, and reiterating boundary conditions between the Upper Model and Lower Model was not feasible due to the extensive run times. The fixed water levels for each of the design storms and the July 8, 2013 rainfall event were extracted from cross-section 16.115 in the HEC-RAS model, which corresponds to the furthest downstream cross-section applied in the Upper Model. The cross-section is located approximately 200 m downstream of the Eastgate Parkway crossing to minimize the impact of the downstream boundary condition on results within the 2D study area.

Water levels in Etobicoke Creek have little backwater impact on Little Etobicoke Creek; therefore, a 1D channel component was not included downstream of the 2D domain and therefore water level boundary conditions were not assigned to the Lower Model. Figure 10 shows the HEC-RAS profile from the TRCA HEC-RAS model, which demonstrates how the backwater conditions do not extend upstream of the Canadian National Railway rail crossing (500 m upstream of the confluence) and therefore will not impact our study area.

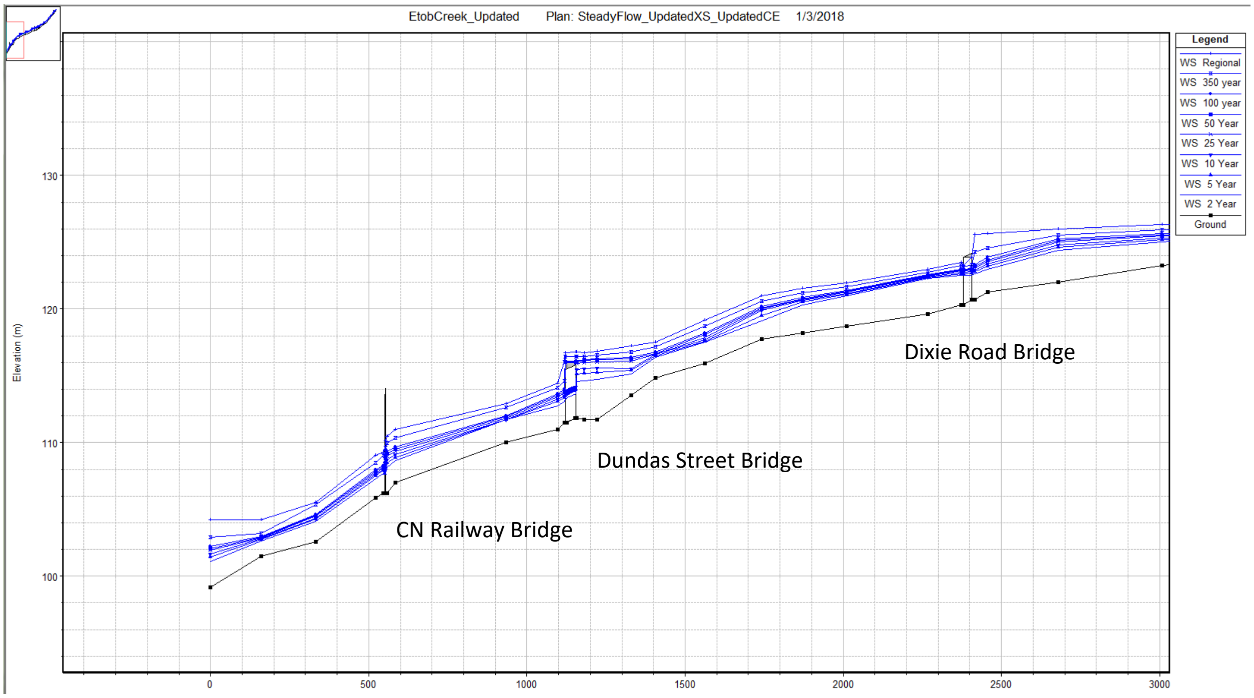


FIGURE 10 HEC-RAS Model - Channel Profile at Etobicoke Creek Confluence

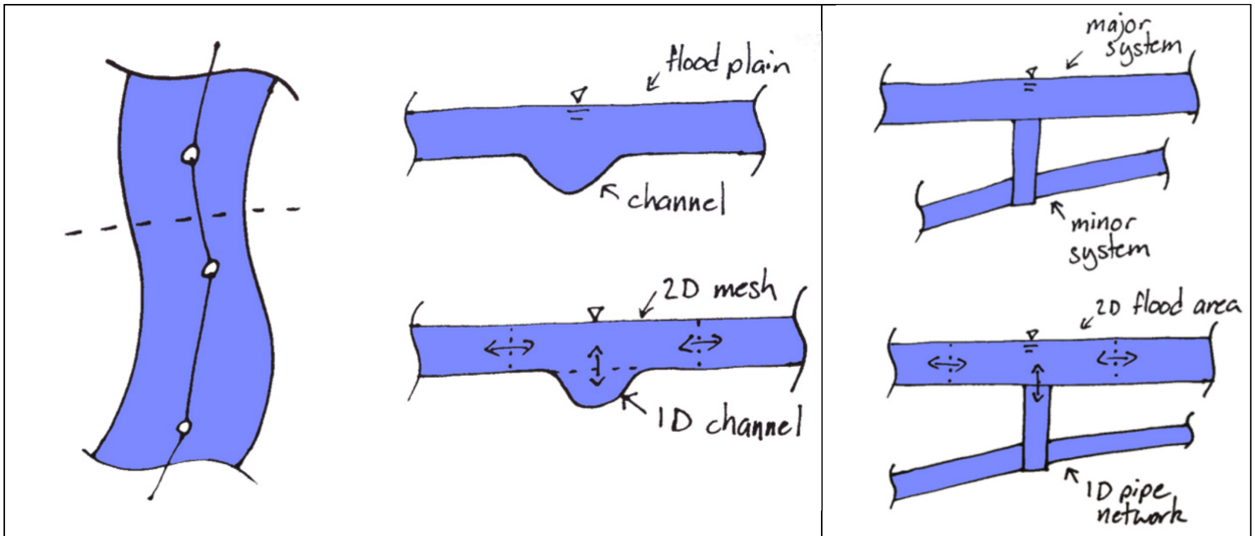
3.5.3 Two-dimensional Boundary Condition

Similarly, a boundary condition was required for the 2D portion of the PCSWMM model to dictate how overland runoff behaves once it reaches the edge of the 2D domain. The PCSWMM model uses a "downstream layer" to represent a line along the 2D boundary where flow can exit the system. The software then generates a number of 2D outflow conduits along this downstream boundary, which were assigned elevations based on the DEM.

The 2D outflow conduits were set up with free outflow conditions to allow flow to exit the model domain. As these conduits were developed from the DEM based on the quasi-2D methodology, there was no adequate and consistent slope along the boundary to enable the use of normal flow outlets. The free outflow 2D conduits along the boundary of the 2D model domain allow overland flow to leave the model domain unimpeded. Depending on the location of the outfall boundary, labels were applied to the outfalls so that volumes spilling into Etobicoke Creek or another adjacent watershed could be accounted for at the end of the model simulation.

3.6 Connecting One-dimensional Model to Two-dimensional Mesh

There are two methods for connecting a 1D model to a 2D mesh: connecting directly to 2D nodes or as a bottom orifice. Schematics of these methods are provided in Figure 11.



1) Sample transect showing 1D channel with 2D overbanks

2) 1D-2D connection using orifices

FIGURE 11 Methods for Connection One-dimensional Model to Two-dimensional Mesh (CHI 2018)

The first method, which uses direct connection of 1D junctions to 2D nodes, was applied to all road crossings in the study area. Using this method, the closest 2D junction is relocated to coincide with the 1D node to create one common junction. This method is appropriate when modelling open channels and river networks as it allows for free transfer of flow from the river to the surface and vice versa. The 1D conduits (i.e., bridges and culverts) were connected at the bottom of the junction, while the 2D conduits were connected at the top of the same junction.

The second method uses a bottom orifice, which connects each 1D junction to the closest 2D junction using an orifice equation. This method is typically used for dual-drainage models when simulating surcharge through a manhole or catch basin. This method was not used in the existing 2D model development but will be used in the future modelling of the flood cluster scenarios where the minor drainage system will be included in the model.

3.7 Additional Considerations

In the 2D model domain, there were a few features that were required in order to represent proper overland flows and runoff volumes. Several stormwater management ponds were visible in the aerial imagery, DEM layers, and on the drainage network drawings. The minor system catchments upstream of these features were directed into these depressions as appropriate to mimic attenuation and storage. To convey larger volumes from the ponds to the river, dummy conduits were added from the pond outlets to the proper river outlet to simulate the pond outfalls to the river, allow flow to be conveyed without impediment and to prevent the stormwater management features from spilling.

Additional dummy conduits to convey flows through roads of low-lying ditch areas (e.g., near the City's rapid transit hub, upstream of Eastgate Parkway) were also added to prevent water from artificially ponding at these locations.

4 MODEL VALIDATION

Model validation was completed for the Little Etobicoke Creek PCSWMM 2D model using several comparisons to previous model simulations. Validation methods included:

- comparing 100-year peak flows and volumes to existing VO4 models
- comparing 100-year and 5-year water levels to existing HEC-RAS models
- comparing visually, the July 8, 2013 storm event to City's flood calls

High water marks (HWMs) were received from the City; however, they were not able to be compared to model results as they did not align with the existing topography. For example, HWMs upstream and downstream of the Rathburn Road crossing show elevations of 138.92 to 138.94 m. When comparing the HEC-RAS section closest to this location, the HWMs are well above (over 4 m) the existing topography and Regional flood levels, (see Figure 12). As this depth of water is not reasonable during the July 8, 2013 event, these HWMs were ignored.

The August 9, 2009 event was also proposed for model validation; however, no data from the event (e.g., flood calls or HWMs) were available for comparison. Therefore, modelling of this event was not completed.

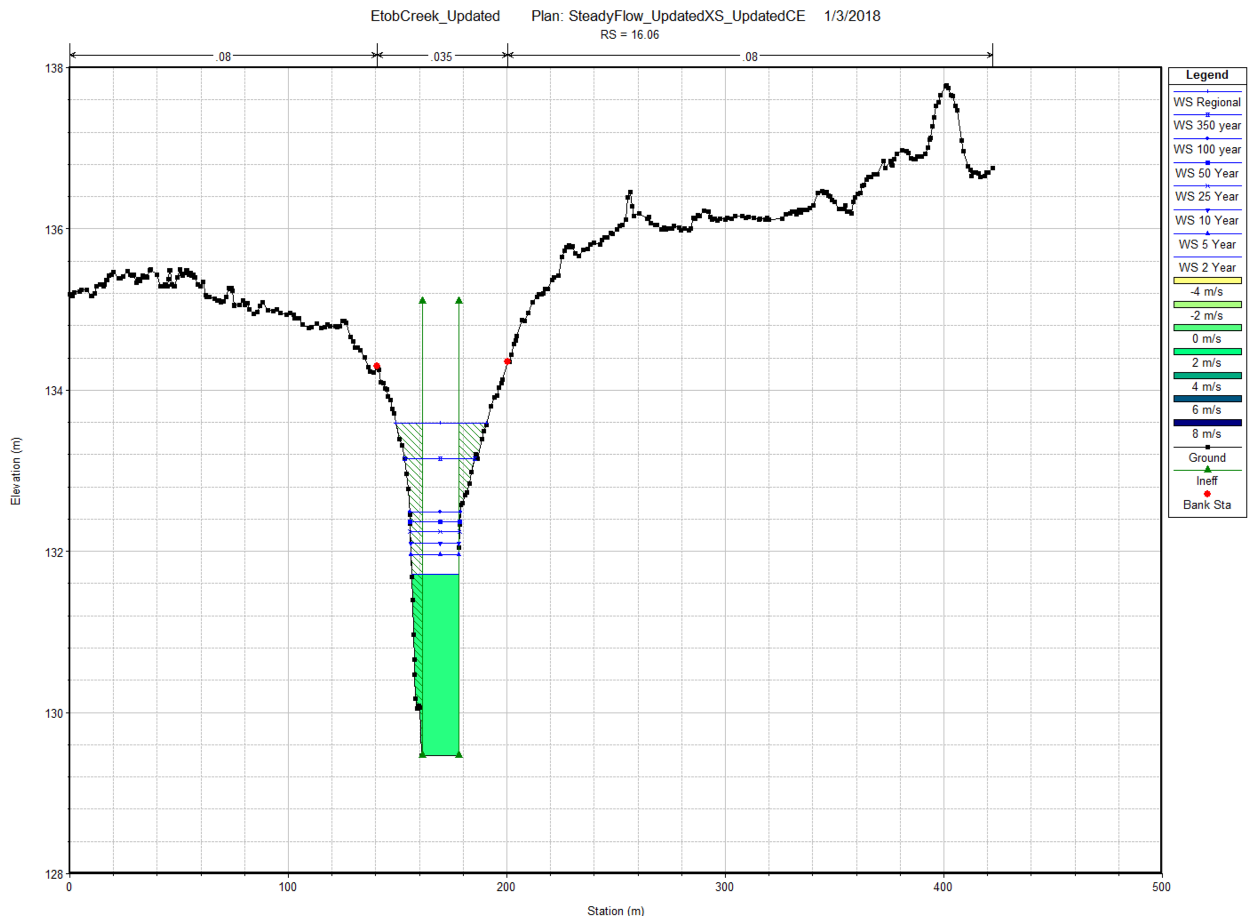


FIGURE 12 HEC-RAS Model Steady-state Model Output at Rathburn Road

4.1 Riverine Model Validation

Prior to pursuing a full 2D approach, a memo titled *Investigation of Differing Water Surfaces in HEC-RAS and PCSWMM 1D Models* (Matrix 2018c) was prepared to summarize the riverine model validation between the PCSWMM and HEC-RAS model. The results showed a good correlation between the simulated water levels given the innate differences in model simulation procedures. Although the riverine model validation appeared to be suitable, the full 1D/2D integrated model development was not pursued for the urban flood risk characterization. Riverine validation checks were included in the integrated model validation described in Section 4.2.

4.2 Two-dimensional Model Validation

The 2D model validation included checks to confirm that the model was simulating reasonable volumes, peak flows, water levels, and velocities throughout the 2D model domain. The following subsections summarize the validation process.

4.2.1 Comparison of Peak Flows to Visual OTTHYMO

To accurately assess if modelled flows in Little Etobicoke Creek match the anticipated flows for the design storms, peak flows were compared between the existing VO4 model and the PCSWMM model for the 100-year design storm. A summary of the differences is provided in Table 3.

Variations between peak flows are expected due to the differences in catchment delineations and splitting of the hyetographs between the major and minor catchments. Hydrographs from the PCSWMM model were extracted at the approximate location of the VO4 catchments for comparison at each road crossing. Peak flows in the PCSWMM model are typically lower than the VO4 model due the storage on the surface on the urban system. Higher flows in the PCSWMM model were captured at the Eglington Avenue road crossing, likely due to differences in the extraction of the hydrograph below some river outfalls. Lower peak flows are shown in the PCSWMM model downstream of the Dixie Road crossing. This is due to the spill volume leaving the riverine area near Dixie and Dundas.

TABLE 3 Peak Flow Comparison to Visual OTTHYMO Model - 100-year

Model Location	Visual OTTHYMO Peak Flow (m^3/s)	PCSWMM Peak Flow (m^3/s)	Percent Difference
Start of Creek	22.68	22.63	-0.2%
Matheson Road Crossing	52.51	47.01	-10.5%
Eglington Avenue Crossing	73.36	81.45	11.0%
Eastgate Parkway Crossing	104.90	105.63	0.7%
Burnhamthorpe Road Crossing	109.08	104.8	-4%
Bloor Street Crossing	112.09	107.2	-4%
Dixie Road Crossing	111.76	91.78	-18%
Dundas Street Crossing	117.42	96.15	-18%
CN Railway Bridge Crossing	116.39	104.1	-11%

A hydrograph comparison between the two simulated model flows is provided in Figure 13 for the Eastgate Parkway and Bloor Street crossings. The results from the PCSWMM model match well with those from the VO4 model, providing similar peak flows and overall shape. Less volume is shown in the PCSWMM hydrograph due to attenuation and storage simulated in the overland system.

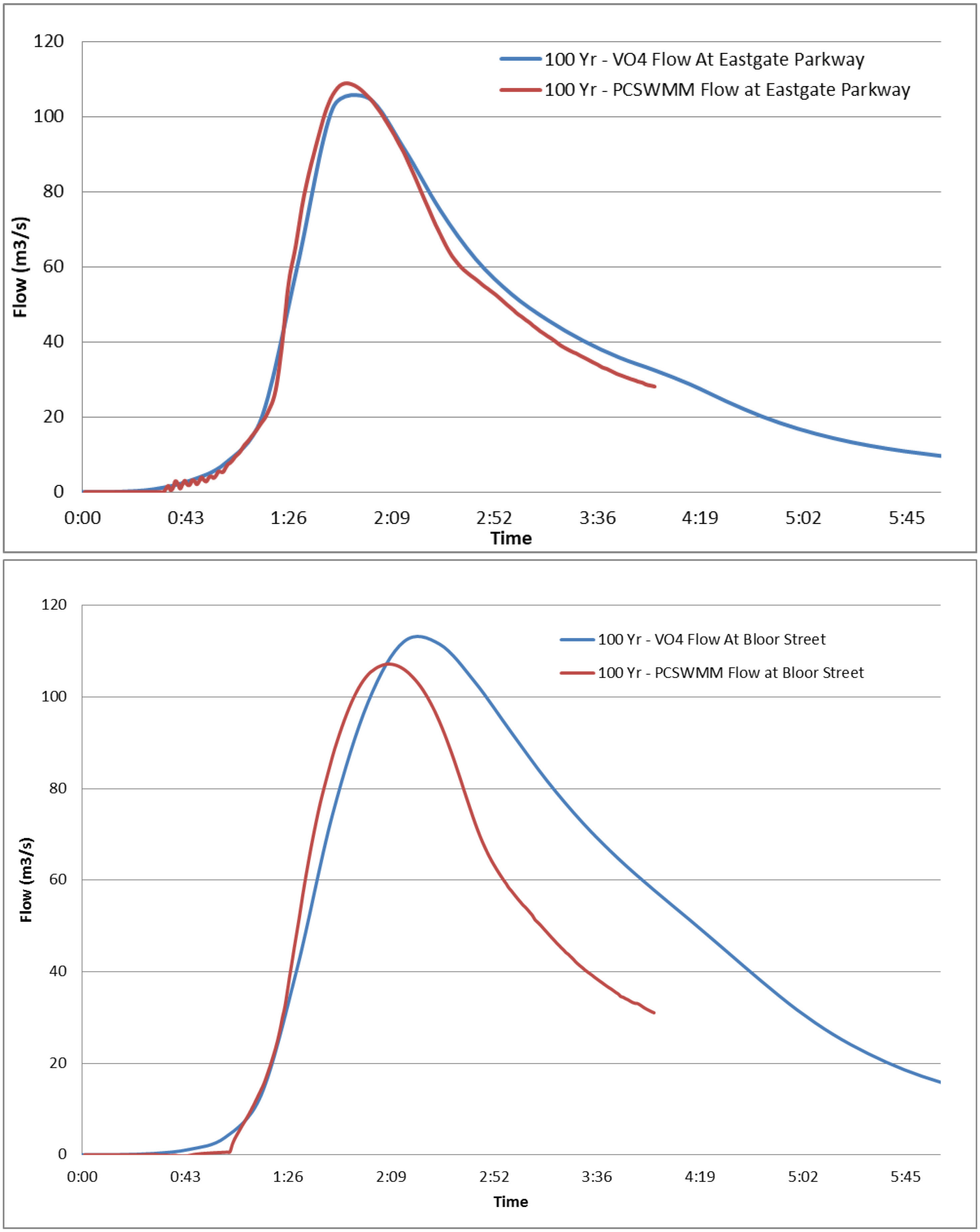


FIGURE 13 Visual OTTHYMO and PCSWMM Hydrograph Comparison

4.2.2 Comparison of Flow Volumes to Visual OTTHYMO

In addition to checking the peak flows and shape of the hydrograph, flow volumes from PCSWMM were also compared to the VO4 model. Table 4 summarizes the volume comparison for the 100-year design storm.

TABLE 4 Flow Volumes at Model Outlet compared to Visual OTTHYMO Model

Water Balance Component	Upper Model (m^3)	Lower Model (m^3)
Visual OTTHYMO v.4 Outflow	1,001,507	1,491,474
PCSWMM		
Storage on Surface	381,290	623,530
Riverine Outflow	624,337	761,290
Dixie/Dundas Spill Location	-	112,239
Overland Outflow (outside of watershed)	27,130	11,066
TOTAL	**1,032,757**	**1,508,125**
Percent Difference in Volume	3.1%	1.1%

The volume of flow accounted for in the Upper Model is within approximately 3% of that in the VO4 model at the same location. Similarly, the volume of water in the Lower Model is within approximately 1% of the VO4 model. Both volume assessments indicate generally good agreement between the two models. This verifies that the infiltration and initial abstractions are properly represented by the multiple catchment methodology.

4.2.3 Comparison of Water Levels from HEC-RAS Model

Water levels in the PCSWMM 2D model were compared against the HEC-RAS model for the 5-year and 100-year storm events. Detailed output for the water levels at each cross-section is provided in Appendix D and a summary is provided in Table 5.

Water levels in the Upper Model are slightly higher overall than the simulated water levels in the HEC-RAS model. This is due to the full 2D approach in which the 3 m cell size in the river reduces the channel definition as compared to HEC-RAS. The lack of definition is most pronounced in the Upper Model as the width of the channel is smaller and is not well represented within the 3 m mesh size. The average difference in water level in the Upper Model for the 100-year storm and 5-year storm were 0.30 m and 0.19 m, respectively.

A lesser difference is noted between the water levels in the Lower Model and the HEC-RAS model due to the larger channel width which is better represented with the 3 m 2D mesh. The average difference in water level in the Lower Model for the 100-year and 5-year storm was 0.01 m and 0.14 m, respectively.

Most differences in water levels between the two models are found at bridges and culverts along road crossings. As noted in *Investigation of Differing Water Surfaces in HEC-RAS and PCSWMM 1D Models* (Matrix 2018c), this is a common issue found when comparing water level results between HEC-RAS and PCSWMM models due to the differences in representation of the openings and losses.

TABLE 5 Summary Water Levels in HEC-RAS and PCSWMM for 100-year and 5-year Events

Model/Event	Average Difference in Water Level (m)	Median Difference in Water Level (m)
Upper Model - 100-year event	0.30	0.27
Upper Model - 5-year event	0.19	0.18
Lower Model - 100-year event	0.01	0.07
Lower Model - 5-year event	0.14	0.13

4.2.4 Comparison of July 8, 2013 Event

Although the HWMs could not be used for validation of the model for the July 8, 2013 event, other methods of comparison were reviewed. Flood calls received from the City were mapped against the modelled water depths for a visual comparison (Map 8 and Map 16 in Appendix E). Overall, there is good consistency between the simulated results and the flood calls received on July 8, 2013. Areas where flooding is shown but no calls were received generally align with commercial developments and rental properties where the flood reports are typically not provided to the City.

No observed flow data from the July 8, 2013 event is available for Little Etobicoke Creek. Flows in the creek from the PCSWMM model were compared against a previous assessment of July 8, 2013 observations (TRCA 2014). Upstream of the spill location at Dixie Road and Dundas Street, peak flows in the PCSWMM model reach 133.5 m^3/s, which is within 3% of the flow predicted by TRCA based on the VO4 model for the area (TRCA 2014).

Matrix also reviewed the PCSWMM results in conjunction with the Phase 1 MIKE FLOOD results for the July 8, 2013 event. However, due to differences between the modelling setup it is difficult to compare the results of the two July 8, 2013 simulations.

The flow node from which peak flows were extracted for the MIKE FLOOD model (TRCA flow node 2.12) is downstream of the identified spill area. This flow node was selected to maintain consistency with the previous MIKE FLOOD study (MMM 2015) and provides a conservative estimate of peak flows within the Dixie-Dundas Special Policy Area (SPA) using quasi-steady-state analyses. On the other hand, the PCSWMM model used Chicago storm hyetograph input applied to the riverine and catch-basin-scale subcatchments. Therefore, the runoff was generated at each catch basin and a number of flow nodes along the creek.

Also, considering that the Phase 1 study was specifically focused on the spill from Etobicoke Creek into the Dixie-Dundas SPA, significant effort was put into ensuring the spill conditions were accurately modelled. In doing so, the flood control berm along the right bank just east of Dixie Road and the flood control wall on the right bank near Queen Frederica Drive were included in the MIKE FLOOD model, and the boundary condition was set quite far away. In the PCSWMM model, the ground elevations of the flood control features were not specifically altered from the LiDAR data and the 2D free outfall location was close to the spill location. These differences in model setup contribute to differences in the amount of modelled spill. The MIKE FLOOD and PCSWMM models were developed for different purposes and each model is appropriate for its intended use.

4.3 Model Resiliency

A sensitivity assessment was conducted to evaluate the resiliency of the modelling assumptions. Two additional model scenarios were included in the flood characterization assessment. The two scenarios were modifications upon the completed 100-year, 4-hour design storm simulation. The first scenario was a test on the assumed capacity of the minor system to convey a flow greater than the 2-year peak rainfall intensity. The second scenario determined the resiliency of the system to increasing flow trends related to climate change. Methods for both scenarios are described in Section 4.3.1.

4.3.1 Minor System Modification

At a meeting with TRCA and the City, it was recommended that a sensitivity analysis be completed on the assumed capacity of the minor system. The intent of this assessment was to determine the effects on the results if the minor system is able to accommodate higher flows than those produced by the assumed 2-year peak rainfall intensity of 19 mm/hour from the previous Malton study (Matrix 2018b).

Several factors determine the capacity of the minor system, including:

- design capacity: what the City's current storm sewer systems are designed to convey
- pipe conveyance capacity: what is the maximum flow the current sewer system can convey
- inlet capacity: how much water can make it into the minor system through the catch basins

The design storm intensity-duration-frequency curves were reviewed for the City. A summary of the intensities for each time of concentration and design storm are provided in Table 6. Currently the City's storm sewer design follows the rational method with a post-development time of concentration of 15 minutes (top 50 m) and 10-year design storm frequency (City of Mississauga 2009). However, the time of concentration increases through the downstream reaches of the sewer system; therefore, the design intensity decreases throughout the system (based on Rational Methods design). Based on the age of the infrastructure and the flood calls received during the July 8, 2013 event, it is unlikely the current storm sewer system was designed to the 10-year, 15-minute time of concentration intensity of 99 mm/hour.

Therefore, a review of the pipe conveyance capacity was completed to provide a more reasonable intensity for the minor system modification.

TABLE 6 Peak Rainfall Intensity - City of Mississauga Design Storms

Time of Concentration (minute)	Intensity (mm/hour)			
	2-year	5-year	10-year	25-year
5	105	140	173	199
10	75	101	125	143
15	60	81	99	114
20	50	67	83	95
25	43	58	72	83

The full flowing capacity of the storm system pipes were estimated for ten locations in the Lower Model domain (Table 7). The full flowing capacity of the pipe was calculated using Manning's pipe flow equation with the City's pipe diameters, average pipe slope (1%), and roughness coefficient of 0.013. The full flow capacity was converted to a maximum rainfall intensity using the City's Rational Method equation with the calculated upstream sewershed area and an average runoff coefficient of 0.75. As shown in Table 7, the maximum conveyance intensity ranged from 41.3 to 98.8 mm/hour, with an average intensity of 59.3 mm/hour.

TABLE 7 Summary of Full Flow Pipe Capacity and Conveyance Intensities

Conduit Name	Location	From Manhole	To Manhole	Catchment Area (ha)	Pipe Diameter (mm)	Pipe Flow Capacity (m^3/s)	Maximum Conveyance Intensity (mm/hour)
C16925	Pinesmoke Crescent	12956	12941	2.71	450	0.29	50.0
C17007	Warner Way	13643	13638	1.67	450	0.29	81.4
C17012	Highgate Crescent	13647	13659	1.11	300	0.10	41.3
C19253	Larny Court	12434	12435	1.37	450	0.29	98.8
C17004	Gryphon Mews	12449	12452	1.27	375	0.18	65.3
C22759	Sugar Maple Court	13534	12458	3.25	450	0.29	41.6
C09420	Golden Orchard	13126	13127	11.1	825	1.44	61.1
C14952	Gatliff Avenue	3026	3403	0.89	300	0.10	51.9
C06420	Havenwood Drive	13064	13083	50.4	1,350	5.34	50.4
C08451	Bluestream Crescent	12841	12861	2.66	450	0.29	50.9
			AVERAGE	**7.64**	**540**	**0.86**	**59.3**

The inlet capacity of the minor system relies on the number of catch basins within the sewershed, the catchment design, and location on the roadway. Relationships are available for capture performance of gutters along roadways (City of Burlington 1998) and at road sags (MTO 1997). To estimate the inlet capacity of the system without simulating flows or depths, a range of inlet capacity (0.06 to 0.20 m^3/s per catch basin) for the ten locations in the Lower Model domain was calculated in Table 8.

TABLE 8 Summary Inlet Flow Capacities

Conduit Name	Location	Catchment Area (ha)	Pipe Flow Capacity (m^3/s)	Number of Catch Basin Inlets	Inlet Flow Capacity (0.06 m^3/s per inlet)	Inlet Flow Capacity (0.20 m^3/s per inlet)
C16925	Pinesmoke Crescent	2.71	0.29	6	0.36	1.20
C17007	Warner Way	1.67	0.29	4	0.24	0.80
C17012	Highgate Crescent	1.11	0.10	4	0.24	0.80
C19253	Larny Court	1.37	0.29	6	0.36	1.20
C17004	Gryphon Mews	1.27	0.18	7	0.42	1.40
C22759	Sugar Maple Court	3.25	0.29	9	0.54	1.80
C09420	Golden Orchard	11.1	1.44	34	2.04	6.80
C14952	Gatliff Avenue	0.89	0.10	4	0.24	0.80
C06420	Havenwood Drive	50.4	5.34	95	5.70	19.00
C08451	Bluestream Crescent	2.66	0.29	12	0.72	2.40
	Average	**7.64**	**0.86**	**18**	**1.09**	**3.62**

Based on a review of the City's storm sewer design standards, current pipe capacities, and catch basin inlet capacities, the most appropriate estimate of the current storm sewer conveyance is the full flowing pipe capacities. Therefore, the average intensities of 59.3 mm/hour from the ten reviewed pipe locations was used as the modified minor system hyetograph abstraction. The modified 100-year, 4-hour storm hyetograph is provided in Appendix C.

Development in the Upper Model is more recent and may have an increased minor system capacity than was found at the ten locations in the Lower Model. However, as the majority of the residential flood concerns are in the Lower Model, it is more appropriate to test the system with the capacity constraints found in the Lower Model residential area.

It should also be noted that the conveyance capacity assumes no limitations such as backwater into the system, debris on the inlets or obstructions in the pipes. Therefore, the 59.3 mm/hour may be conservative from a design perspective but more realistic or an overestimate of the capacity during a real-time event.

4.3.2 Climate Change

The climate change analysis run was completed as sensitivity on the 100-year storm event. Generally, General Circulation Models (GCMs; i.e., the global climate change models) are used for future climate temperature forecasts, but they typically do a poor job of predicting event scale rainfall. There are applications for predicting future intensity duration frequencies based on down-scaled versions of these GCMs; however, the GCMs and their inherent assumptions remain a large source of uncertainty.

The Clausius-Clapeyron relationship states that with increased air temperature there is an increased capacity for water vapour in the air. This relationship can be used to determine future rainfall potential. High-intensity summer storm cells do not retain moisture in the atmosphere but rather precipitate out all of the available water vapour (Allen and Ingram 2002, Westra et al. 2014). Therefore, for consideration of typical design storms in southern Ontario, a direct relationship between temperature and rainfall can be established. This relationship is considered to be a 7% increase in rainfall per degree Celsius (Panthou et al. 2014).

The climate change analysis for the Little Etobicoke Creek sensitivity run assumed the following:

- GCM predicted temperature increase (to year 2050) = 3.1°C
- 3.1°C x 7% = 22% increase in event rainfall = 1.22 scaling factor
- current 100-year 4-hour Chicago volume for City of Mississauga = 79.4 mm
- future (2050s) 100-year 4-hour Chicago volume for City of Mississauga = 79.4*1.22 = 96.9 mm

The 100-year, 4-hour storm climate change hyetograph is provided in Appendix C. The initial 19 mm/hour minor system abstraction was subtracted from the minor system.

5 MODEL RESULTS

Model results for the Regional, July 8, 2013, and 2- through 100-year design storms (including sensitivity scenarios) are provided in Appendix E. Maps for each simulation include maximum depth, maximum velocity, depth x velocity and overall flood risk.

Flood risk characterization and mapping is typically undertaken with consideration of three risk factors: depth, velocity, and depth-velocity product. In accordance with current MNRF practices, the following risk mapping criteria apply (Table 9). Low-risk areas are inundated, but vehicular and pedestrian access and egress are still feasible. Medium-risk areas do not permit vehicular access and egress, 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 Maps 1 through 16 and on the additional scenarios Maps CC-6, CC-14, MM-6, and MM-14.

TABLE 9 Flood Risk Criteria

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

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

6 NEXT STEPS

The existing condition design storm simulations are complete and flood risk characterization has been undertaken. The next steps include preliminary screening of flood cluster areas and identification of flooding mechanisms.

7 REFERENCES

Allen M.R. and W.J. Ingram. 2002. "Constraints on future changes in climate and the hydrologic cycle." *Nature 419*: 228–232. September 2002.

City of Burlington. 1998. *Hydraulic Performance of Catchbasin Covers Located in Gutters*. Drawing No. S-5D-3, Rev. 2. June 1998.

City of Mississauga. 2009. *City of Mississauga Transportation and Works Department Development Requirements Manual*. Mississauga, Ontario. January 2009.

Computational Hydraulics International (CHI). 2018. *PCSWMM Manual*.

Matrix Solutions Inc. (Matrix). 2018a. *Progress Report #1 - Floodplain Spill Assessment, Flood Evaluation Study, Little Etobicoke Creek*. Prepared for City of Mississauga. Guelph, Ontario. January 2018.

Matrix Solutions Inc. (Matrix). 2018b. *Malton Flood Characterization Study*. Prepared for Toronto and Region Conservation Authority. Guelph, Ontario. March 2018.

Matrix Solutions Inc. (Matrix). 2018c. *Investigation of Differing Water Services in HEC-RAS and PCSWMM 1D Models*. Prepared for City of Mississauga and Toronto and Region Conservation Authority. Guelph, Ontario. January 4, 2018.

Metropolitan Area Planning Council (MAPC). 2015. *Neponset Outfall Catchment Analysis*. Boston, Massachusetts. February 2015. 30 pp. 2015.

Ministry of Transportation of Ontario (MTO). 1997. *MTO Drainage Management Manual*. Drainage and Hydrology Section, Transportation Engineering Branch, Quality and Standards Division. 1997.

MMM Group Limited (MMM). 2015. *Floodplain Mapping in Applewood and Dundas/Dixie Special Policy Area, Little Etobicoke Creek*. Prepared for Toronto and Region Conservation Authority, Report No. 1412606-000. Mississauga, Ontario. January 2015.

MMM Group Limited (MMM). 2013. "Etobicoke Creek Hydrology Update." Draft prepared for the Toronto and Region Conservation Authority. April 2013.

Panthou G. et al. 2014. "Relationship between surface temperature and extreme rainfalls: a multi timescale and event based analysis." *Journal of Hydrometeorology 15*: 1999–2011. 2014.

Toronto and Region Conservation Authority (TRCA). 2014. *Estimated Flows of July 8, 2013 Within Etobicoke Creek using 2013 Etobicoke Creek Hydrology Model*. Vaughan, Ontario. June 18, 2014.

Westra S. et al. 2014. "Future changes to the intensity and frequency of short-duration extreme rainfall." *Reviews of Geophysics 52* (*3*): 522–555. 2014.

APPENDIX A
Historical Aerial Photographs

APPENDIX A

HISTORICAL AERIAL PHOTOGRAPHS

1954 – Confluence to Eastgate Parkway

Source: University of Toronto Libraries
(https://mdl.library.utoronto.ca/collections/air-photos/1954-air-photos-southern-ontario/index)

Figure A1 1954 Historical Aerial Photograph

1970 – Between Dundas Street and Burhamthorpe Road

Source: City of Toronto (http://jpeg2000.eloquent-systems.com/toronto.html?image=ser12/s0012_fl1970_it0059.jp2)

Figure A2 1970 Historical Aerial Photograph

1970 – Between Burhamthorpe Road and Eastgate Parkway

Source: City of Toronto (http://jpeg2000.eloquent-systems.com/toronto.html?image=ser12/s0012_fl1970_it0080.jp2)

Figure A3 1970 Historical Aerial Photograph

1985 – Between Dundas Street to Rathburn Road

Source: City of Toronto (http://jpeg2000.eloquent-systems.com/toronto.html?image=ser12/s0012_fl1985_it0041h.jp2)

Figure A4 1985 Historical Aerial Photograph

1985 – Between Eastgate Road and Matheson Boulevard East

Source: City of Toronto (http://jpeg2000.eloquent-systems.com/toronto.html?image=ser12/s0012_fl1985_it0040j.jp2)

Figure A5 1985 Historical Aerial Photograph

APPENDIX B
Minor System Abstraction Approach

APPENDIX B

MINOR SYSTEM ABSRACTION METHOD AND VERIFICATION

1 MINOR SYSTEM SUBCATCHMENTS (MATRIX 2018, P.11)

To accurately assess the overland drainage system without specifically modelling the minor sewer system in PCSWMM, the flow expected to be conveyed by the minor system was separated from the total runoff hydrographs during rainfall events. Given the age of the subdivision we assumed that the minor system was designed to convey the 2-year design storm, and as such, the 2-year storm peak rainfall intensity was extracted from the existing VO4 model for Mimico Creek. The 2-year storm sewer capacity assumption was validated through the inclusion of the minor system in the areas of the pumping station and the historic Village of Malton.

The 2-year peak rainfall intensity is approximately 19 mm/hr. As this was assumed to be the minor system capacity, it was subtracted from the rainfall hyetographs for the remaining design storm events. The resulting hyetographs were applied to each of the small urban catchments to generate the runoff hydrographs representing overland flow (the green portion of the hyetograph in the provided figures). Figure 1 indicates the hyetographs used for the July 8, 2013 storm event.

While the minor system flow was abstracted from the urban overland flow model, these flows still need to be accounted for in the riverine portion of the model. As such, lumped sewershed catchments were included to represent the minor system outflows to the river at each outlet; these are illustrated as the large colour-coded areas on Figure 5. Instead of being connected to catch basins, these minor system catchments were connected directly to the sewer outlets. The portion of the hyetograph which was subtracted from the overland catchments was applied to these sewershed catchments (the blue portion of the hyetograph in the provided figures).

The combination of inputs to the discretized urban catchments and the lumped sewershed catchments represent the complete event hyetograph within the study area. An example of this division is provided in Figure 1 for the July 8, 2013 event (for both rain gauges within the 2D model domain).

This methodology could be adjusted to abstract the 5-year flow (or other storms) to explore the effect that a different design capacity would have on the model results. However, given anecdotal information of system performance combined with the known age of infrastructure, the 2-year flow abstraction is considered conservative and appears reasonable for the overland flow assessment at this time. Changes in the amount of flow accounted for in the minor system will not have a significant impact on the riverine water levels; however, some changes would be expected in surface flows within the urban areas.

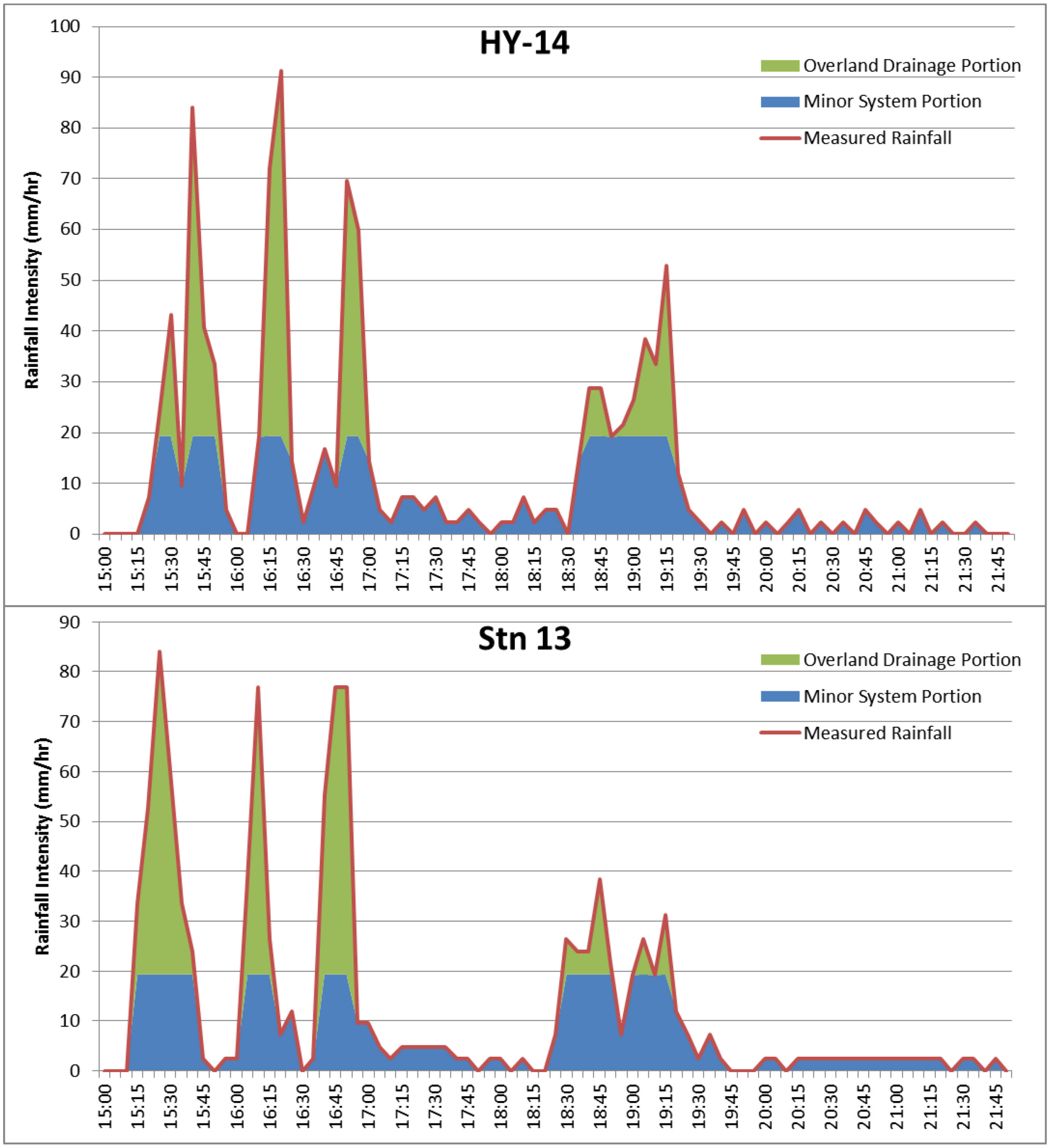


FIGURE 1 July 8, 2013 Hyetographs

2 RUNOFF ABSTRACTION CHECK (MATRIX 2018; P.34)

The addition of the minor system in the neighbourhood to the west of the pumping station enabled verification of the appropriateness of the 2-year abstraction assumption.

Flow hydrographs for a number of pipes within the minor system area were exported from the model results. The contributing catchment areas to each pipe segment were also determined and were used to calculate the peak intensity in the pipes. The peak intensity was then compared to the assumed 19 mm/hr 2-year abstraction value. Table 1 provides a summary of the findings.

TABLE 1 Runoff Abstraction Check Summary

Conduit Name	Location	From MH	To MH	Contributing Area (ha)	Peak Flow (m^3/s)	Peak Intensity (mm/hr)
C878846	Princess St.	PRI_MH2	PRI_MH3	32.3	0.92	10.2
C878875	Knaseboro St.	KNA_MH3	HUL_MH3	2.4	0.03	4.6
C878837	Sledman St.	SLE_MH5	HUL_MH5	3.6	0.25	25.3
C878883	North Alarton St.	NAL_MH3	HUL_MH4	12.2	0.85	25.2
C878884	Harrow St.	HAR_MH2	HUL_MH8	1.03	0.12	43.4
C878849	**Scarboro St. Outlet**	**SCA_MH1**	**SCA_MH2**	**67.4**	**3.19**	**17.0**

The results shown in Table 1 indicate a wide range of peak intensities in the pipe system ranging from 4.6 mm/hr to 43.4 mm/hr. Upon further review of the catchments, it is expected that this variation in intensity is due to the catchment delineation, wherein some catchments include an entire block of residences. One possible explanation for this may be that the subdivision design assumed that the contributing area to the storm sewers were split down abutting rear yards and conveyed toward the front of the lots to the appropriate road; however, in reality, based on the LiDAR data some catchments encompass entire blocks.

To average the discrepancies of the catchment delineation, the peak flows in the entire minor system area was reviewed. Using the minor system outlet at Scarboro Drive as shown in 1, the peak intensity was calculated to be 17 mm/hr, which confirms appropriateness of the 19 mm/hr assumption.

3 REFERENCES

Matrix Solutions Inc. (Matrix). 2018. *Malton Flood Characterization Study*. Prepared for Toronto and Region Conservation Authority. Guelph, Ontario. March 2018.

APPENDIX C
Design Storm and July 8, 2013 Hyetographs

APPENDIX C

DESIGN STORM HYETOGRAPHS

JULY 8, 2013 EVENT

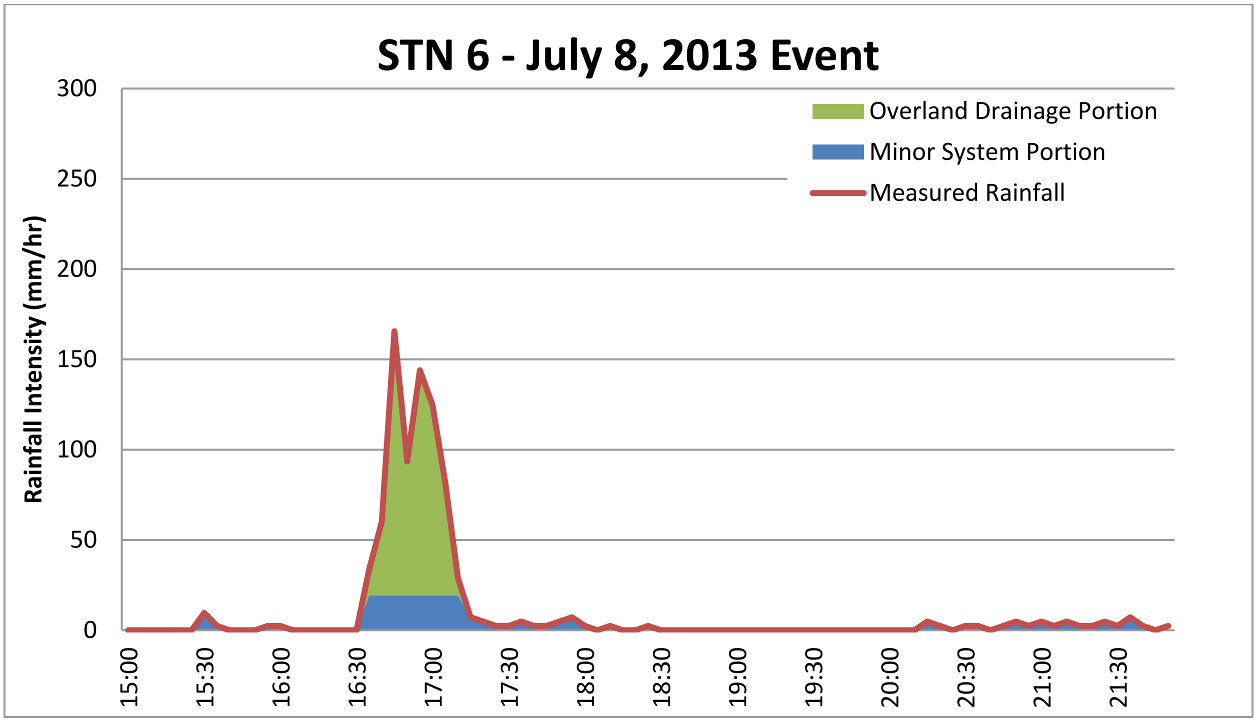


FIGURE C1 STN 6 July 18, 2013 Event

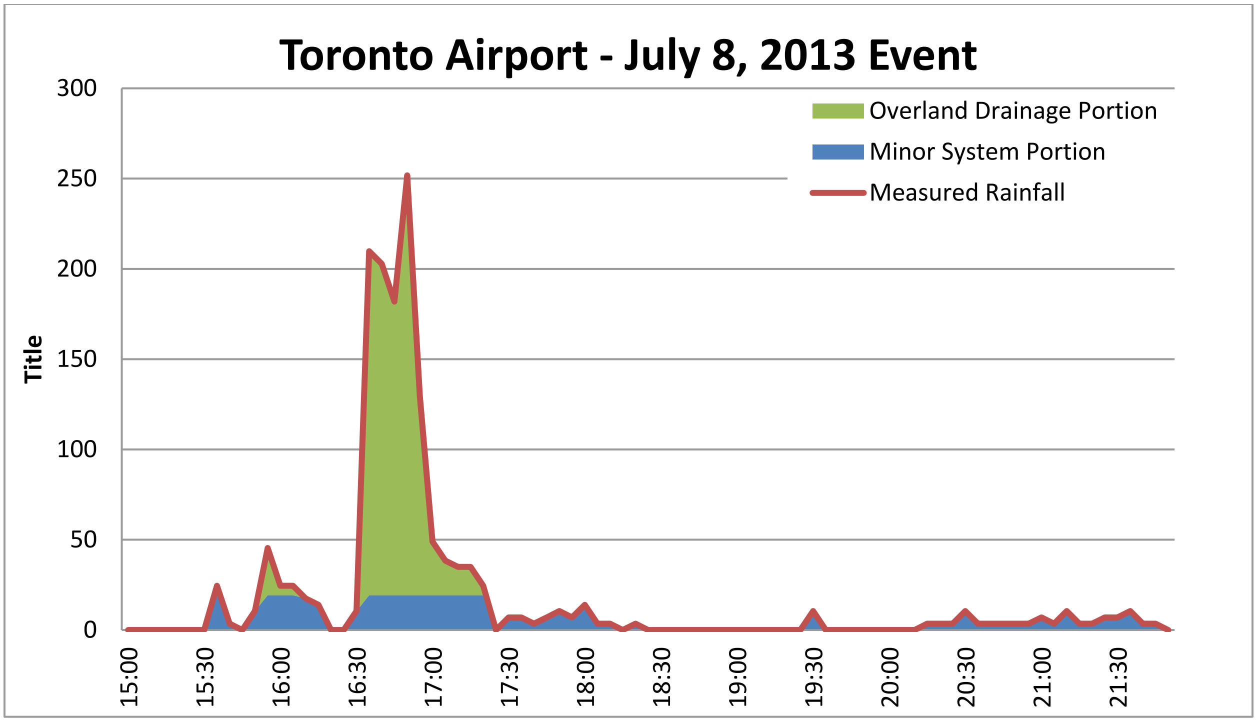


FIGURE C2 Toronto Airport July 8, 2013 Event

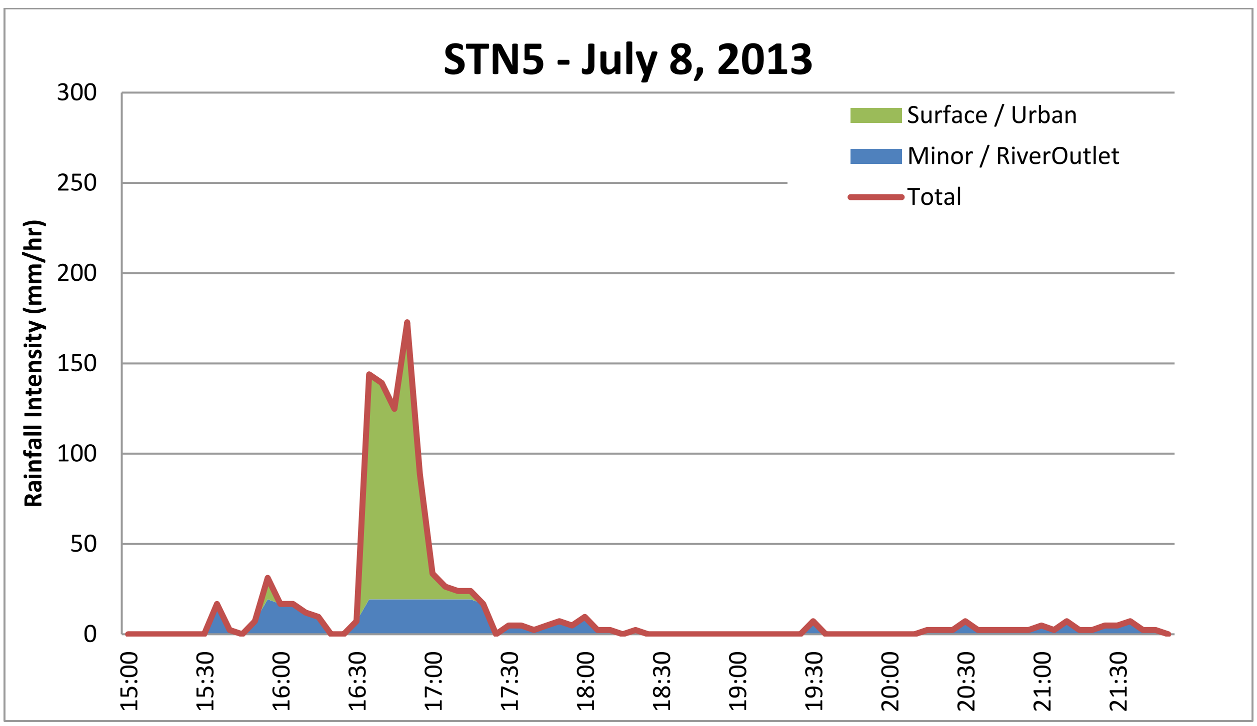


FIGURE C3 STN 5 July 8, 2013 Event

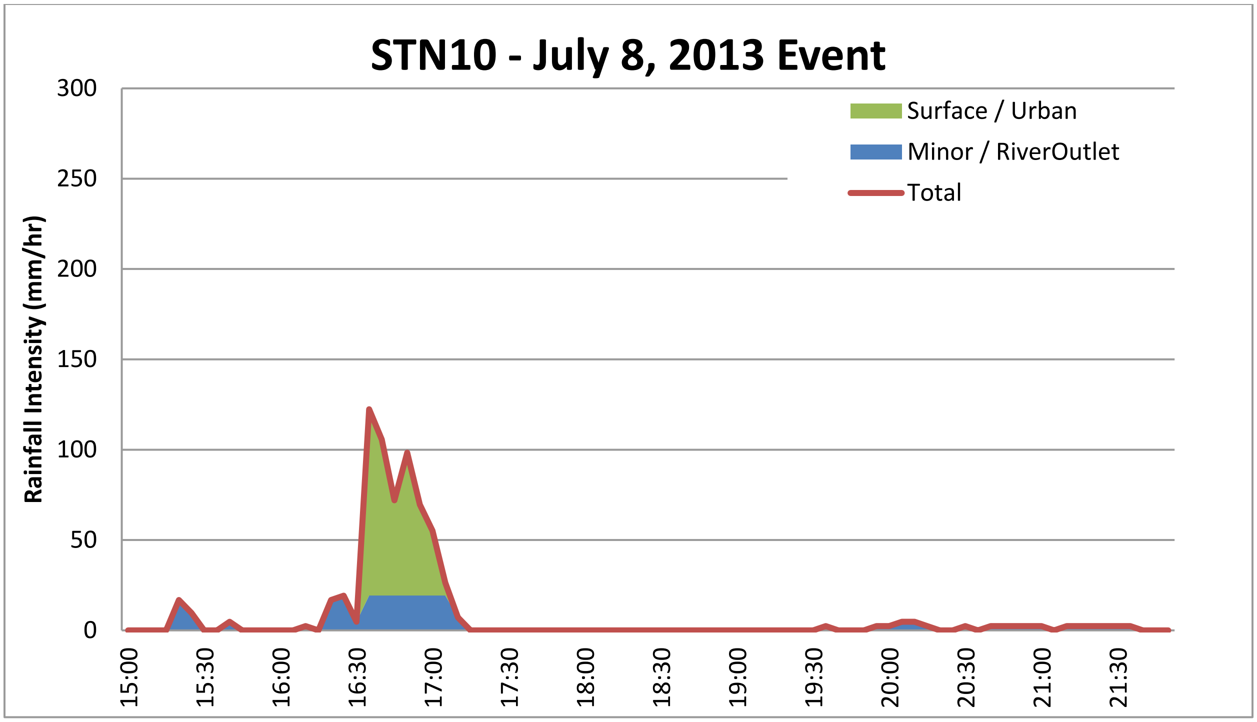


FIGURE C4 STN 10 July 8, 2013 Event

CHICAGO STORM

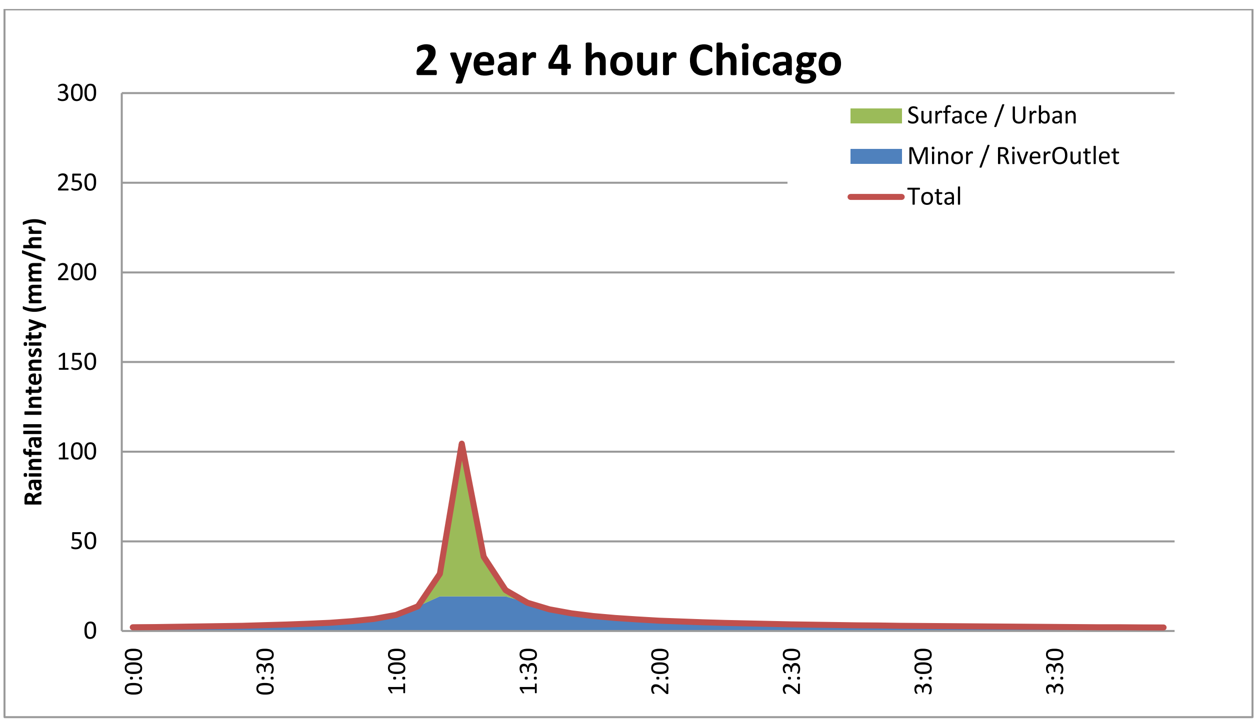


FIGURE C5 2-year 4-hour Chicago Storm

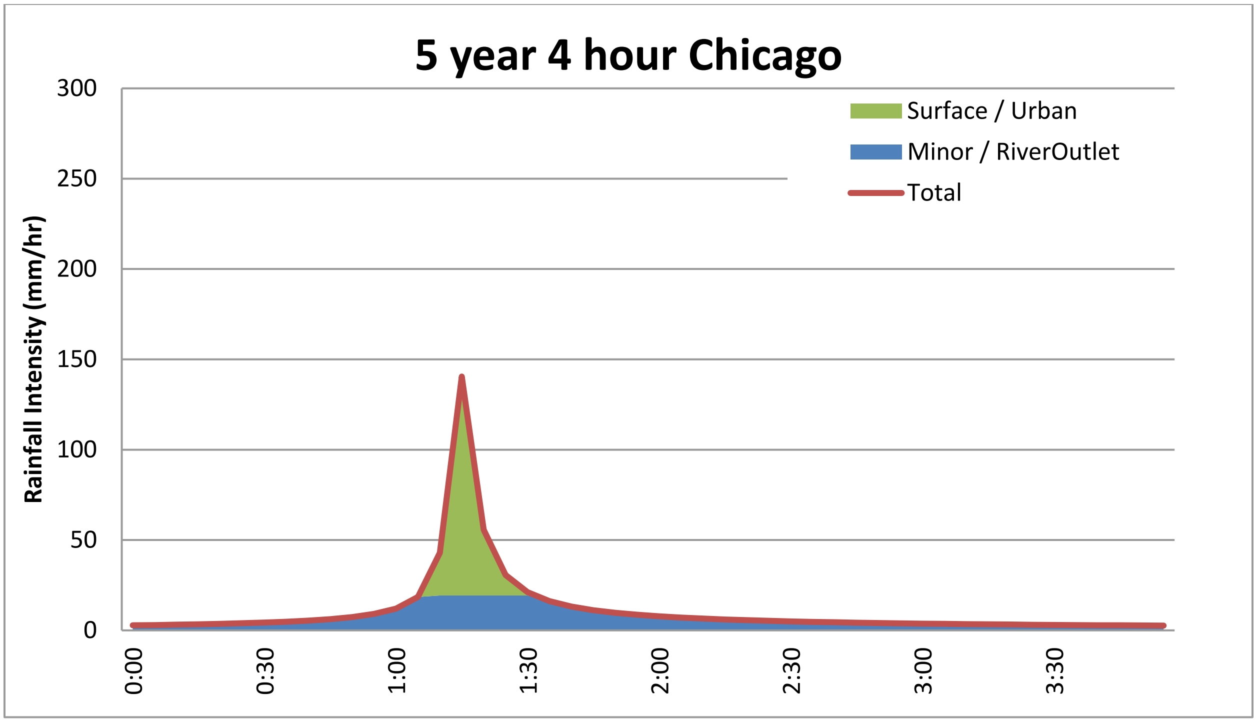


FIGURE C6 **5-year 4-hour Chicago Storm**

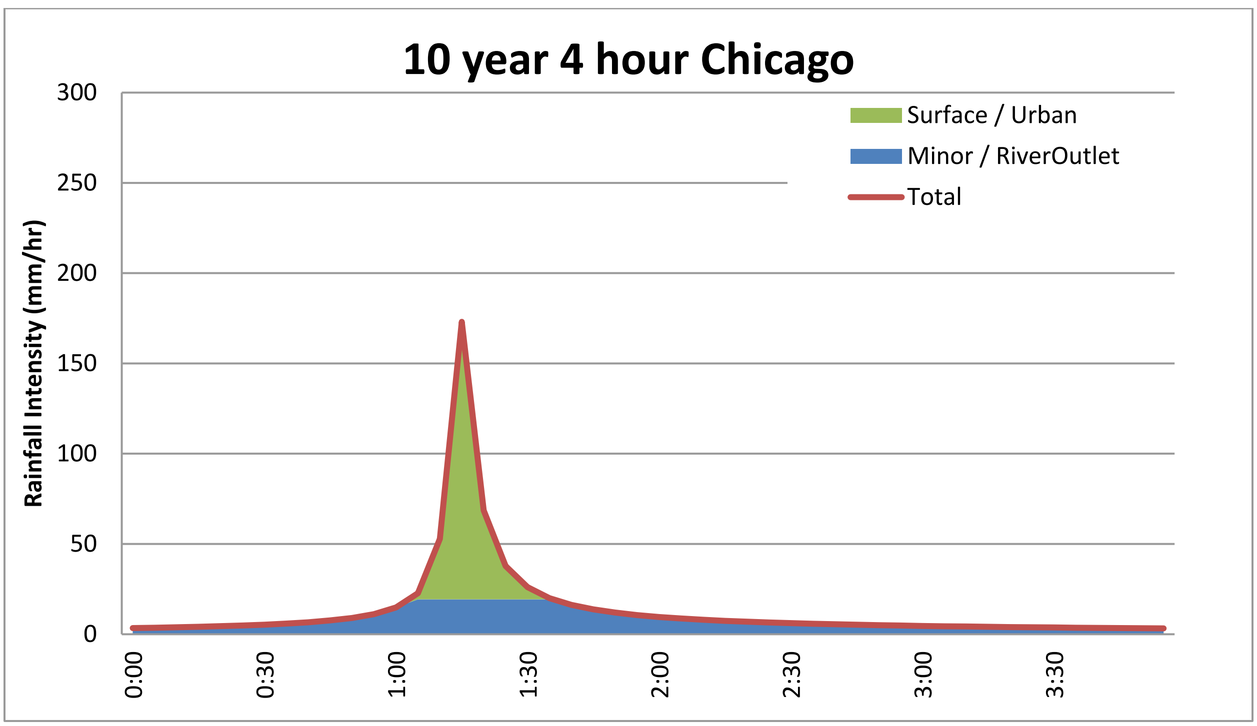


FIGURE C7 **10-year 4-hour Chicago Storm**

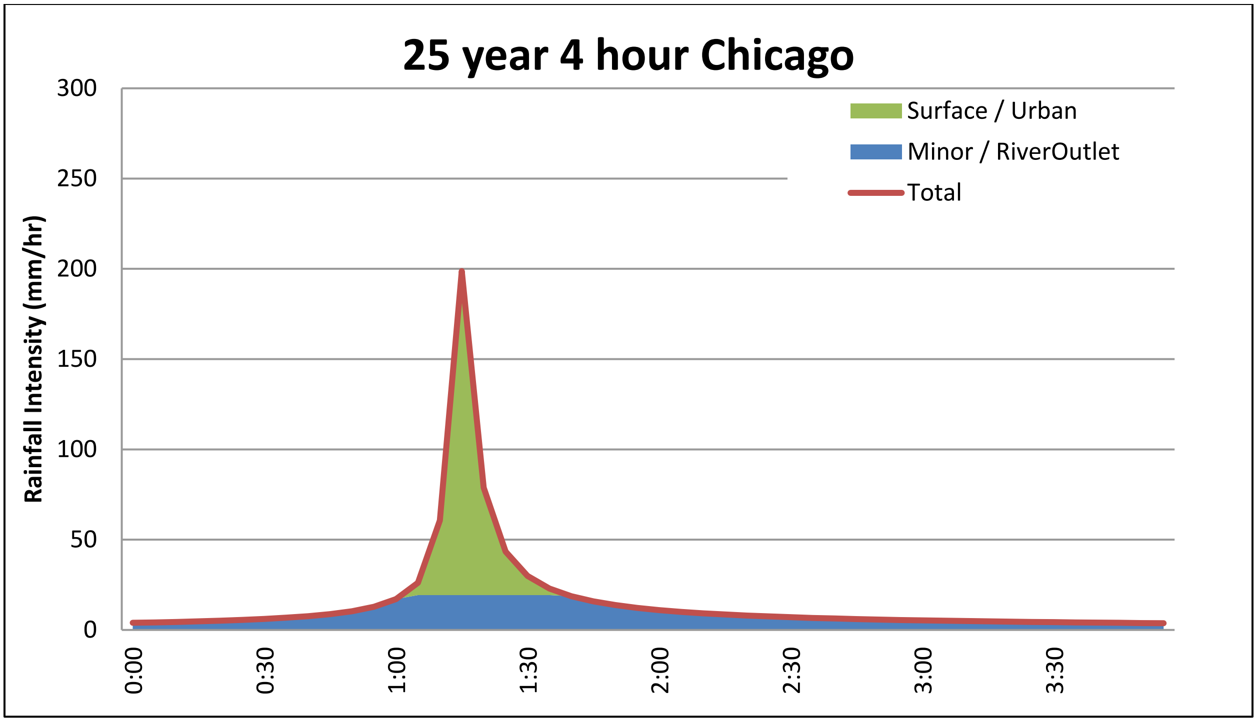


FIGURE C8 25-year 4-hour Chicago Storm

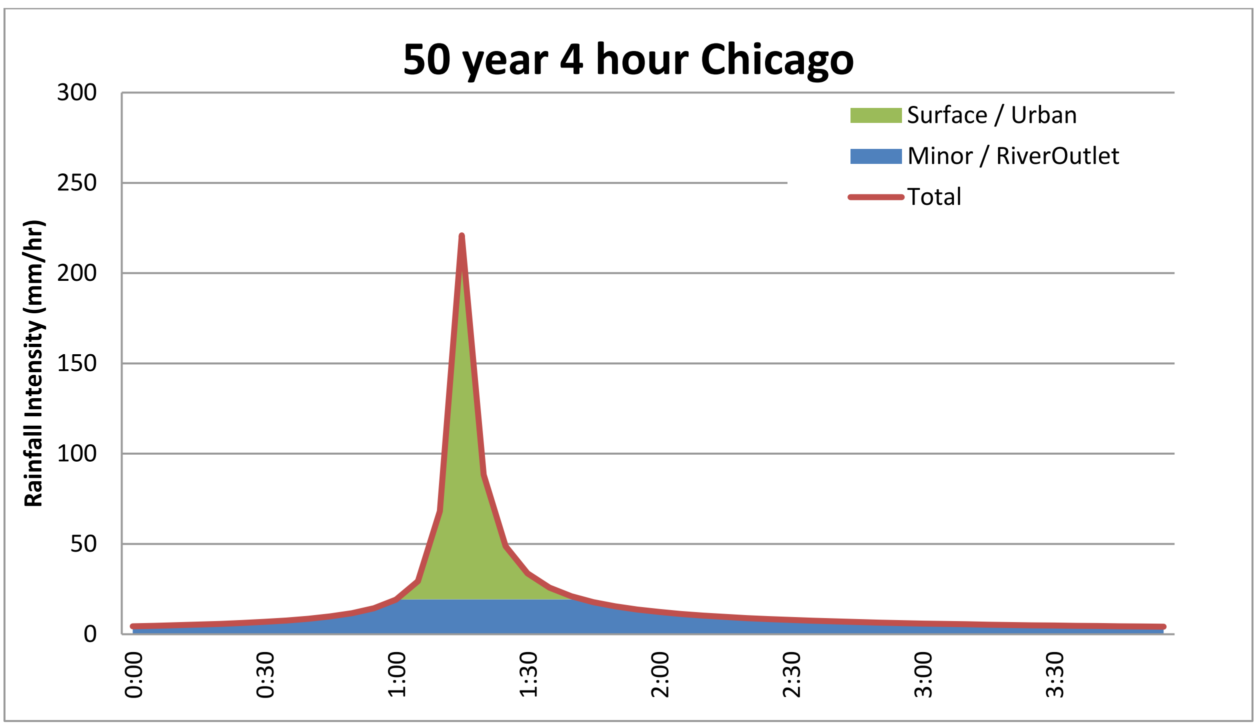


FIGURE C9 50-year 4-hour Chicago Storm

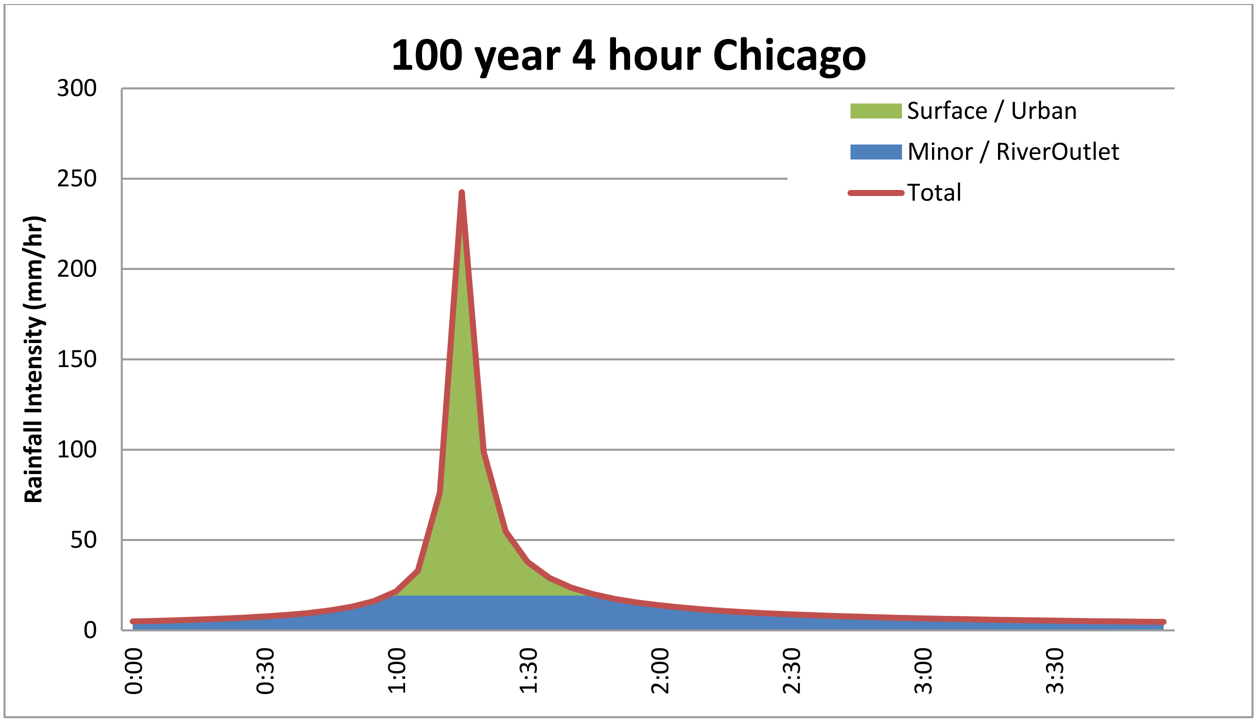


FIGURE C10 **100-year 4-hour Chicago Storm**

HURRICANE HAZEL

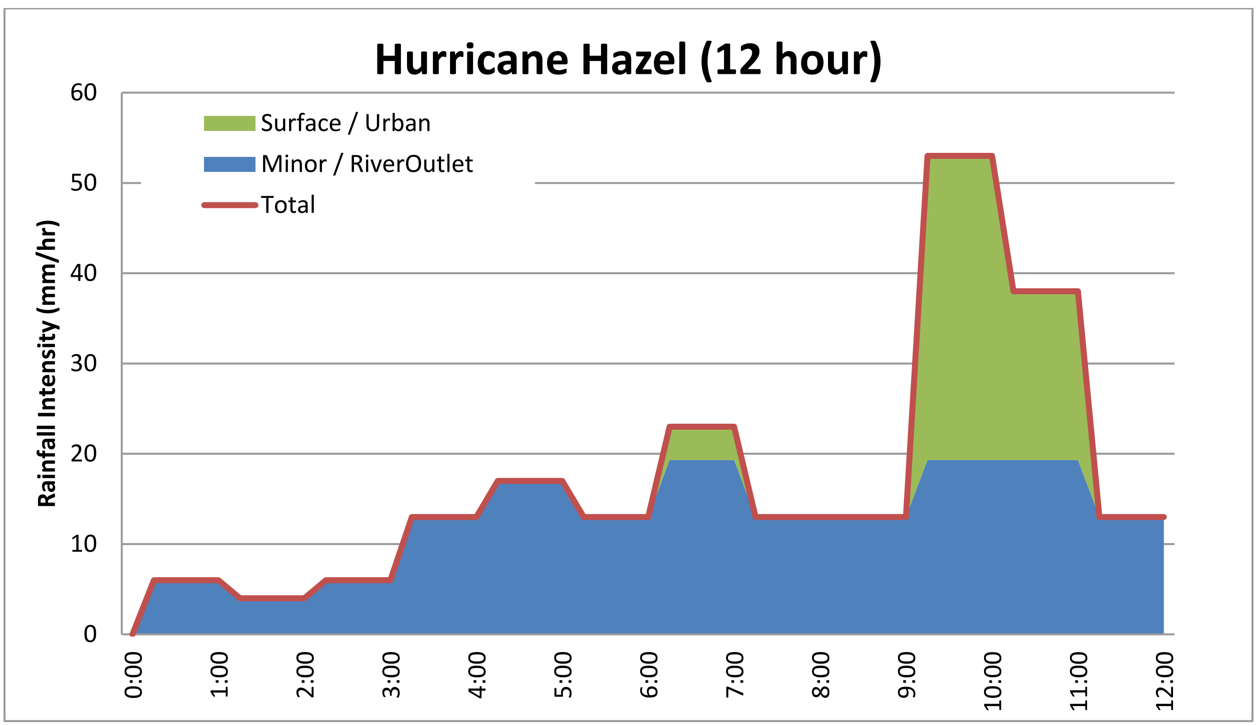


FIGURE C11 **Hurricane Hazel (12-hour)**

100-YEAR, 4-HOUR - MINOR ABSTRACTION MODIFIED

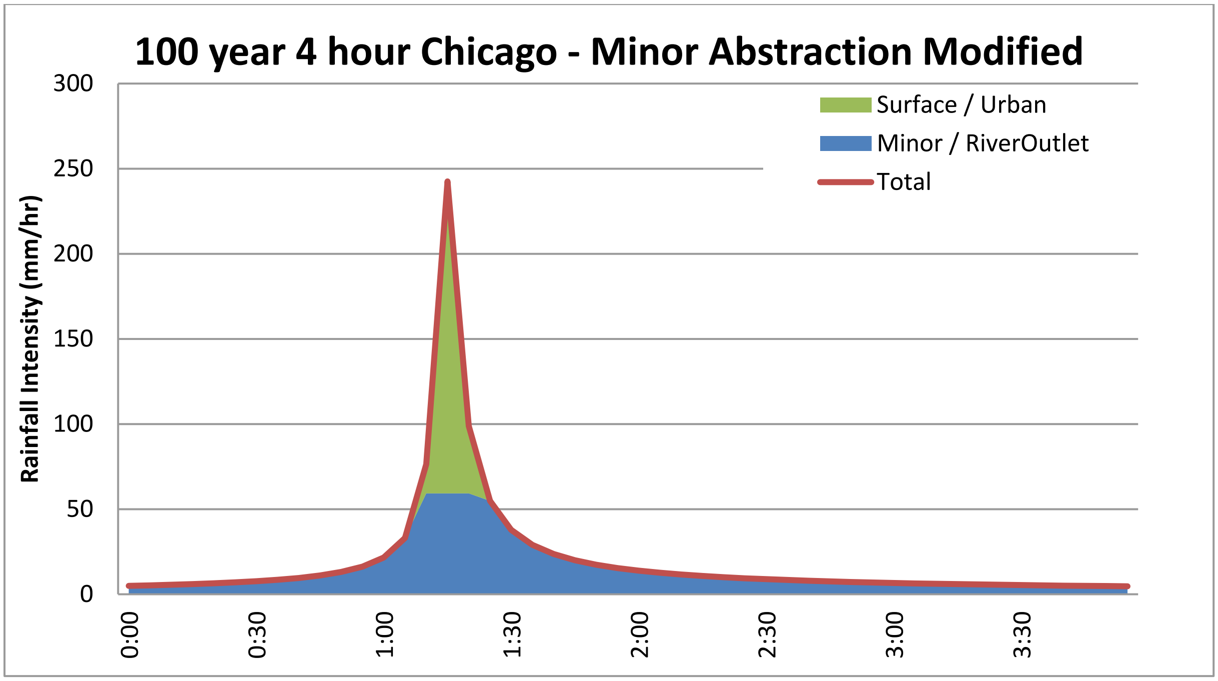


FIGURE C12 **100-year 4-hour Chicago - Minor Abstraction Modified**

100-YEAR, 4-HOUR - CLIMATE CHANGE SCENARIO

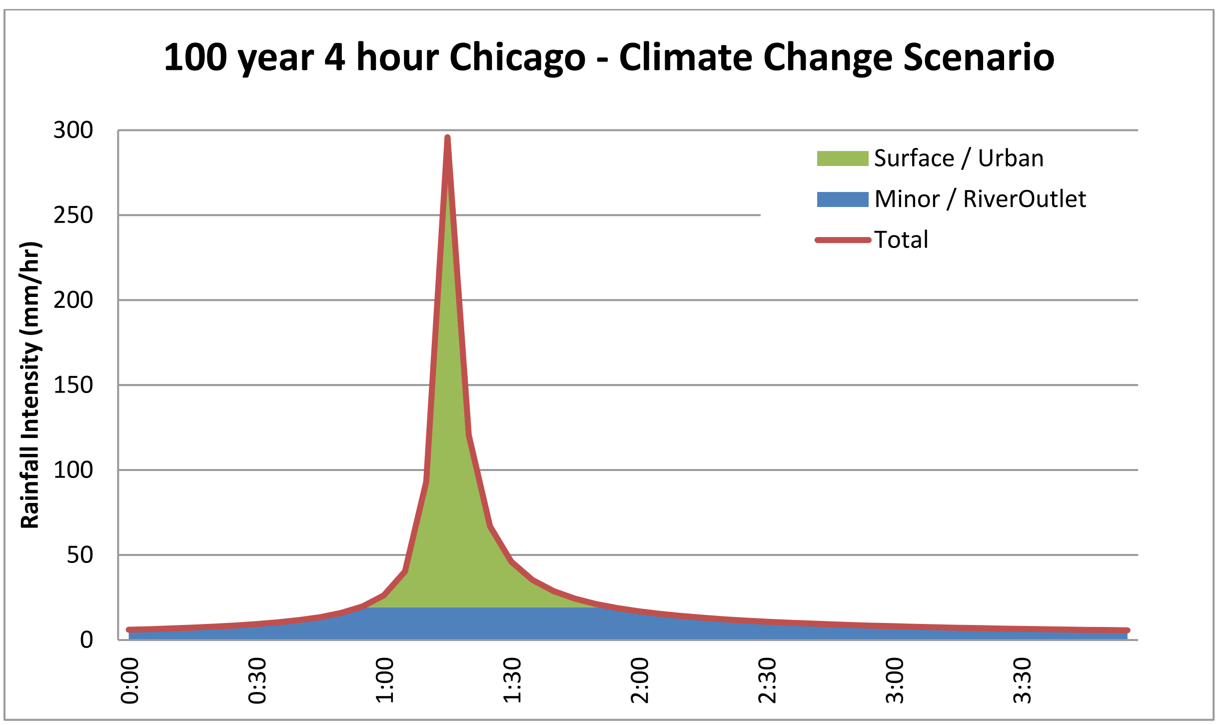


FIGURE C13 **100-year 4-hour Chicago - Climate Change Scenario**

APPENDIX D
HEC-RAS and PCSWMM Water Level Comparison
100-year and 5-year Events

TABLE D1 5-year Storm - Water Level Comparison

HEC-RAS River Station	HEC-RAS Q Total (m^3/s)	HEC-RAS Water Surface Elevation (m asl)	Full 2D PCSWMM Water Surface Elevation (m asl)	Difference (m)
16.36	9.28	156.64	157.28	0.64
16.355	9.28	156.30	156.55	0.25
16.35	11.51	154.27	154.32	0.05
16.34	11.51	152.70	152.94	0.24
16.33	11.51	152.37	152.68	0.31
16.325	**Culvert**			
16.32	13.95	152.22	152.41	0.19
16.31	13.95	152.00	152.04	0.04
16.305	13.95	151.19	151.11	-0.08
16.3	15.91	150.63	150.42	-0.21
16.295	15.91	149.89	149.96	0.07
16.29	15.91	148.37	148.55	0.18
16.28	15.91	147.04	147.49	0.45
16.27	15.91	146.84	147.25	0.41
16.265	**Culvert**			
16.26	20.05	146.34	146.61	0.27
16.25	20.05	146.11	146.29	0.18
16.24	21.68	145.06	145.07	0.01
16.235	21.68	143.62	143.67	0.05
16.23	21.68	142.22	142.35	0.13
16.22	26.75	140.51	140.80	0.29
16.215	26.75	139.93	140.08	0.15
16.21	26.75	138.91	139.42	0.51
16.2	30.38	138.66	139.25	0.59
16.195	**Bridge**			
16.18	31.71	138.26	138.50	0.24
16.17	39.01	137.15	137.43	0.28
16.165	39.01	136.14	136.19	0.05
16.16	46.65	135.71	135.63	-0.08
16.15	46.65	134.98	135.15	0.17
16.14	52.19	134.24	134.25	0.01
16.135	**East Gate Road Culvert - Upper and Lower Model Seperation**			
16.12	52.19	133.94	134.01	0.07
16.115	52.19	133.16	133.56	0.40
16.11	52.19	132.99	133.24	0.25
16.1	52.19	132.96	133.20	0.24
16.095	**Culvert**			
16.09	52.19	132.88	132.81	-0.07
16.08	53.19	132.65	132.69	0.04
16.075	53.19	132.56	132.60	0.04
16.07	53.19	132.11	132.17	0.06
16.06	53.19	132.12	132.08	-0.04

HEC-RAS River Station	HEC-RAS Q Total (m^3/s)	HEC-RAS Water Surface Elevation (m asl)	Full 2D PCSWMM Water Surface Elevation (m asl)	Difference (m)
16.055	**Culvert**			
16.05	53.19	132.08	131.89	-0.19
16.04	53.19	131.74	131.81	0.07
16.035	53.19	131.70	131.72	0.02
16.03	53.19	131.10	131.21	0.11
16.02	53.19	130.18	130.66	0.48
16.01	55.21	129.87	130.60	0.73
8.335	**Bridge**			
8.33	55.21	129.58	130.33	0.75
8.32	55.21	129.62	129.69	0.07
8.319	55.21	129.44	129.63	0.19
8.315	55.21	128.85	129.01	0.16
8.31	55.21	128.21	128.49	0.28
8.3	55.21	127.86	127.50	-0.36
8.29	55.21	127.54	127.25	-0.29
8.285	55.21	126.95	126.92	-0.03
8.28	55.37	126.66	126.78	0.12
8.27	55.37	126.41	126.73	0.32
8.265	**Bridge**			
8.26	55.37	126.29	126.58	0.29
8.25	55.37	126.19	126.42	0.23
8.245	55.37	126.20	126.34	0.14
8.24	55.37	125.74	125.72	-0.02
8.23	54.49	125.51	125.19	-0.32
8.21	54.49	123.23	123.35	0.12
8.2	54.49	123.01	122.94	-0.07
8.195	**Bridge**			
8.19	54.49	122.92	122.70	-0.22
8.18	54.49	122.37	122.14	-0.23
8.17	54.49	121.20	121.07	-0.13
8.16	54.49	120.55	120.56	0.01
8.15	54.49	119.36	119.90	0.54
8.14	54.49	117.88	118.20	0.32
8.13	54.49	116.54	116.52	-0.02
8.121	54.49	115.70	115.89	0.19
8.12	54.49	115.23	115.43	0.20
8.11	54.49	115.15	115.35	0.20
8.1	54.49	115.10	115.32	0.22
8.095	**Culvert**			
8.09	54.49	113.36	113.76	0.40
8.08	54.49	112.97	113.53	0.56
8.07	54.49	111.69	112.18	0.49
8.06	54.49	108.82	109.01	0.19
8.05	54.49	108.45	108.87	0.42
8.045	**CN Railway Bridge**			
			Average Difference (m)	**0.16**
			Median Difference (m)	**0.16**

TABLE D2 100-year Storm - Water Level Comparison

HEC-RAS River Station	HEC-RAS Q Total (m^3/s)	HEC-RAS Water Surface Elevation (m asl)	Full 2D PCSWMM Water Surface Elevation (m asl)	Difference (m)
16.36	15.69	156.86	157.56	0.70
16.355	15.69	156.53	156.80	0.27
16.35	19.40	154.52	154.63	0.11
16.34	19.40	152.98	153.36	0.38
16.33	19.40	152.78	153.17	0.39
16.325	**Culvert**			
16.32	23.47	152.49	152.70	0.21
16.31	23.47	152.31	152.41	0.10
16.305	23.47	151.47	151.42	-0.05
16.3	26.74	150.98	150.82	-0.16
16.295	26.74	150.32	150.36	0.04
16.29	26.74	148.71	148.91	0.20
16.28	26.74	147.42	148.20	0.78
16.27	26.74	147.45	148.13	0.68
16.265	**Culvert**			
16.26	33.66	146.78	147.12	0.34
16.25	33.66	146.51	146.84	0.33
16.24	36.37	145.61	145.50	-0.11
16.235	36.37	144.00	144.09	0.09
16.23	36.37	142.56	142.83	0.27
16.22	44.79	140.90	141.23	0.33
16.215	44.79	140.38	140.60	0.22
16.21	44.79	139.54	140.41	0.87
16.2	50.83	139.51	140.37	0.86
16.195	**Bridge**			
16.18	53.03	138.64	138.89	0.25
16.17	65.1	137.55	137.90	0.35
16.165	65.1	136.65	136.69	0.04
16.16	77.72	136.15	136.08	-0.07
16.15	77.72	135.14	135.51	0.37
16.14	86.87	134.53	134.98	0.45
16.135	**East Gate Road Culvert - Upper and Lower Model Seperation**			
16.12	86.87	134.28	134.54	0.26
16.115	86.87	134.10	134.35	0.25
16.11	86.87	133.81	134.26	0.45
16.1	86.87	133.70	134.20	0.50
16.095	**Culvert**			
16.09	86.87	133.48	133.52	0.04
16.08	88.99	133.31	133.42	0.11
16.075	88.99	133.28	133.35	0.07
16.07	88.99	132.89	133.07	0.18
16.06	88.99	132.86	133.01	0.15

HEC-RAS River Station	HEC-RAS Q Total (m^3/s)	HEC-RAS Water Surface Elevation (m asl)	Full 2D PCSWMM Water Surface Elevation (m asl)	Difference (m)
16.055	**Culvert**			
16.05	88.99	132.72	132.55	-0.17
16.04	88.99	132.38	132.46	0.08
16.035	88.99	132.33	132.37	0.04
16.03	88.99	131.79	131.88	0.09
16.02	88.99	131.55	131.49	-0.06
16.01	93.27	131.44	131.44	0.00
8.335	**Bridge**			
8.33	93.27	129.97	130.72	0.75
8.32	93.27	130.17	130.21	0.04
8.319	93.27	130.02	130.15	0.13
8.315	93.27	129.47	129.45	-0.02
8.31	93.27	128.81	128.94	0.13
8.3	93.27	128.64	128.00	-0.64
8.29	93.27	128.48	127.84	-0.64
8.285	93.27	128.36	127.65	-0.71
8.28	93.68	128.32	127.56	-0.76
8.27	93.68	128.02	127.52	-0.50
8.265	**Bridge**			
8.26	93.68	126.63	127.12	0.49
8.25	93.68	126.53	126.92	0.39
8.245	93.68	126.68	126.82	0.14
8.24	93.68	126.14	126.14	0.00
8.23	92.4	125.89	125.59	-0.30
8.21	92.4	124.10	123.70	-0.40
8.2	92.4	123.67	123.34	-0.33
8.195	**Bridge**			
8.19	92.4	123.50	123.04	-0.46
8.18	92.4	122.74	122.43	-0.31
8.17	92.4	121.60	121.33	-0.27
8.16	92.4	121.04	120.81	-0.23
8.15	92.4	120.03	120.18	0.15
8.14	92.4	118.28	118.51	0.23
8.13	92.4	116.93	116.87	-0.06
8.121	92.4	116.60	116.54	-0.06
8.12	92.4	116.23	116.31	0.08
8.11	92.4	116.13	116.26	0.13
8.1	92.4	116.03	116.24	0.21
8.095	**Culvert**			
8.09	92.4	114.02	114.09	0.07
8.08	92.4	113.55	113.86	0.31
8.07	92.4	112.17	112.47	0.30
8.06	92.4	109.64	109.37	-0.27
8.05	92.4	109.25	109.47	0.22
8.045	**CN Railway Bridge**			
			Average Difference (m)	**0.11**
			Median Difference (m)	**0.12**

APPENDIX E
Results Maps

(see companion digital files)