DRAFT

FINAL REPORT

Floodplain Mapping for Lynde Creek

Central Lake Ontario Conservation Authority

Project No. 60707688

January 2025

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Rev #	Revision Date	Revised By:	Revision Description
1	July 2024	Sara Esmaeili	Model and Report were updated
2	January 2025	Sara Esmaeili	Model and Report were updated

Distribution List

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Executive Summary

Introduction

AECOM Canada Ltd. (AECOM) was retained by the Central Lake Ontario Conservation Authority (CLOCA) to complete the Lynde Creek Floodplain Mapping project, which included review and revisions of previous hydrologic modeling, the development of a hydraulic model and data processing to generate updated regulatory floodplain maps for Lynde Creek and selected tributaries. The regulatory flood hazard standard for Lynde Creek is the greater of uncontrolled 100-year or Regional Storm event which is defined within Zone 1 of the *Technical Guide – River & Stream Systems: Flooding Hazard Limit* (MNRF, 2002).

CLOCA has received funding through the National Resources Canada (NRCan) Flood Hazard Identification and Mapping Program (FHIMP) to complete this project. This project includes the development of a one-dimensional (1D) steady state hydraulic model (HEC-RAS) as well as the preparation of a project report and regulatory flood mapping sheets which is a requirement of the FHIMP funding agreement. The model includes flood events with various return periods. An existing hydrologic model provided by CLOCA was revised and updated by AECOM for this project. Peak flows at selected flow change locations were extracted from the updated hydrologic model as flow inputs to the hydraulic model. Based on the FHIMP Flood Hazard Modelling and Mapping requirements, an additional Climate Change scenario was selected for analysis.

Lynde Creek and its tributaries are under increased development pressure such as increased urbanization with additional road crossings as well as other local works such as road and channel realignment projects. Proximity of the channel to a number of 400 series highways have increased crossings on Lynde Creek including (17) new road crossings as a result of the construction of Highway 407 and Highway 412, and updates in road profiles and bridge configurations as a result of construction on Highway 401. The works related to the 400 series highways was under the jurisdiction of the Ontario Ministry of Transportation (MTO).

Hydrologic Analysis

A Visual OTTHYMO (VO) hydrologic model developed by AECOM to support the Lynde Creek Master Drainage Plan study (AECOM, 2022) was used as the base hydrologic model for this project as directed by CLOCA. The goal of the hydrologic analysis was to produce flow inputs to be used in the hydraulic model at flow change locations for the development of flood line mapping for the 100-year, Regional (Hurricane Hazel) and Climate Change events.

Future land use conditions with uncontrolled flows were used for the flood line mapping, by removing SWM facilities when simulating the Regional and Climate Change events. This approach is based on the MNRF 2002 guidelines for flood line mapping. In addition, the antecedent soil moisture parameters were increased under larger events than the 100-year to represent AMC III conditions.

Hydraulic Analysis

A one-dimensional (1D) steady state hydraulic model was developed using the latest version of HEC-RAS (USACE), which is currently version 6.4.1. Data from available sources including CLOCA and government databases was obtained to build the hydraulic model. Relevant information includes but is not limited to the following:

- Geo-referenced base mapping (i.e., catchment areas, topography, flow change locations, transportation networks, buildings and infrastructure, hydraulic structures, streams, waterbodies, wetlands, and aerial images).
- LiDAR derived Digital Elevation Model (DEM) with post-processing already included to reflect bare earth conditions and hydrologically conditioned.

- Available drawings and survey information for hydraulic structures, including site visits by AECOM staff and further surveys by third party surveyors where data gaps where identified.
- Boundary conditions including flow change locations and water levels at Lake Ontario (upstream and downstream, respectively).
- A land cover base mapping layer was included in the hydraulic model using the Ontario Land Cover Compilation layer *Version 2.0* (OLCC, 2014). The Manning's roughness coefficients were derived from HEC-RAS Hydraulic Reference Manual (USACE, 2023) and Open Channel Hydraulics (Chow, 1959).

A geometry file was used by HEC-RAS to represent the physical properties of the model domain and form the basis of the hydraulic simulation. The addition of parameters to the model was used to simulate the flow regime of the river during normal conditions and flood events. A total of 1847 cross sections within 45 reaches were used to develop a HEC-RAS model, where the start of each reach is defined by a maximum catchment area upstream of 125 Ha, as per MNRF guidelines (MNRF, 2002).

Sensitivity Analysis

A sensitivity analysis was completed to assess the potential impacts that variations of Manning's n value can have on resulting water levels. The sensitivity of the water elevations to an overall increase of 20% in Manning's n coefficients was examined.

The sensitivity analysis indicated that an increase in Manning's n coefficients resulted in changes to water levels throughout the Lynde Creek system. This indicates that the model is sensitive to changes in Manning's n. However, this increase did not have a significant impact at hydraulic control points or changed the conveyance capacity through the structures.

Model Results

From the modeling results, water surface slopes indicate that several hydraulic control points that are governed by hydraulic structures or terrain throughout the reach. A total of 67 hydraulic structures were identified to be overtopped by flood events of different magnitudes.

The floodplain boundaries from the previous flood study (Earth Tech, 2008) and the current HEC-RAS model for are in general agreement; however, differences between flood boundaries were noted. Furthermore, a total of 11 lateral spill locations were identified within the current model results.

Flood Maps

Flood maps have been developed for Lynde Creek and its tributaries including floodplain boundaries for the 100-year event, Regional, and Climate Change events to comply with FHIMP guidelines. These map tiles have a resolution of 1:2000 metres and result in a total of 86 tiles to cover the model domain. These map tiles are labeled L1 to L86 and are arranged in a grid pattern from south to north.

The results of the HEC-RAS model were exported to GIS software (ArcGIS Pro) to generate the flood maps with a template provided by CLOCA. The maps include LiDAR – 2019 aerial imagery to clearly show the buildings, infrastructure, vegetation, and other details. The maps also include elevation contours with a resolution of 1 metre, flood lines (future uncontrolled 100-year, Regional, and Climate Change) and spot elevations at low points located at road/railway crossings, HEC-RAS cross section ID numbers and the corresponding water elevation for the 100-year and Regional Storm events, spill areas, mapping limits, sheet index number, associated legend, geographic datums, scale and north arrow. The maps are included in **Appendix E**.

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1. Introduction

AECOM Canada Ltd. (AECOM) was retained by the Central Lake Ontario Conservation Authority (CLOCA) to complete an updated Floodplain Mapping project for Lynde Creek and selected tributaries. This included review and revisions of previous hydrologic modeling, the development of a hydraulic model and data processing to generate updated regulatory floodplain maps for selected streams within the Lynde Creek watershed.

CLOCA has received funding through the National Resources Canada (NRCan) Flood Hazard Identification and Mapping Program (FHIMP) to complete this project. This project includes the development of a one-dimensional (1D) steady state hydraulic model using HEC-RAS (*Ver. 6.4.1*) as well as the preparation of a project report and regulatory flood mapping sheets for Lynde Creek and selected tributaries, which is a requirement of the FHIMP funding agreement. The model includes flood events with various return periods. These peak flows at selected flow change locations are based on previous hydrologic modelling provided by CLOCA. AECOM has carried out revisions and updates to the hydrologic modelling for this project, which include the removal of SWM ponds within the model and change of CN values to account for increase in soil antecedent moisture conditions (AMC) for extreme events (Regional and Climate Change). The hydrologic model has been used to extract peak flows at nodes where the hydraulic model in HEC-RAS requires flow inputs.

A previous floodplain mapping project for Lynde Creek was completed by Earth Tech Consulting Engineers Ltd. in 2008. There have been multiple changes observed within the watershed since then. The watershed is located within an area of active urban development east of Toronto and within the Greater Toronto Area. Therefore, the purpose of this study was to develop a hydraulic model that reflects these changes. Some major watershed updates include:

- The addition of seventeen (17) new road crossings in Lynde Creek because of the construction of Highway 407 and Highway 412, which are under the jurisdiction of the Ontario Ministry of Transportation (MTO).
- Updates in road profiles and bridge configurations because of construction and related works on Highway 401, also by MTO.
- Widening of Victoria Street and resultant upgrades in bridge sizing and elevated road embankments across Lynde Creek near the outlet into Lynde Marsh.
- Upgrades in road profiles (Taunton Road West) and two (2) crossings because of lane extensions and urban development near Taunton Road West and Des Newman Boulevard intersection.
- Updates to the river crossing structures as a result of road extensions or widening across the study area.
- Replacement (upgrade) of one (1) crossing under Townline Road West, located west of Bryant Side Road intersection.
- Urban development has increased the percentage of impervious areas within the catchment as shown in the latest Ontario Land Cover Compilation Layer (OLCC, 2014).

2. Previous Studies

The following background documents and studies received from CLOCA were reviewed to support the hydraulic analysis and flood mapping:

- *CLOCA Regulatory Flood Plain Mapping Study*, Earth Tech Consulting Engineers Ltd. (2008);
- *Comprehensive Floodplain Reduction Report, L6 Tributary of Lynde Creek, West Whitby Secondary Plan Area*, Candevcon Limited. (Revised 2016);
- *Michael Boulevard Flood Mitigation Strategy Final Report*, The Municipal Infrastructure Group (TMIG) Ltd. in association with Palmer Environmental Consulting Group Inc. (2020);
- *The Town of Whitby Bridge and Culvert Master Plan Environmental Study Report*, Ecosystem Recovery Inc. (2020);
- *Lynde Creek Master Drainage Plan Update – Municipal Class Environmental Assessment*, AECOM (2022);
- MTO As-Built drawings and construction documents for hydraulic structures associated with Highway 412 and Highway 407.

The list of technical documents used in the preparation of this hydraulic analysis and flood mapping is provided in **Section 6**.

3. Study Area

The project study area is located within the Lynde Creek watershed which has a total drainage catchment of 128.9 km^2. This includes approximately 142 km of stream segments including Lynde Creek and tributaries where hydraulic analysis and floodplain mapping was completed. There is a total of 115 hydraulic crossings that were identified within the study reach; these include 79 culverts and 36 bridges.

The watershed is predominantly located in the Town of Whitby and also extends into adjacent municipalities to the north and west (parts of the Townships of Scugog and Uxbridge, the City of Pickering and the Town of Ajax). The Lynde Creek watershed is divided into five sub-watersheds: Lynde Main, Heber Down, Kinsale, Ashburn, and Myrtle Station. The hydraulic model includes reach names which are defined by these five sub-watersheds. A numbering system was added for reaches that include junctions to other tributaries (i.e., reaches Lynde 1 to Lynde 6 include the main channel of the hydraulic model) for a total of 45 stream reaches.

The watershed maintains an elongated shape that is approximately 21 kilometres long and varies in width from 5 kilometres near Lake Ontario to 8 kilometres near its headwaters. The Lynde Creek stream network, including tributaries within the watershed, is shown in **Figure 1**.

4. Objectives

The current study has been developed with goals centered on updating regulatory flood flows and floodplain mapping, provide guidance to CLOCA, and other affected municipalities for the ongoing management of the Lynde Creek watershed and stream corridors. This includes addressing flows, erosion, resource protection, and land development. Recognizing that watershed planning, and associated Master Drainage Plans have evolved over the years, this study supports the watershed management objectives set forth in the previous floodplain study (Earth Tech, 2008). Given the pressures from urban and rural development, which impact flood potential, erosion potential, and ecosystem health, effective management strategies are necessary to protect and restore the Lynde Creek watershed.

5. Floodplain Criteria

Provincial floodplain policy in Ontario is to establish the regulatory floodplain limits using:

- The flood resulting from either the Hurricane Hazel Storm (1954) or the Timmins Storm (1961), depending on the location in the province; or
- The 100-year flood; or
- An observed flood event, subject to the approval of MNR.

The Regulatory Flood Plain for Lynde Creek and tributaries is the greater of the water levels produced from the ‘uncontrolled’ 100-year storm and Hurricane Hazel.

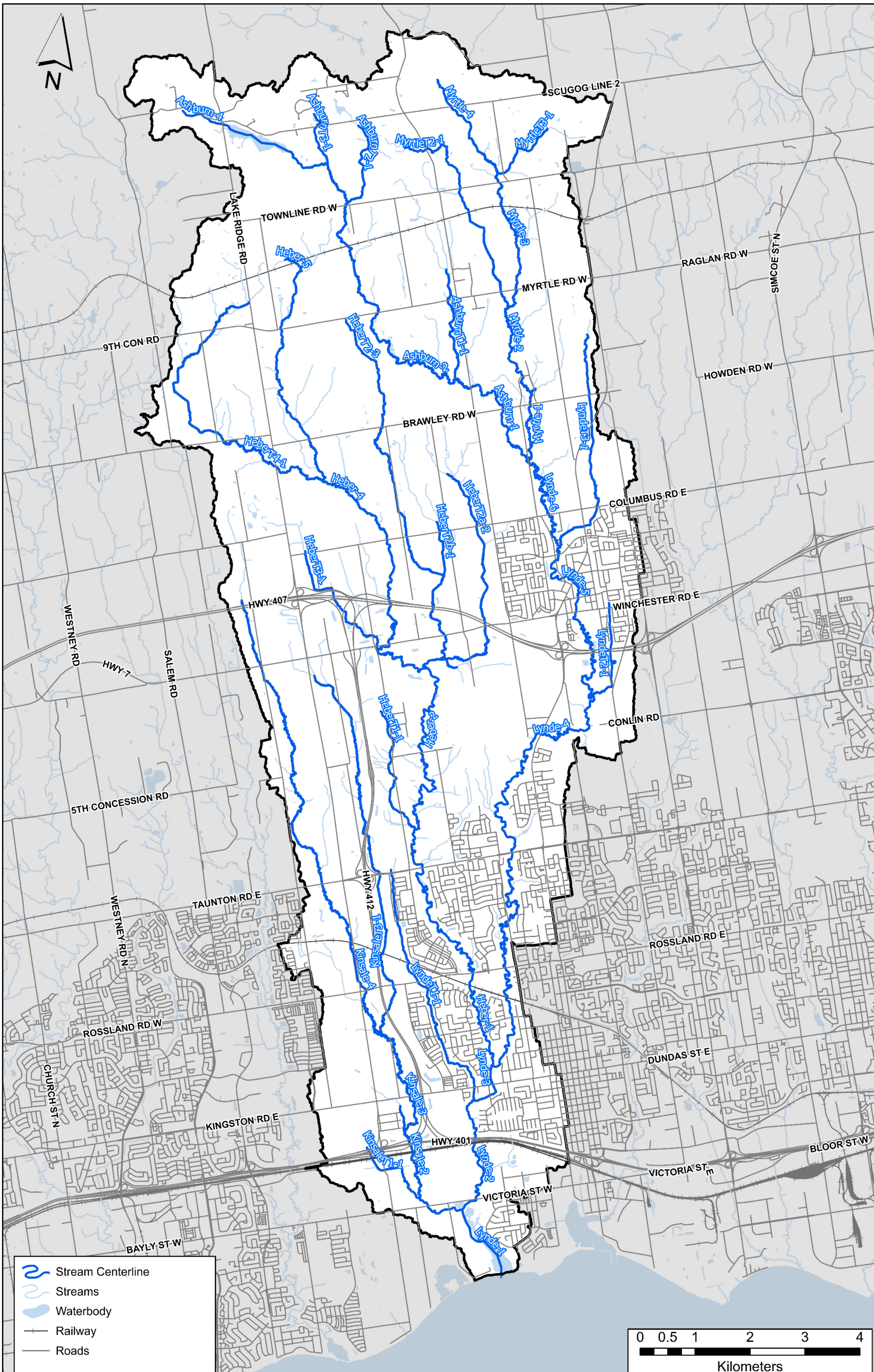

Figure 1: Study Area

6. Structure Data

The database files provided by CLOCA were imported into ESRI ArcGIS software to extract the layers that show roadways, railway networks and trails located within the study area. The existing information from municipal, regional, and provincial sources, including the previous floodplain mapping studies, were also reviewed to retrieve available hydraulic structure details (culvert/bridge) and roadway networks.

The LiDAR terrain surface along with the google satellite imagery was used as a reference to create the new channel centreline in HEC-RAS while reflecting the watershed updates, as mentioned in **Section 1**. Further details regarding the HEC-RAS hydraulic model and associated geometry are provided in **Section 8.3**.

The new river centreline was used in conjunction with the existing Durham Region Road and Railway network shapefiles (.shp) to identify the stream crossings within the Lynde Creek watershed. ESRI ArcMap (*Ver. 10.8*) was utilized to conduct the GIS analysis and extract the intersection points at all locations where the watercourse centreline intersects the road or railway network. These intersection points are identified to be the stream crossings within the Lynde Creek watershed and were assigned unique reference 2023 field IDs. The analysis showed that there is a total of 115 crossings within the study domain, out of which 103 crossings are roadways including MTO structures and 12 crossings are located at railways.

Multiple sources were utilized to verify and collect the hydraulic information related to the 115 structures identified. These sources include field inspection visits to confirm the available structure information from the Earth Tech Regulatory Flood Plain Mapping Study (2008), record drawings and plans provided as part of background information, geodetic surveys (2023/2024) and past surveys & hydraulic models completed as part of Town of Whitby Bridge and Culvert Master Plan (ERI, 2020). Information on data sources is provided in **Appendix A.1**.

6.1 2023 Field Verification

Field inspection visits by AECOM staff were carried out from September 8 -18, 2023, for all identified locations except highway (MTO) structures and railway crossings. The field inspection was used to confirm the type of crossing and cross-check the required structural information from 2008 Floodplain Study (Earth Tech, 2008) for hydraulic modelling purposes. During field visits, a total of 18 crossings were identified as unsafe to access due to heavy vegetation and/or deep channels and therefore were excluded from field inspections. The field information was verified for 23 crossings that includes structure dimensions, shape, material, general condition, depth of siltation at upstream and downstream sides, number of openings, and other details.

The ArcGIS 'Field Maps' mobile application, designed by ESRI, was used to capture the field observation notes and structure/cross section data during field visits by AECOM staff throughout the project study area. The available GIS information and location of identified crossings were imported in the 'Field Maps Designer' which were utilized to generate interactive GIS forms with editable fields and the ability to capture and reference photographs. These forms were deployed to the ESRI mobile application ('Field Maps') which was used by the field crew to capture structure information on-site. The application requires an active internet connection and therefore, for all locations with limited connectivity, offline maps were additionally generated to maintain the efficiency of field work and the data collection system. Upon returning to an area with internet connection, the data was automatically uploaded to the GIS server using the cellular network.

Based on the observations completed during field work, an inventory sheet was prepared for each stream crossing which included the aforementioned parameters along with a basic channel cross section and channel photographs. Refer **Appendix A.2** for 2023 structure inventory sheets. It should be noted that the invert elevations of the structures were not verified upstream and downstream of the crossings during the field inspections.

In addition to the field collection of hydraulic structure information, background documents were used to validate information for those structures that could not be accessed during field work. More details are provided in subsequent sections.

6.2 2008 Floodplain Study

An extensive review of previous HEC-RAS model and structure inventory sheets from 2008 Floodplain Study (Earth Tech, 2008) was completed to verify any changes to the structures observed since 2008. This includes comparison of 2008 structure photos with most recent pictures collected during 2023 field verification visits (if available) and/or google imagery data, including verification of the 2008 top of road elevation against the available LiDAR data (2019). Based on the analysis, a total of 30 crossings were referenced using the 2008 Floodplain Study as data source. Also, as mentioned in **Section 6.1**, no invert elevation data was collected during field inspection visits completed by AECOM in 2023, and therefore once a structure was verified, the 2008 geodetic data, along with other verified structural information, was used for modelling purposes. Refer **Appendix A.3** for 2008 structure inventory sheets. For all structures, where an upgrade, replacement or modification was observed, a geodetic survey was completed in 2023/2024 (explained in **Section 6.3**).

The geodetic data from 2008 Floodplain Study was based on the vertical datum of CGVD28, and therefore to reflect the correct elevation points in the hydraulic model, a datum conversion from CGVD28 to CGVD2013 was completed. Using the vertical datum separation data from Natural Resources Canada for the Town of Ajax (Station Number 67U039) and the Town of Whitby (Station Number 67U020), an elevation difference of 0.39 m between CGVD28 and CGVD2013 levelling points is identified, as shown in **Table 1**. Based on this, the elevation data obtained from 2008 Floodplain Study was lowered by 0.39 m before incorporating it in the hydraulic model.

Table 1: Vertical Datum Conversion (CGVD28 - CGVD2013)

Station Location	Station Number	Elevation (m)		Approximate Difference (m)
		CGVD2013	CGVD28	
Town of Ajax	67U039	86.083	86.473	-0.39
Town of Whitby	67U020	75.750	76.145	-0.39

(Source: Geodetic tools and data, Natural Resources Canada, Date Modified August 6, 2024.)

6.3 2023/2024 Geodetic Survey

As described in **Section 6.1**, in all cases where there is no information available in previous studies (Earth Tech, 2008 and ERI, 2020), the crossings were marked for further geodetic surveys. The new crossings identified as part of this study were also marked for future surveys. A total of 22 crossings were surveyed in December 2023 and June 2024 by Callon Dietz to obtain the geometric and geodetic information at both upstream and downstream of each structure, including the top of road and other spot elevations. Additionally, the crew captured the structure face photos for determining general conditions and record other observations. The inventory sheets for these surveyed structures are included in **Appendix A.4**.

The 2023/2024 survey data was collected using the following datums:

- **Horizontal Datum**: NAD 83 CSRS, UTM Grid Co-ordinate System, Zone 17, Central Scale Factor 0.99989327
- **Vertical Datum**: CGVD2013

6.4 2020 HEC-RAS Model (Town of Whitby Master Plan Study)

The CLOCA HEC-RAS model completed as part of the previous flood plain study (Earth Tech, 2008) was updated in 2020 by Ecosystem Recovery Inc. (ERI) for the Town of Whitby Bridge and Culvert Master Plan Study (Environmental Study Report) based on topographic surveys completed at each crossing and overall structure updates observed. The 2020 HEC-RAS model along with the relevant master plan reports (ERI, 2020) were provided as part of the background information.

A total of five (5) structures (no information in 2008 Floodplain Study) were modelled using the structure/ topographic data available in 2020 HEC-RAS Model (ERI, 2020). Additionally, these structures were also cross-checked to ensure no structure modifications have been completed since 2020. Spot checks were also completed to confirm the vertical datum of the structure elevation data used in the 2020 HEC-RAS model. It was observed that the crossing information in the model was updated based on the survey completed by ERI as part of the master plan study in 2020; therefore, the invert elevations were lowered for these structures, suggesting that the model was modified based on CGVD2013 vertical datum. As a result, no datum conversions were completed for these five (5) structures. More information on these structures is available in **Appendix A.5**.

6.5 Record Drawings

MTO As-Built Drawings

Lynde Creek watershed observed major updates that includes construction of Highway 407 and Highway 412 starting from 2015. The relevant Ministry of Transportation (MTO) as-built drawings and reports were provided for majority of the structures located over Highway 407 and Highway 412, along with Highway 401. These available engineering drawings were utilized to extract the hydraulic information related to crossing type, shape, dimensions, invert elevation data, bridge soffit heights, and abutment and pier information for a total of 22 crossings. The relevant MTO as-built drawings are included in **Appendix A.6**.

Other Drawings and Topographic Plans

In addition to MTO As-Built, the construction drawings prepared by AECOM in 2013 for the Lynde Creek tributary bridge (2023 Structure ID: 89) over Victoria Street West located east of Halls Road South intersection, and topographic plans of railway crossing north of Rossland Road West (2023 Structure ID: 104) prepared by JD Barnes Limited in 2016 and included in the West Whitby Comprehensive Floodplain Reduction Report (CDC, Revised 2016), were also provided as part of the background reference materials. These drawings were reviewed and utilized to include the respective structures in the 2023 hydraulic model.

All the record drawings were based on vertical datum of CGVD28, and therefore, the datum conversions to CGVD2013 were completed for the elevation data based on the methodology identified in **Section 6.2**. The record drawings and topographic plans are included in **Appendix A.7**.

6.6 Structure Inventory Summary

To summarize, out of a total of 115 identified crossings, the following considerations are noted:

- 11 crossings were marked as ‘Not Modelled’ in the hydraulic model because these are located at the upstream section of the channel and therefore have no impact on the hydraulic model;
- 23 crossings were verified in the field as part of this project (2023);
- 30 crossings were verified using the 2008 Regulatory Floodplain Mapping Study;

- 22 crossings were included in the list for additional survey work to capture the required structural information and elevation data for hydraulic modelling, including the one (1) overbridge which was marked as not to be modelled (Structure 42);
- 5 crossings were confirmed via the available Bridge and Culvert Inventory data prepared by ERI for the Town of Whitby Master Plan Study in 2020;
- 22 crossings were validated using MTO As Built Drawings;
- 1 crossing was verified using the Lynde Creek tributary bridge (Victoria Street) As Built Drawings prepared for the Town of Whitby (Region of Durham) by AECOM in 2013 (provided as part of the background information); and
- 1 crossing was verified using the structure topographic plans (provided as part of the background information) prepared by JD Barnes in 2016 for the West Whitby Comprehensive Floodplain Reduction Report (CDC, Revised 2016).

The structure inventory is summarized in **Table 2**, including crossings that were not used in the model. Refer **Appendix A** for detailed structure inventory information, referred MTO As Built Drawings and summary of verification data used for each structure.

Table 2: Structure Inventory Summary

Structure ID	River	Reach	Type of Structure	Source of Information
1	Ashburn	4	Culvert	N/A – Not Modelled
2	Myrtle	4	Culvert	Field Verified
3	MyrtleT3	1	Culvert	Field Verified
4	Myrtle	3	Culvert	2024 Survey
5	Ashburn	2	Culvert	2008 Floodplain Study
6	Myrtle	3	Culvert	2008 Floodplain Study
7	MyrtleT2	1	Culvert	2008 Floodplain Study
8	AshburnT1	1	Culvert	2008 Floodplain Study
9	Ashburn	2	Culvert	Field Verified
10	Heber	5	Culvert	Field Verified
11	HeberT4	1	Culvert	2008 Floodplain Study
12	HeberT4	1	Culvert	Field Verified
13	HeberT4	1	Culvert	2008 Floodplain Study
14	HeberT4	1	Culvert	Field Verified
15	HeberT4	1	Culvert	Field Verified
16	Heber	5	Culvert	2008 Floodplain Study
17	HeberT2	3	Culvert	2008 Floodplain Study
18	Ashburn	1	Culvert	2008 Floodplain Study
19	Ashburn	1	Culvert	2008 Floodplain Study
20	Myrtle	2	Culvert	2020 Town of Whitby Master Plan Study
21	MyrtleT1	1	Culvert	2020 Town of Whitby Master Plan Study
22	Myrtle	1	Culvert	2008 Floodplain Study
23	Ashburn	1	Bridge	2008 Floodplain Study
24	Lynde	6	Culvert	2008 Floodplain Study

Structure ID	River	Reach	Type of Structure	Source of Information
25	HeberT2a	2	Culvert	2008 Floodplain Study
26	HeberT2	3	Culvert	Field Verified
27	HeberT2	3	Culvert	Field Verified
28	Heber	4	Bridge	2008 Floodplain Study
29	HeberT3	1	Culvert	N/A – Not Modelled
30	LyndeT3	1	Culvert	Field Verified
31	Lynde	5	Bridge	2020 Town of Whitby Master Plan Study
32	Lynde	5	Bridge	2008 Floodplain Study
33	Lynde	5	Bridge	Field Verified
34	Lynde	5	Bridge	Field Verified
35	Lynde	5	Bridge	2008 Floodplain Study
36	Lynde	5	Bridge	Field Verified
37	LyndeT2	1	Culvert	N/A – Not Modelled
38	LyndeT2	1	Culvert	Field Verified
39	LyndeT2	1	Culvert	MTO As-Builts
40	Lynde	5	Bridge	MTO As-Builts
41	HeberT2a	2	Bridge	MTO As-Builts
42[1]	HeberT2a	2	Culvert	2023 Survey
43	HeberT2	2	Bridge	MTO As-Builts
44	Heber	4	Bridge	MTO As-Builts
45	Heber	4	Bridge	MTO As-Builts
46	HeberT3	1	Culvert	MTO As-Builts
47	HeberT3	1	Culvert	MTO As-Builts
48	HeberT3	1	Culvert	N/A – Not Modelled
49	Kinsale	4	Culvert	MTO As-Builts
50	HeberT3	1	Culvert	MTO As-Builts
51	HeberT3	1	Bridge	MTO As-Builts
52	HeberT3	1	Bridge	2020 Town of Whitby Master Plan Study
53	HeberT3	1	Culvert	2023 Survey
54	Heber	4	Culvert	2023 Survey
55	HeberT2	2	Culvert	2008 Floodplain Study
56	HeberT2a	2	Culvert	2008 Floodplain Study
57	Kinsale	4	Culvert	Field Verified
58	Kinsale	4	Culvert	Field Verified
59	KinsaleT3	1	Culvert	2008 Floodplain Study
60	Kinsale	4	Culvert	Field Verified
61	KinsaleT3	1	Bridge	MTO As-Builts
62	KinsaleT3	1	Culvert	MTO As-Builts
63	Heber	2	Bridge	2008 Floodplain Study
64	Heber	1	Bridge	2023 Survey
65	Lynde	4	Culvert	2008 Floodplain Study
66	Lynde	4	Culvert	2008 Floodplain Study

Structure ID	River	Reach	Type of Structure	Source of Information
67	LyndeT2	1	Culvert	2008 Floodplain Study
68	Lynde	4	Bridge	2008 Floodplain Study
69	Lynde	4	Bridge	2008 Floodplain Study
70	Heber	1	Bridge	2008 Floodplain Study
71	KinsaleT3	1	Culvert	MTO As-Builts
72	Kinsale	4	Culvert	MTO As-Builts
73	Kinsale	4	Culvert	2023 Survey
74	KinsaleT3	1	Culvert	MTO As-Builts
75	LyndeT1	1	Culvert	N/A – Not Modelled
76	Heber	1	Bridge	Field Verified
77	Lynde	4	Bridge	Field Verified
78	LyndeT1	1	Culvert	Field Verified
79	Lynde	3	Bridge	Field Verified
80	Lynde	3	Bridge	Field Verified
81	Kinsale	3	Culvert	MTO As-Builts
82	Kinsale	3	Culvert	Field Verified
83	Lynde	2	Bridge	2023 Survey
84	Lynde	2	Bridge	2023 Survey
85	Kinsale	2	Bridge	MTO As-Builts
86	Kinsale	2	Bridge	MTO As-Builts
87	KinsaleT1	1	Culvert	MTO As-Builts
88	KinsaleT1	1	Culvert	MTO As-Builts
89	Kinsale	1	Bridge	Town of Whitby As-Built Drawing (AECOM, 2013)
90	Kinsale	1	Culvert	2008 Floodplain Study
91	Lynde	2	Bridge	2023 Survey
92	Myrtle	3	Culvert	2023 Survey
93	MyrtleT2	1	Culvert	2023 Survey
94	Ashburn	2	Culvert	2023 Survey
95	Heber	5	Bridge	N/A – Not Modelled
96	Lynde	4	Culvert	2023 Survey
97	Heber	1	Bridge	2008 Floodplain Study
98	KinsaleT3	1	Culvert	MTO As-Builts
99	Kinsale	4	Culvert	2023 Survey
100	Lynde	2	Bridge	2023 Survey
101	Kinsale	2	Culvert	2023 Survey
102	KinsaleT1	1	Culvert	2023 Survey
103	LyndeT1	1	Culvert	2020 Town of Whitby Master Plan Study
104	LyndeT1	1	Culvert	West Whitby Comprehensive Floodplain Reduction Report (CDC, Revised 2016)
105	LyndeT1	1	Culvert	2023 Survey
106	LyndeT1	1	Culvert	2023 Survey
107	MyrtleT2	1	Culvert	2024 Survey

Structure ID	River	Reach	Type of Structure	Source of Information
108	LyndeT3	1	Culvert	N/A – Not Modelled
109	LyndeT3	1	Culvert	2024 Survey
110	HeberT1	1	Culvert	2024 Survey
111	HeberT1	1	Culvert	N/A – Not Modelled
112	HeberT1	1	Culvert	N/A – Not Modelled
113	HeberT1	1	Culvert	N/A – Not Modelled
114	HeberT1	1	Culvert	N/A – Not Modelled
115	KinsaleT1	1	Culvert	2008 Floodplain Study

[1] *This is an overbridge with bridge deck higher than the modelled 100-year/ Regional (uncontrolled) W.S.E. and therefore, this crossing was marked to be ignored and not included in the hydraulic model.*

6.7 Low Flow Channel

During the field validation visits, a basic cross-sectional data perpendicular to the channel at both upstream and downstream sides of the structure were recorded to represent the low flow channel in the hydraulic model. The following methodology was used to collect the data:

- Two levelling pins were placed on either side of the channel, close to the observed right and left bank edges, such that the pins were installed securely and perpendicular to the ground.
- A twine string was tied tightly to the levelling pins and the height above the water on both channel extremes (i.e., height from water surface to the string) was used as an arbitrary benchmark to make the string parallel to the water surface.
- Once the levelling was completed, the depth of water in the channel at multiple points was measured and documented while looking in the downstream direction and walking in a straight line along the string from left bank to right bank.
- The data was recorded as X and Y coordinates, where X represents the lateral distance of the point from left bank of the channel and Y indicates the depth of water at that location.

A general representation of field set-up to measure cross section data is shown in **Figure 2**.

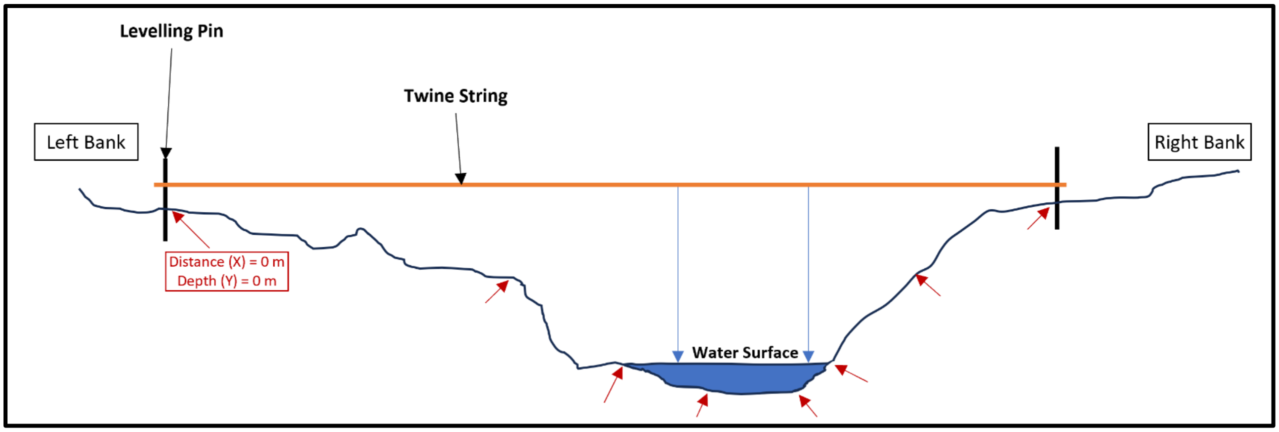

Figure 2: Field Equipment Set-Up

This method was used to get an overall understanding of the stream geometry at the crossing locations and used to develop low flow channels (if deemed necessary) within the Digital Elevation Model generated from available LiDAR data. Refer **Table 7** (**Section 8.3.1**) for further details regarding the locations where these low flow channel geometry modifications were applied in the hydraulic model.

7. Hydrologic Analysis

7.1 Methodology

A hydrologic assessment was completed by AECOM for the 2022 Lynde Creek Master Drainage Plan, which included analyses of both existing and future conditions. AECOM developed a Visual OTTHYMO (VO) hydrologic model to support the 2022 study (AECOM, 2022). The AECOM 2022 VO model was based on the 2008 floodplain mapping and the 2022 model includes updates on land use hence it has been used to generate flow inputs for the current study as being the most update model. The model in the current study used to generate flow inputs includes the following storm events: 100-year (uncontrolled), Regional (Hurricane Hazel) (uncontrolled), and Regional + Climate Change events (uncontrolled). The VO analysis for all these events includes future land use conditions.

To obtain uncontrolled condition flows, the SWM facilities were removed following the MNRF 2002 guidelines for flood line mapping. The antecedent soil moisture parameters were increased to represent AMC III conditions for the Regional Storm and the Climate Change event assessments. The future controlled conditions represent the original state of the model with SWM facilities included and AMC II conditions.

Resulting flows from the VO model were incorporated to the HEC-RAS model at the flow junctions where changes in flow take place.

7.1.1 Model Update

The base VO model "Consolidated Model – updated 20211104.voprj", simulated existing and future land use conditions, was obtained from the 2022 Lynde Creek Master Drainage Plan. Since it was created in an older version of VO, it would not initially run in Version 6.2 due to errors. These errors included the calculation time step (DT) being equal or less than the inflow time step and the pervious/impervious slope (SLP) was reported as being outside the range of reasonable values (0.25% <SLP< 5%). The following changes were applied to fix the errors and run the simulations:

- DT changed from 10 min to 5 min
- SLP changed from 0.2% to 0.25%

The results for various locations for the 2-year, 10-year and 100-year storm events were checked between the original model and updated VO model with fixed errors. The results for the original model were taken from the 2022 Lynde Creek Master Plan Report (AECOM, 2022). Comparison of the original and updated model was undertaken using approaches. First, flows reported in Table 3-3 of the 2022 AECOM Report were compared to the updated model results (updated model results provided in **Appendix B.1**). Second, the detailed output results presented in 2022 AECOM Report for the Chicago 12-hour 10-year storm event were compared to the updated model results (model results presented in **Appendix B.1**). The only detailed output results of VO model reported in the 2022 AECOM Report was Chicago 12-hour 10-year storm event and therefore used to compare results.

The two comparisons between the 2022 AECOM Report model results and updated model (presented in **Appendix B.2**) showed minimal difference between the two models indicating the changes made in fixing the errors did not result in significant variation in the latest model results.

As part of the review of the results from the updated VO model, additional warnings were notes. Further investigation into the warnings indicated that there were three route channels connected to NHYD 86, 94 and 168 had warnings of "Failed to converge" in the output results from VO for all storm events and scenarios. The warnings were also observed in the output results of 2022 model as well as 2008 VO model. AECOM reached out to Smart

City Water Inc. (developers of the VO model). Smart City Water reviewed the model and provided a few recommendations:

- All the route channel within the model were changed to “Compound Channel” from “Route Channel”, to ensure the flow analysis for the channel and floodplains is modeled accurately.

- The time steps were kept consistent for all components in VO and all parameters NashHyd, StandHyd, route channel and route reservoir were changed to time step of 5 min, this is to ensure uniformity across all relevant parameters and prevent potential errors.

Four (4) route channels with NHYDs of 86, 94, 231 and 168 were changed to “Muskingum” route channel command in the VO model. This change was suggested since using the “Compound Channel” routine was still returning a “Failed to converge” warning in the VO output. It should be noted, not all route channels were changed to “Muskingum-Cunge” command due to VO single-event model limitations in presenting comprehensive data particularly in scenarios involving long channels. In such cases, the model's representation of flow dynamics may not fully capture the nuances of the system, leading to underestimations or inaccuracies in peak flow estimations which can cause some data loss and may have compounded impacts downstream. Therefore, only to resolve the convergence warning issue and any fluctuations caused, “Muskingum-Cunge” command was used for specific route channels of NHYD 86, 94, 231, and 168 while the routine “Compound Channel” was used for all other route channels.

7.2 Design Storm Events

The 2022 AECOM VO model uses a Chicago 12-hour rainfall distribution and was chosen as the representative event for peak flow assessment for this current study. The VO model includes return periods for the 2-yr, 5-yr, 10-yr, 25-yr, 50-yr and 100-yr with addition of Regional Storm and Climate Change Storm events.

7.2.1 Establishing the Climate Change Scenario

To represent a Climate Change scenario, a design storm was created following the 2023 NRCan guidelines entitled, ‘Incorporating Climate Change in Floodplain Mapping under the Flood Hazard Identification and Mapping Program (FHIMP) where the Regulatory Storm event is Timmins or Hurricane Hazel’, as requested by CLOCA for this project.

The steps described by the 2023 guidelines (NRCan, 2023) are based on recommendations by Environment and Climate Change Canada (ECCC) and data collected and extracted from the climatedata.ca portal. The following steps summarize the approach taken to generate the new hourly rainfall intensity data considering climate change effects.

1. The Zone of the study area was identified based on the Flood Hazard Criteria Zones of Ontario delineated in Figure B-1 from the 2002 Guidelines (MNRF, 2002). The study area was identified to be within Zone 1.

2. A hyetograph for the regulatory storm in the zone where the study area is located was obtained. The Regional storm was provided by CLOCA. The *Lynde_Regional_UPDATED* storm event was used as the hyetograph for Zone 1 of the study area.

3. The 50^{th} percentile of mean annual temperature change for the time horizon of 2050s corresponding to the representative pathway concentration RCP 4.5 for the study area was then obtained. It should be noted that the climate data portal requires a gird location to be selected to extract the data. Only one grid box within the study area was selected since the RCP 4.5 values for the Lynde Creek catchment were all the same and

equal to 2.89 for the mean annual temperature change for RPC 4.5 for time horizon of 2050s. Hence, only one grid cell was selected. The data results extracted from Climate Data Canada are presented in **Appendix B.3.**

4. Using the following equation, the new hourly rainfall intensity was generated from the known *Lynde_Regional_UPDATED* hourly rainfall intensity (mm/hr).

$$R_p = R_c \, x \, 1.07^{\Delta T}$$

Where:
R_p is future estimated rainfall intensity value
R_c is historic estimated rainfall intensity
ΔT is Annual mean temperature change

The new hourly rainfall increased by 22% in intensity under Climate Change event. The new hourly rainfall intensity data with climate adjusted parameters and the FHIMP guidelines document (NRCan, 2023) are presented in **Appendix B.4.**

7.3 Modelling Parameters

Model parameters for each sub-catchment are provided in **Table 3**. **Appendix B.5** provides the VO schematics for future controlled and uncontrolled scenarios.

Table 3: Hydrologic Parameters - Future Conditions

Catchment Name	NashHyd/ StandHyd ID	Subwatershed Command	Area (ha)	Impervious Ratio	Time to peak (hr)	SCS Curve Number (CN) – AMC II	SCS Curve Number (CN) – AMC III	Initial Abstraction (mm)
H7	H7A	StandHyd	54	0.47	-	74	88	1.5
H7	SWMP1	-	-	-	-	-	-	-
H8	H8	StandHyd	12.06	0.45	-	50	70	1.5
H9	H9R	NashHyd	21.83	-	0.24	75	88	5.2
H9	H9U	StandHyd	32.57	0.71	-	85	94	1.5
K1	K1R	NashHyd	293.19	-	1.44	79	91	5.7
K1	K1U	StandHyd	66.12	0.69	-	85	94	1.5
K2	K2R	NashHyd	406.12	-	1.09	81	92	6.7
K2	K2U1	StandHyd	33.25	0.65	-	85	94	1.5
K2	K2U2	StandHyd	42.73	0.77	-	85	94	1.5
K2	K2U3	StandHyd	72.94	0.8	-	85	94	1.5
K3	K3	NashHyd	119.9	-	0.79	78	90	5.7
K4	K4R	NashHyd	64.88	-	1.34	70	85	6.7
K4	K4U	StandHyd	29.02	0.74	-	85	94	1.5
K5	K5	NashHyd	309.9	-	1.2	62	79	4.8
K6	K6	NashHyd	312.8	-	1.12	67	83	5.5
K7	K7	NashHyd	446.9	-	0.79	70	85	6.4
L1	L1	NashHyd	227.8	-	1.69	71	86	3.2
L10	L10R	NashHyd	134.86	-	0.72	64	81	6.6

Catchment Name	NashHyd/ StandHyd ID	Subwatershed Command	Area (ha)	Impervious Ratio	Time to peak (hr)	SCS Curve Number (CN) – AMC II	SCS Curve Number (CN) – AMC III	Initial Abstraction (mm)
L10	L10U	StandHyd	48.68	0.64	-	85	94	1.5
L11	L11	StandHyd	69	0.54	-	74	88	1.8
L11	L11A	StandHyd	49.2	0.54	-	74	88	1.5
L11	SWMP2	-	-	-	-	-	-	-
L12	L12	StandHyd	23.29	0.47	-	68	84	1.5
L13	L13 South	StandHyd	100.85	0.78	-	74	88	3.4
L13	SWMP3	-	-	-	-	-	-	-
L14	L14	StandHyd	67.01	0.2	-	74	88	4.0
L14	L14A	StandHyd	10.48	0.73	-	74	88	1.5
L14	SWMP4	StandHyd	-	-	-	-	-	-
L15	L15	StandHyd	165	0.41	-	73	87	2.0
L16	L16 South	StandHyd	47.84	0.43	-	61	78	5.6
L161	L13 North	StandHyd	69.31	0.46	-	82	92	1.5
L16	L16U	StandHyd	69.09	0.43	-	85	94	1.5
L16	L16R	NashHyde	54.06	-	0.45	73	87	5.6
L17	L17	StandHyd	192.31	0.37	-	70	85	1.5
L2	L2	StandHyd	307.1	0.58	-	72	86	2.4
L2	L2A	StandHyd	24.72	0.62	-	75	88	5.0
L2	L2B	StandHyd	11.91	0.99	-	75	88	5.0
L2	L2C	StandHyd	1.07	0.75	-	73	87	5.0
L22	K2U	StandHyd	21.66	0.7	-	80	91	5.0
L3	L3	StandHyd	139.27	0.71	-	76	89	1.9
L33	L6C	StandHyd	33.27	0.61	-	76	97	1.7
L4	L4	StandHyd	122.65	0.71	-	74	88	2.1
L5	L5	StandHyd	59.85	0.53	-	74	88	3.4
L6	L6	StandHyd	57.32	0.36	-	82	92	4.4
L6	L6A	StandHyd	10.59	0.45	-	74	88	1.5
L6	L6B	StandHyd	34.00	0.61	-	92	97	1.7
L6	L6D	StandHyd	15.29	0.5	-	74	88	1.5
L6	L6G	StandHyd	11.73	0.67	-	77	89	3.3
L6	L6E	StandHyd	30.43	0.34	-	73	87	3.7
L6	L6F	StandHyd	38.06	0.37	-	74	88	3.2
L7	L7	StandHyd	29.09	0.45	-	73	87	4.4
L8	L8	StandHyd	421.32	0.34	-	73	87	2.9
L9	L9R	NashHyd	180.35	-	1.64	74	88	5.2
L9	L9U	StandHyd	168.78	0.72	-	85	94	1.5
M1	M1	NashHyd	443.36	-	1.65	69	84	6.3
M2	M2	NashHyd	896.81	-	0.9	63	80	6.8
M3	M3	NashHyd	221.68	-	1.2	61	78	6.6

Catchment Name	NashHyd/ StandHyd ID	Subwatershed Command	Area (ha)	Impervious Ratio	Time to peak (hr)	SCS Curve Number (CN) – AMC II	SCS Curve Number (CN) – AMC III	Initial Abstraction (mm)
H7	H7A	StandHyd	54	0.47	-	74	88	1.5
H7	SWMP1	-	-	-	-	-	-	-
H8	H8	StandHyd	12.06	0.45	-	50	70	1.5
H9	H9R	NashHyd	21.83	-	0.24	75	88	5.2
H9	H9U	StandHyd	32.57	0.71	-	85	94	1.5
K1	K1R	NashHyd	293.19	-	1.44	79	91	5.7
K1	K1U	StandHyd	66.12	0.69	-	85	94	1.5
K2	K2R	NashHyd	406.12	-	1.09	81	92	6.7
K2	K2U1	StandHyd	33.25	0.65	-	85	94	1.5
K2	K2U2	StandHyd	42.73	0.77	-	85	94	1.5
K2	K2U3	StandHyd	72.94	0.8	-	85	94	1.5
K3	K3	NashHyd	119.9	-	0.79	78	90	5.7
K4	K4R	NashHyd	64.88	-	1.34	70	85	6.7
K4	K4U	StandHyd	29.02	0.74	-	85	94	1.5
K5	K5	NashHyd	309.9	-	1.2	62	79	4.8
K6	K6	NashHyd	312.8	-	1.12	67	83	5.5
K7	K7	NashHyd	446.9	-	0.79	70	85	6.4
L1	L1	NashHyd	227.8	-	1.69	71	86	3.2
L10	L10R	NashHyd	134.86	-	0.72	64	81	6.6

[1] *Catchment L13 is part of L16 under based on VO model.*
[2] *Catchment K2U is part of L2 under based on VO model.*
[3] *Catchment L6C is part of L3 under based on VO model.*

7.3.1 Establishing Antecedent Soil Moisture Parameters (AMC III) for Regional Storm Event

The CN values in the original model are based on antecedent soil moisture condition (AMC) II condition. For storm events greater than the 100-year, the AMC parameters were increased to AMC III to represent the effect of the first 36 hours of rain and the saturated ground conditions that would be created but it is not included in the rainfall hyetograph. To update the AMC, a CN value conversion table was used and is provided in **Table 4**. The CN numbers were updated accordingly to reflect the AMC III condition for the Regional Storm and Climate Change effect. Further details are included in **Appendix B.6**.

Table 4: CN Value Conversion (AMC I, II and III)

AMC II	AMC I	AMC III	AMC II	AMC I	AMC III
100	100	100	61	41	78
99	97	100	60	40	78
98	94	99	59	39	77
97	91	99	58	38	76
96	89	99	57	37	75
95	87	98	56	36	75
94	85	98	55	35	74
93	83	98	54	34	73
92	81	97	53	33	72
91	80	97	52	32	71
90	78	96	51	31	70
89	76	96	50	31	70
88	75	95	49	30	69
87	73	95	48	29	68
86	72	94	47	28	67
85	70	94	46	27	66
84	68	93	45	26	65
83	67	93	44	25	64
82	66	92	43	25	63
81	64	92	42	24	62
80	63	91	41	23	61
79	62	91	40	22	60
78	60	90	39	21	59
77	59	89	38	21	58
76	58	89	37	20	57
75	57	88	36	19	56
74	55	88	35	18	55
73	54	87	34	18	54
72	53	86	33	17	53
71	52	86	32	16	52
70	51	85	31	16	51
69	50	84			
68	48	84	30	15	50
67	47	83	25	12	43
66	46	82	20	9	37
65	45	82	15	6	30
64	44	81	10	4	22
63	43	80	5	2	13
62	42	79	0	0	0

Sourse: Mishra, Surendra and Vijay P. Singh (2003). Soil Conservation Service Curve Number (SCS-CN) Methodology. Norwell, MA: Kluwer Acedemic Publishers, p103.

7.3.2 Future Uncontrolled (No SWM Ponds)

To represent the uncontrolled condition, the SWM facilities SWMP1, SMWP2, SMWP3, SMWP4, Node 161 (a site storage) and Mattamy Pond were removed from the VO model.

7.3.3 Flow Comparison to Previous Floodplain Hydrologic Model

In **Table 5** the flows from the original 2008 VO and updated model (2024) VO model have been compared for specific points of interest of the future scenario for return periods of 2-yr, 10yr, 100-yr and Regional Storm event.

The 2008 VO model was used to compare flows per request by CLOCA. **Table 5** shows mainly increase of flows in 2024 model compared to 2008 due to model updates applied to the 2024 model.

As discussed in **Section 7.1.1**, there were some updates applied to the VO model, mainly the change of route channel type to ensure the flow analysis for the channel and floodplains is modeled accurately. The update of route channels type showed increase in flows downstream of the route channels.

Table 5: Flow Comparison to 2008 VO Model

Hydrologic Model NHYD ID	Location	Flow 2-yr future (m^3/s)		Flow 10-yr future		Flow 100-yr (Uncontrolled) future		Regional Flow future	
		2008	2024	2008	2024	2008	2024	2008	2024
190	Myrtle 1 Upstream Columbus	14.5	12.6	22.9	20.5	38.1	37.2	131.4	134.9
45	Lynde 4 Downstream Brooklin	21.1	25.1	46.4	59.4	90.4	113.7	342.5	382.9
49	Lynde 4 Upstream Whitby	21.6	28.4	49.3	64.6	97.8	122.4	369.0	409.1
86	Route Channel (Herber T2a - downstream of catchment H11)	1.2	7.5	2.8	13.2	6.3	21.5	27.3	34.2
94	Route Channel (Herber T2a - downstream of catchment H10)	1.9	8.6	4.1	16.8	8.5	28.4	36.0	50.8
84	Heber 2 Downstream Winchester	13.4	21.1	34.2	52.3	72.2	100.6	280.3	300.4
5	Heber 1 at Taunton	14.3	22.2	35.3	52.0	73.7	98.2	318.5	335.0
13	Lynde 3 at Dundas	35.5	53.4	82.6	117.9	170.0	231.3	714.5	795.2
59	Lynde 2 at Highway 401	37.4	56.0	86.3	121.8	176.6	239.0	734.3	820.5
24	Kinsale 1 Downstream Victoria	10.6	13.2	26.1	29.3	55.7	59.3	187.4	191.3
168	Route Channel (Lynde 1 - upstream of catchment L1)	40.0	63.3	96.2	142.8	202.7	288.7	914.1	1013.3
221	Lynde 1 at Lake Ontario	40.8	63.6	98.2	144.0	206.1	292.3	940.7	1030.4

7.4 Flow Inputs to Hydraulic Model

For future controlled conditions, the simulations were completed for the 2-year, 5-year, 10-year, 25-year, 50-year, 100-year storm events. For future uncontrolled conditions, the simulations were completed for the 100-year storm, Regional Storm event, and Regional Storm event with Climate Change impact scenario. The simulation results from VO for controlled and uncontrolled future conditions are provided in **Appendix B.7**. **Figure 3** shows the flow change locations. **Table 6** presents the peak flows at flow change locations that were input in the hydraulic model for both future controlled and future uncontrolled conditions.

As shown in **Table 6**, some flow nodes were determined based on the percentage of the area contributing to the river within that particular catchment area. For example, 36.7% of the catchment area A2 contributes towards River Ashburn stream 4, hence 36.7% of the flow from catchment A2 flow was input at the node. **Figure 3** shows the flow nodes that are based on a percentage of the total catchment area or flow nodes that were directly from a NHYD VO model node.

Table 6: Future Controlled and Uncontrolled Peak Flows for Various Storm Events

River	Reach	NYHD ID	Cross Section ID	%Catchment Area	Upstream catchment area	Future Controlled						Future Uncontrolled		
						2-year	5-year	10-year	25-year	50-year	100-year	100-year AMCII	Regional AMC III	Regional + CC AMCIII
Ashburn	4	(36.7%)180	11451.99	36.7% A2	1103.6	1.8	3.5	4.5	6.6	8.3	9.7	9.7	36.5	46.1
Ashburn	2	180	3401.11	A2	1103.6	4.9	9.4	12.2	17.9	22.6	26.3	26.3	99.5	125.5
Ashburn	1	183	2.71	-	1728.0	10.1	18.9	24.1	35.0	43.8	50.7	50.7	161.5	201.5
Ashburn T1	1	(44.9%)182	62.44	44.9% A1	624.4	2.9	5.2	6.6	9.3	11.4	13.0	13.0	29.1	35.7
Ashburn T2	1	(15.9%)180	73.13	15.9% A2	1103.6	0.8	1.5	1.9	2.8	3.6	4.2	4.2	15.8	20.0
Ashburn T3	1	(13.5%)180	76.66	13.5% A2	1103.6	0.7	1.3	1.6	2.4	3.0	3.6	3.6	13.4	16.9
Heber	1	9	83.69	-	4604.6	23.2	41.5	52.2	73.0	88.6	101.1	101.1	352.9	439.0
Heber	5	1	18600.38	-	595.3	2.1	4.0	5.1	7.3	9.1	10.5	10.5	42.4	53.0
Heber	3	209	12004.71	-	2319.9	8.8	17.3	23.2	33.2	41.5	48.3	48.3	186.7	234.7
Heber	2	5	7027.23	-	4301.1	22.2	41.1	52.0	71.6	86.8	98.5	98.2	335.0	414.4
Heber	4	204	13579.38	-	1887.3	7.9	15.7	20.6	29.3	36.5	42.3	42.3	155.9	194.9
Heber T1	1	(24.1%)169	100.67	24.1% H3	648.9	1.6	2.5	2.9	4.0	4.7	5.2	5.2	9.6	12.1
Heber T2	3	(49.7%)171	2737.69	49.7% H5	637.5	5.6	8.7	10.4	13.6	16.1	18.0	18.0	32.2	39.7
Heber T2	2	(97.9%)171	488.75	97.9%H5	637.5	10.9	17.1	20.4	26.8	31.7	35.5	35.5	63.5	10.9
Heber T2	1	218	24.73	-	1332.3	16.4	27.1	33.1	46.4	57.4	66.0	66.0	129.9	160.2
Heber T2a	2	85	163.75	-	586.8	10.4	16.4	19.5	25.4	30.0	33.4	30.5	55.7	68.8
Heber T2a	1	217	36.6	-	694.9	9.5	16.2	19.9	27.0	32.5	36.7	35.7	66.6	82.2
Heber T2aa	1	179	35.09	-	108.0	3.2	4.5	5.2	6.5	7.5	8.3	8.3	11.1	13.6
Heber T2b	1	(25.9%)171	52.99	25.9% H5	637.5	2.9	4.5	5.4	7.1	8.4	9.4	9.4	16.8	20.7
Heber T4	1	200	105.01	-	870.6	5.6	10.4	13.3	19.2	23.8	27.5	27.5	83.8	104.0

River	Reach	NYHD ID	Cross Section ID	%Catchment Area	Upstream catchment area	Future Controlled						Future Uncontrolled		
						2-year	5-year	10-year	25-year	50-year	100-year	100-year AMCII	Regional AMC III	Regional + CC AMCIII
Herber T3	**1**	**206**	**36.72**	**-**	**356.1**	2.1	3.9	4.9	7.0	8.6	9.9	9.9	31.5	39.0
Kinsale	**1**	**24**	**95.47**	**-**	**2197.8**	13.2	23.3	29.3	41.3	51.4	59.3	59.3	191.3	238.8
Kinsale	**4**	**16+37.71%(241+21)**	**6410.47**	**-**	**-**	6.9	11.9	14.7	20.2	24.5	28.0	28.0	83.6	104.2
Kinsale	**3**	**20+72.13%(241+21)**	**2959.53**	**-**	**-**	13.6	23.4	28.9	39.6	48.2	54.9	54.9	154.7	192.2
Kinsale T1	**1**	**66.2%(236)**	**97.87**	**66.2%K1**	**359.3**	2.7	4.3	5.2	6.9	8.2	9.3	9.3	21.2	26.0
Kinsale T2	**1**	**25.7%(241+21)**	**78.91**	**25.7% K2**	**555.0**	2.4	3.8	4.5	5.9	7.0	7.8	7.8	14.1	17.3
Kinsale T3	**1**	**19+10%(241+21)**	**210.83**	**-**	**-**	4.7	8.2	10.2	14.4	17.8	20.5	20.5	59.0	73.0
Kinsale T3	**1**	**17**	**3773.78**	**-**	**446.9**	3.7	6.9	8.8	12.6	15.7	18.2	18.2	46.3	57.3
Lynde	**6**	**35**	**23262.94**	**-**	**3482.2**	19.8	38.5	47.5	66.5	82.2	94.7	94.7	311.9	389.9
Lynde	**5**	**43**	**18006.87**	**-**	**4065.8**	23.3	45.1	55.4	76.9	94.2	108.1	107.9	355.9	444.2
Lynde	**4**	**55**	**5290.33**	**-**	**5250.3**	31.6	55.1	68.0	94.5	115.7	132.1	132.8	442.9	554.2
Lynde	**3**	**57**	**4351.82**	**-**	**9977.5**	54.1	95.2	118.9	166.5	203.3	233.2	233.5	802.2	1001.8
Lynde	**2**	**11**	**1662.7**	**-**	**10713.9**	57.0	99.4	123.6	172.9	211.3	242.2	243.0	836.0	984.1
Lynde	**1**	**221**	**80.7**	**-**	**13139.5**	63.6	114.5	144.0	204.3	251.4	290.1	292.3	1030.4	1237.9
Lynde	**5**	**136**	**23143.92**	**-**	**3722.5**	22.5	43.7	53.7	74.6	91.6	105.2	105.2	332.7	415.6
Lynde	**6**	**189**	**26403.96**	**-**	**3289.9**	21.6	38.1	43.7	60.7	75.1	86.5	86.5	294.7	368.6
Lynde	**5**	**39**	**21095.04**	**-**	**3887.5**	23.0	45.1	55.3	76.7	94.0	107.9	107.9	344.1	429.5
Lynde	**4**	**199**	**17523.12**	**-**	**4207.3**	24.2	46.7	57.4	79.5	97.3	111.4	110.3	366.8	457.7
Lynde	**4**	**45**	**15594.54**	**-**	**4390.9**	25.1	48.1	59.4	82.2	100.3	114.8	113.7	382.9	477.3
Lynde	**4**	**49**	**12287.35**	**-**	**4740.0**	28.4	52.5	64.6	88.8	107.9	122.9	122.4	409.1	509.1
Lynde	**4**	**52**	**7931.42**	**-**	**5161.4**	31.1	54.9	67.7	94.1	115.1	131.1	131.4	438.8	548.5
Lynde	**4**	**53**	**6977.5**	**-**	**5190.4**	31.1	54.6	67.4	93.6	114.6	130.9	131.5	439.0	549.3
Lynde	**2**	**219**	**4162.78**	**-**	**10140.9**	54.7	95.9	119.8	167.7	204.6	234.7	235.1	808.4	1009.5
Lynde	**2**	**59**	**3410.27**	**-**	**10347.5**	56.0	97.7	121.8	170.3	207.9	238.5	239.0	820.5	1024.3
Lynde	**1**	**220+32.11%(173)**	**1505.82**	**-**	**-**	68.6	119.3	148.7	208.9	256.2	294.8	296.4	1024.9	1230.2

River	Reach	NYHD ID	Cross Section ID	%Catchment Area	Upstream catchment area	Future Controlled						Future Uncontrolled		
						2-year	5-year	10-year	25-year	50-year	100-year	100-year AMCII	Regional AMC III	Regional + CC AMCIII
Lynde T1	**1**	**134**	**67.29**	**-**	**163.4**	9.7	14.4	17.0	24.8	30.8	34.8	34.8	21.4	26.4
Lynde T2	**1**	**197**	**81.81**	**-**	**141.5**	6.7	10.2	12.2	15.7	18.3	20.8	32.3	18.2	22.5
Lynde T2	**1**	**122**	**2109.93**	**-**	**23.3**	2.1	3.1	3.5	4.4	5.2	5.7	5.7	3.1	3.8
Lynde T3	**1**	**28**	**102.36**	**-**	**240.3**	4.6	6.9	8.1	10.3	12.1	13.4	13.4	23.9	29.2
Myrtle	**1**	**190**	**104.18**	**-**	**1561.9**	12.6	19.4	20.5	26.3	32.3	37.2	37.2	134.9	168.9
Myrtle	**2**	**186**	**4075.2**	**-**	**1118.5**	5.7	11.0	14.2	20.7	26.0	30.3	30.3	103.8	130.0
Myrtle	**4**	**33.4%(185)**	**7699.85**	**33.4% M2**	**896.8**	1.6	3.1	4.0	5.9	7.4	8.6	8.6	28.6	35.7
Myrtle	**3**	**185**	**4300.38**	**-**	**896.8**	4.9	9.4	12.1	17.7	22.2	25.8	25.8	85.6	107.0
Myrtle T1	**1**	**28.7%(188)**	**24.15**	**28.7% M1**	**443.4**	0.6	1.1	1.4	2.0	2.4	2.8	2.8	10.0	12.5
Myrtle T2	**1**	**184**	**110.37**	**-**	**221.7**	0.9	1.8	2.3	3.3	4.1	4.8	4.8	18.7	23.5
Myrtle T3	**1**	**34.1%(185)**	**44.44**	**34.1% M2**	**896.8**	1.7	3.2	4.1	6.0	7.6	8.8	8.8	29.2	36.5

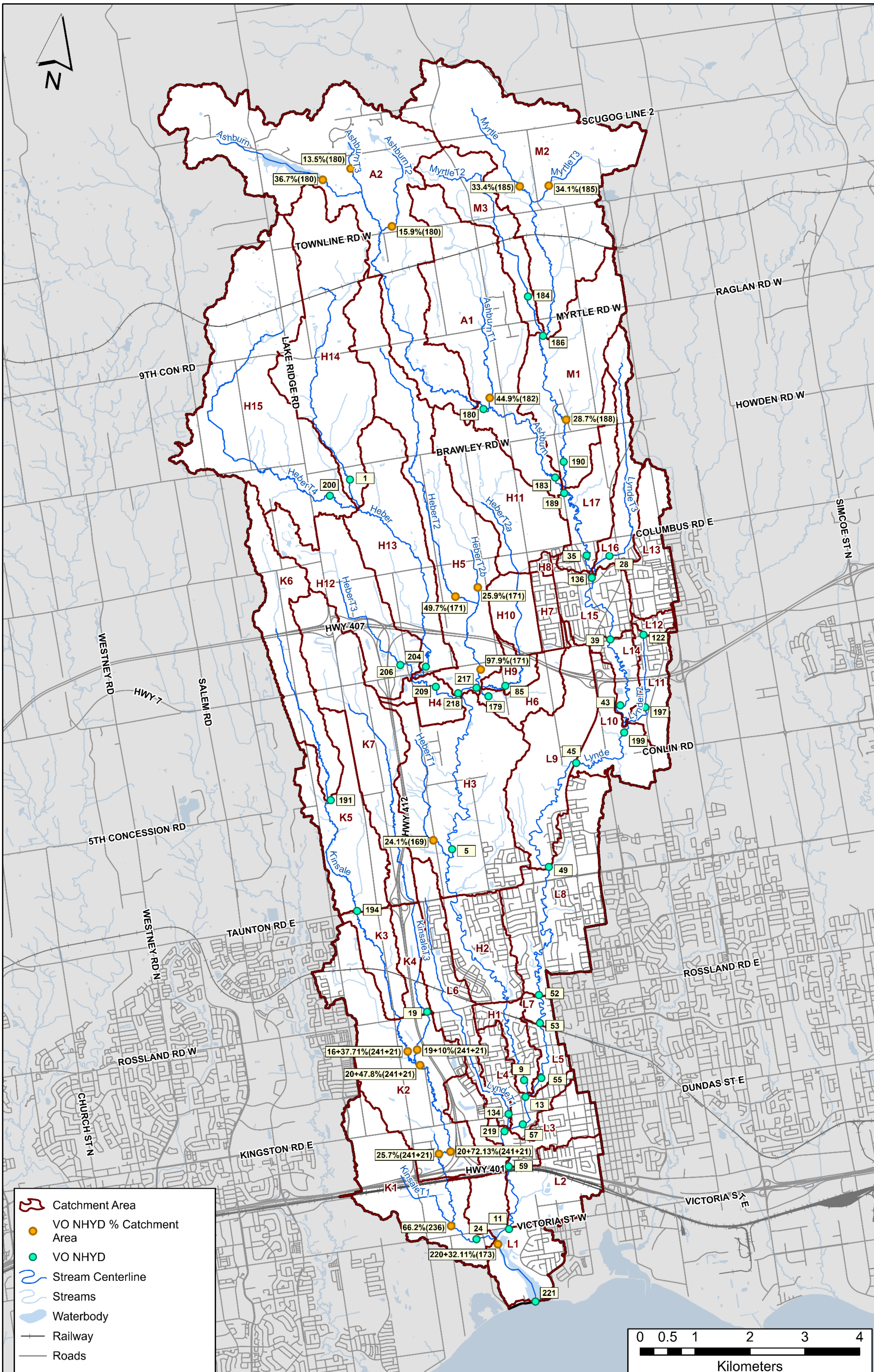

Figure 3: Flow Change Locations

8. Hydraulic Analysis

8.1 Methodology

A one-dimensional (1D) steady state hydraulic model was created using HEC-RAS Version 6.4.1 (USACE) to carry out the hydraulic analysis of Lynde Creek and tributaries (approximately 142 km of stream reaches) within the study area. The background documents (mentioned in **Section 2**) were reviewed, and the required information was extracted for model development.

The new hydraulic model was built using a specific series of steps to maintain consistency and provide a framework for the Lynde Creek watercourse system. These steps included defining the model horizontal and vertical projections, creating a terrain surface based on available LiDAR data, adding channel geometric features, setting up the model cross sections, entering boundary conditions and roughness coefficients, adding flow change locations, as well as carrying out a sensitivity analysis. More details on the gathering of the base information are provided in **Section 8.3**.

For the scope of this study report, an overview flow chart is presented to outline the key steps and procedures that were followed to create the 1D hydraulic model. The flow chart is shown in **Figure 4**.

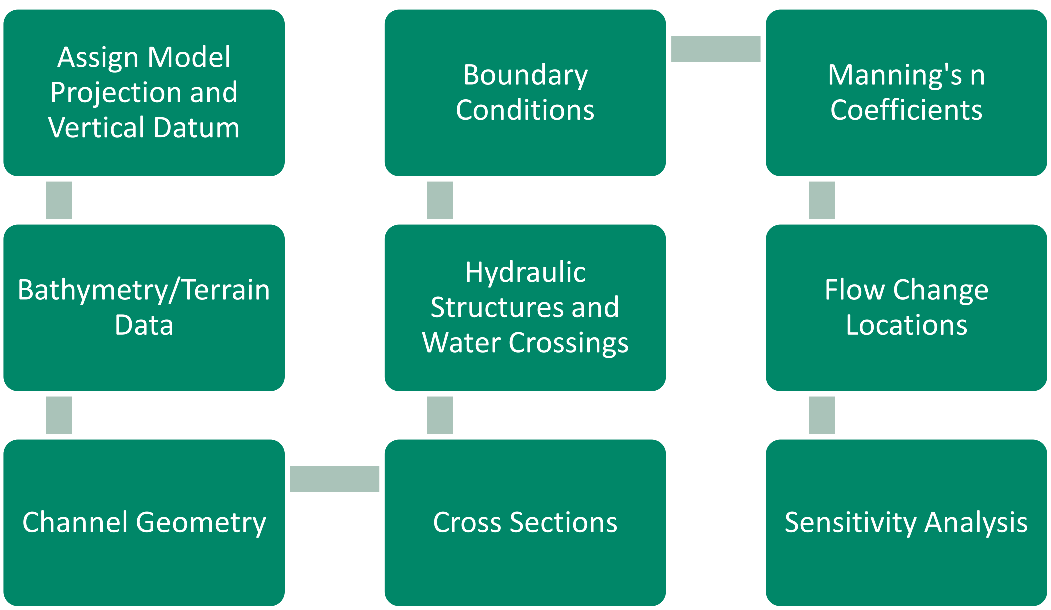

Figure 4: HEC-RAS Procedure - Flow Chart

8.1.1 Technical Guidelines

Relevant technical standards and guidelines that were considered for the development of the hydraulic model and floodplain delineation and mapping are listed below:

- *Understanding Natural Hazards (Great Lakes - St. Lawrence River System and large inland lakes, river and stream systems and hazardous sites)*, Ontario Ministry of Natural Resources (2001)
- *Technical Guide – River and Stream Systems: Flooding Hazard Limit*, Ontario Ministry of Natural Resources (2002)
- *Technical Guidelines for Flood Hazard Mapping*, Environmental Water Resources Group Ltd. (2017)
- *Bibliography of Best Practices for Flood Mitigation Version 2.0*, Natural Resources Canada (2018)
- *Federal Flood Mapping Framework Version 2.0*, Natural Resources Canada (2018)
- *Federal Geomatics Guidelines for Flood Mapping Version 1.0*, Natural Resources Canada (2019)
- *Federal Hydrologic and Hydraulic Procedures for Flood Hazard Delineation Version 1.0*, Natural Resources Canada (2019)
- *Federal Land Use Guide for Flood Risk Areas Version 1.0*, Natural Resources Canada (2022)
- *Flood Hazard Identification and Mapping Program Project Eligibility and Requirements*, Ministry of Natural Resources and Forestry (2002)
- *Incorporating Climate Change in Floodplain Mapping under the Flood Hazard Identification and Mapping Program (FHIMP) where the regulatory Storm Event is Timmins or Hurricane Hazel*, Natural Resources Canada (2023)

In case of any conflicts between the reference documents mentioned above, the *Technical Guide – River & Stream Systems: Flooding Hazard Limit* (MNRF, 2002) will take precedence over federal guidelines.

8.2 Model Data

The data that was used to build the hydraulic model was a combination of available background information and new structure details obtained during field visits as a part of this study. The following sections highlight the data and the relevant sources that were used to generate the base HEC-RAS model.

8.2.1 Data Sources

Multiple existing hydraulic documents provided by CLOCA were reviewed for the purpose of this floodplain mapping study. The related GIS information in geodatabase and shapefile format is also provided and used to develop the hydraulic model. The key data sources are listed below:

- Reports and updates for the CLOCA Regulatory Floodplain Mapping Study (2008) completed by Earth Tech Consulting Engineers Ltd.

- Comprehensive Floodplain Reduction Report for L6 Tributary of Lynde Creek, West Whiby Secondary Plan (Revised 2016) completed by Candevcon Limited (CDC).
- The Town of Whitby Bridge and Culvert Master Plan Environment Study Report and HEC-RAS Model (2020) completed by Ecosystem Recovery Inc. (ERI) Professional Engineers.
- Flood modelling package for Lynde Creek Master Drainage Plan Update (2022) completed by AECOM.
- Topographic mapping including 2018 LiDAR data from Canada Provincial Government and 2019 orthography (Geodetic Vertical Datum of 2013 – CGVD2013).
- Bathymetric mapping for Lynde Creek Marsh from Highway 401 to Lake Ontario which was integrated with the topographic mapping.
- Available generalized watershed/sub-watershed boundaries provided by CLOCA.
- Available drainage information including virtual segments, stream/river shorelines, ponds/lakes and flow direction.
- Digital Elevation Model (DEM) (UTM Zone 17 NAD83) and contour line data in shapefile format.
- Obtained CLOCA regulatory limits and study area boundaries.
- Geo-referenced air photography and data including land use information, transportation (roadways, trails, and railway networks), building and infrastructure locations, waterbodies, streams, wetlands, damage centres, and aerial images.
- Available as-builts, construction drawings and stormwater management reports for MTO structures.
- Flow rates at key cross sections obtained from hydrologic model as mentioned in **Section 7**.
- Updated hydraulic structure inventory information and low flow channel data recorded during the field analysis completed as part of this study.

8.2.2 Spatial Projections

The horizontal and vertical spatial projections used for this project are NAD83 UTM Zone 17N and CGVD2013, respectively. The data received from CLOCA satisfied the project standard requirements and therefore no data conversion was done for vertical datum adjustments. If warranted, the horizontal projections were adjusted for base layers received from open data sources (ESRI Base Map and Ontario GeoHub).

8.2.3 LiDAR and Bathymetry

CLOCA provided LiDAR data in the form of a Digital Elevation Model (DEM) layer. The LiDAR was flown in December 2018 by Airborne Imaging Inc. and was processed with a resolution of 0.5 m x 0.5 m to a bare earth condition. Additionally, 1 m contours were also provided in shapefile format. Bathymetric mapping was also added to the DEM for the Lynde Creek Marsh between Highway 401 to Lake Ontario. These bathymetric products were provided by Natural Resources Canada and created by KBM Resources Group in 2018. **Figure 5** shows the available DEM for Lynde Creek.

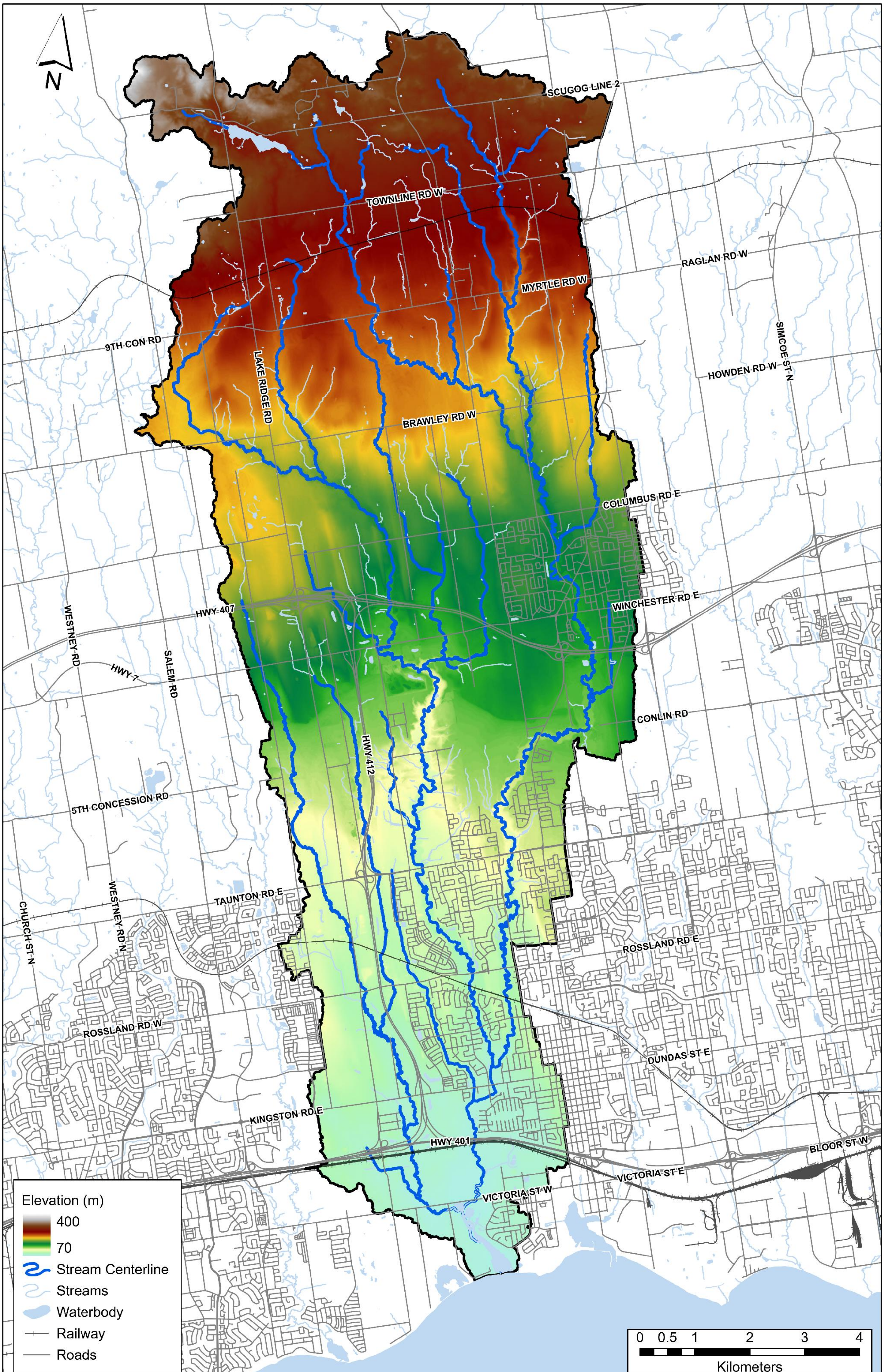

Figure 5: Topography of Lynde Creek

8.3 Model Geometry

The development of geometric data is necessary in 1D hydraulic modelling to establish a stream network and to simulate runoff conveyance along the Lynde Creek and its tributaries. The following steps were completed to create a master geometry file for running the base hydraulic simulations:

- A terrain layer (DEM) was developed using the bathymetric and LiDAR data as mentioned in **Section 8.2.3**. The terrain surface is required for defining the ground surface information incorporated into channel cross sections, thereby determining the channel's conveyance capacity. This layer also captures roadways, buildings, channel shapes, and flow directions, which can be further used to establish detailed channel schematics.
- The Lynde Creek channel centreline was created in the direction of flow (looking downstream) using terrain data and google satellite imagery as a reference. The bank lines were also generated using the same source data to represent the channel bank stations. The centreline plays a key role in defining reach lengths and river stations and do not intersect with the bank lines. The junctions were automatically created by HEC-RAS at each stream junction.
- Additionally, the upstream channel lines for all the reaches within the model were started where a maximum of 125 ha of contributing area was located, based on the Technical Guidelines for Flood Hazard Mapping (Environmental Water Resources Group Ltd., 2017), which states that the flooding hazard limit has been generally applied to watercourses which drain areas that are equal to or greater than 125 ha.
- The flow paths were drawn in the direction of flow along the channel using the terrain surface, imagery data and surrounding conditions. The flow path lines were estimated based on centre-of-mass of flow and are used to calculate reach lengths between cross sections.
- The channel centreline, bank lines, flow paths and terrain surface were utilized to develop the cross sections along the entire reach of Lynde Creek included in the study area. For every hydraulic structure (culvert/bridge) two cross sections were added upstream and downstream of the structure as required by the model.
- The cross-section locations were set for all the reaches of Lynde Creek at an approximate distance of 100 meters to represent the flow regime and considering the simplifications that exist when using the one-dimensional solver in HEC-RAS. The cross sections were drawn from left to right of the bank looking in the downstream direction. Based on the recommended provincial flooding hazard limit guidelines (MNRF, 2002), the channel centerline and cross sections were generated starting from the point along the channel at which the accumulated upstream contributing catchment area was equal to or lower than 125 hectares. The model includes 45 river reaches with a total 1847 cross sections connected by 22 junctions.
- Due to the lack of available data for the private entrances within the study area, an additional 36 cross sections were added in the model to represent the road deck for these private driveways and allow the computed flood lines to be shown continuous over these entrances.

8.3.1 Low Flow Channel

For channels having a width of at least 10 metres, a low flow channel was added to the terrain based on field data obtained as described in **Section 6.7**. The methodology to add these low flow channels was based on the modification (lowering) of the entire terrain using vectors (lines/polygons) with elevations assigned to them. This elevation value represents the depth of water in the low flow channel. This approach was necessary because LiDAR is unable to penetrate water and therefore shows the water surface at the time it was flown. For smaller channels (width less than 10 metres), it was assumed that the LiDAR captured most of the channel and the cross sections were applied without major modifications. This approach is considered more conservative because the volume which is not occupied by the low flow channel is transferred to the floodplain. Additionally, given the high resolution of the LiDAR data the impacts of not adding the low flow channel in small tributaries are considered as small to negligible for modelling purposes.

It is to be noted that the topographic information provided as part of the background documents included bathymetric information for the marsh area located around Lynde 1 (near Lake Ontario outlet), and therefore no terrain modifications were completed for this area.

Table 7 indicates the locations where the low flow terrain modifications were added along the channel.

Table 7: Low Flow Channel Modifications

River	Reach	Location From/To	Original Terrain Elevation (m)	Modified Terrain Elevation (m)	Source of Data
Lynde	3	Junction (Heber 1 & Lynde 4)	78.38	77.26	Same as downstream
		Structure 79	77.87	76.75	2023 Field Investigation
Lynde	3	Structure 79	77.85	76.63	2023 Field Investigation
		Structure 80	77.22	76.57	2023 Field Investigation
Lynde	2	Structure 80	77.13	75.99	2023 Field Investigation
		Structure 83	75.81	75.38	2023 Survey
Lynde	2	Structure 83	75.81	75.38	2023 Survey
		Structure 100	75.44	75.14	2023 Survey

In addition to the above low flow channels, some terrain modifications were also completed for small lakes/ponds that are located along the river centreline to ensure continuous flood lines in the flood maps. Depending on their size and extent, the terrain surface elevation was adjusted to allow the uninterrupted flood flow over these small inline lakes/ponds.

8.3.2 Hydraulic Structures

A total of 115 hydraulic crossings (including the 12 crossings that are proposed not to be added to the model) were identified within the study model reach, which includes 103 road crossings and 12 railway crossings. Crossings located within private properties were ignored. **Figure 6** shows the location of hydraulic structures on Lynde Creek.

There are 79 culverts and 36 bridge crossings identified within the study area. The simulations of these hydraulic crossings in the model required a minimum of four (4) cross sections with two upstream and two downstream. A plan view of the basic cross section placement with respect to each crossing is shown in **Figure 7**. Based on the guidelines provided in the HEC-RAS hydraulic reference manual (USACE, 2023), one cross section is placed downstream from the structure such that it does not affect the flow in the channel, typically at a ratio of 2:1 of the average obstruction length (Cross Section 1). Additionally, two cross sections (so-called Bounding Cross Sections which are Cross Sections 2 and 3) are placed near the toe of embankment, each at the upstream and downstream sides of the hydraulic structure. The bounding cross sections were created so that they best represent the geometry inside of the structure. The fourth cross section (Cross Section 4) is placed upstream of the crossing, typically at a ratio of 1:1 of the average obstruction length, where the flow lines are approximately parallel, and the cross section is fully effective.

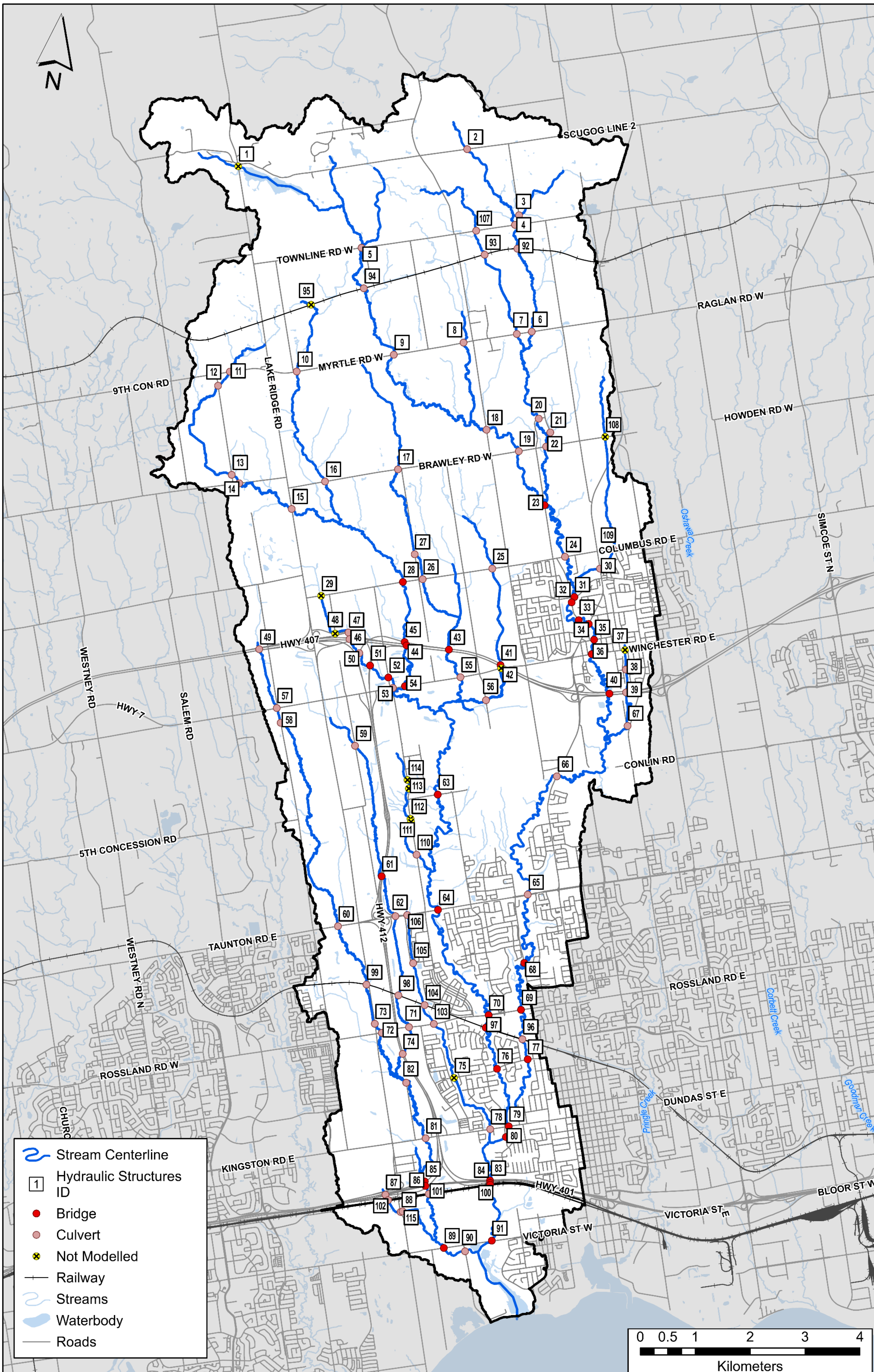

Figure 6: Location of Hydraulic Structures

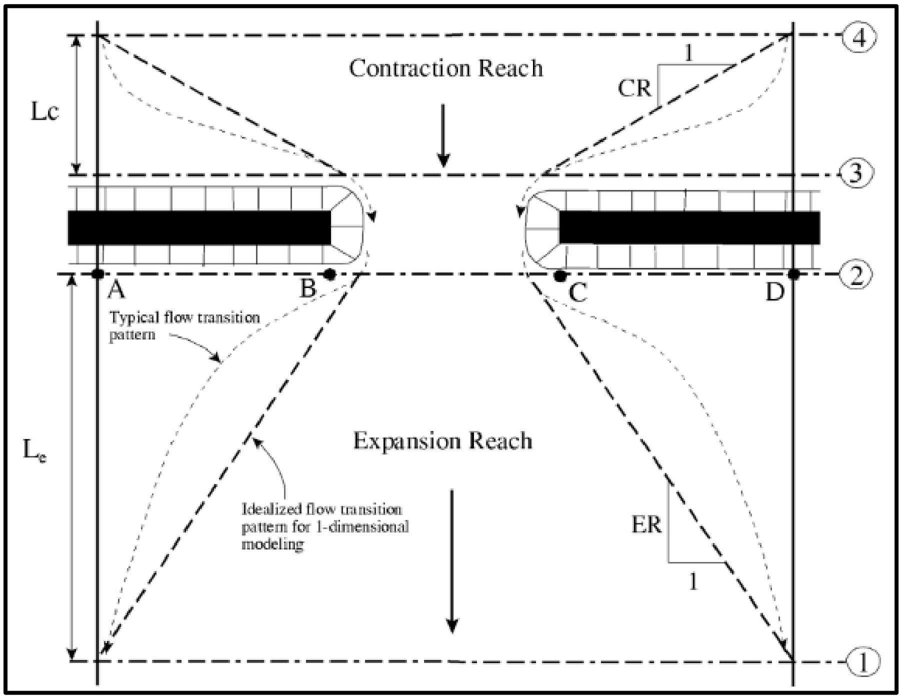

Figure 7: Cross Section Locations at a crossing (HEC-RAS Manual, 2023)

The information gathered for each hydraulic crossing used multiple sources as mentioned in **Section 6**. At a minimum, the HEC-RAS model requires defining the geometry of the crossing (i.e., diameter, span and width), road deck elevation, soffit elevation (for bridges), bottom type (i.e., open-bottom or closed-bottom for culvert), upstream and downstream invert elevations (for culvert), number of culvert barrels or bridge piers, headwall features and treatment, and structure material (i.e., concrete, corrugated steel pipe, PVC). Elevations along the roadway deck was extracted from LiDAR for each structure.

Following the input of the hydraulic crossings, ineffective areas were added to the upstream and downstream cross sections at each crossing. The criteria used to define these ineffective areas is discussed in **Section 8.3.3**. The hydraulic characteristics and general geometry of the culverts and bridges are summarised in **Table 8** and **Table 9**, respectively.

Table 8: Hydraulic Characteristics of Culverts

Structure ID	Shape	Cross Section ID	US Invert (m)	DS Invert (m)	Diameter or Rise (m)	Width or Span (m)	Deck Roadway Width (m)	Culvert Length (m)
1	Not Modelled – Beginning of the channel.							
2	Circular	9497.34	292.43	292.35	1.50	N/A	10.30	19.50
3	Elliptical	117.65	267.09	266.79	1.05	1.72	9.00	14.10
4	Arch	7367.6	262.20	262.06	2.60	4.80	9.00	25.07
5	Circular	10182.37	268.91	268.76	1.55	N/A	10.00	18.00
6	Arch	4769.58	228.23	228.03	3.30	6.00	14.50	29.70
7	Circular	417.32	233.89	233.57	1.20	N/A	13.00	45.00
8	Circular	1935.15	244.28	244.18	1.90	N/A	14.50	27.60
9	Arch	7106.6	241.21	240.97	1.30	2.20	14.50	24.00
10	Circular	22088.94	240.88	240.62	2.25	N/A	15.00	26.00
11	Circular	6752.64	236.72	236.11	1.38	N/A	15.00	32.30
12	Arch	6392.25	231.01	230.60	1.00	1.51	6.70	9.20
13	Box	3551.74	208.02	207.92	1.20	3.20	6.50	12.30
14	Box	3304.39	206.24	206.19	1.70	3.60	7.60	7.60
15	Box	1350.33	195.91	195.73	2.39	6.80	13.70	37.10
16	Circular	19480.63	199.20	198.94	2.90	5.00	11.00	20.90
17	Circular	6569.4	219.84	219.16	1.20	N/A	10.00	17.20
18	Arch	2756.72	211.19	211.12	3.60	5.00	11.60	22.60
19	Arch	1610.5	196.46	196.21	3.20	5.10	10.00	20.00
20	Arch	2305.7	199.70	199.56	2.30	6.00	8.90	25.00
21	Arch	102.56	197.17	196.41	2.00	6.00	10.50	25.00
22	Arch	1539.02	190.95	190.74	3.00	4.60	10.20	16.00
24	Box	24188.66	167.52	167.26	2.70	6.10	10.50	16.60
25	Box	3886.35	171.00	170.87	1.33	3.60	9.80	16.40
26	Arch	3992.19	176.01	175.85	1.70	3.00	10.50	18.00
27	Arch	4534.79	180.58	180.41	0.78	1.70	8.50	18.30
29	Not Modelled – Beginning of the channel.							
30	Circular	814.78	173.33	173.22	1.50	N/A	16.65	24.80
37	Not Modelled – Beginning of the channel.							
38	Box	1704.7	157.75	157.69	1.20	2.40	10.40	24.50
39	Box	1310.38	154.41	153.73	1.75	9.50	66.50	86.56
46	Box	1698.04	180.16	177.12	1.28	6.00	76.00	117.92
47	Box	1811.98	183.47	181.62	1.28	6.00	36.00	70.62
48	Not Modelled - No crossing exists at this location.							
49	Box	18065.59	186.65	184.65	3.18	8.00	58.00	85.49

Structure ID	Shape	Cross Section ID	US Invert (m)	DS Invert (m)	Diameter or Rise (m)	Width or Span (m)	Deck Roadway Width (m)	Culvert Length (m)
50	Box	1322.89	171.44	170.67	1.28	6.00	13.00	38.63
53	Box	85.59	143.45	143.27	1.40	4.30	21.50	40.73
55	Box	1089.88	143.96	142.61	1.56	6.10	23.00	40.50
56	Arch	732.75	143.99	143.78	1.90	2.83	10.00	23.10
57	Box	16793.09	161.27	160.92	1.56	2.44	25.00	25.10
58	Box	16493.99	155.51	155.26	1.11	2.20	7.44	7.44
59	Arch	8055.81	144.72	144.59	1.00	1.65	10.50	31.50
60	Box	10853.73	105.38	105.26	1.95	2.42	23.00	40.36
62	Arch	3763.78	106.38	106.17	3.10	14.66	35.00	54.90
65	Arch	11911.29	106.50	106.00	4.70	10.00	32.00	36.40
66	Box	15584.74	133.00	132.76	5.06	9.60	16.50	40.00
67	Box	535.26	149.42	149.26	0.87	2.07	12.00	32.80
71	Arch	1414.25	93.45	93.12	4.01	12.80	22.50	44.32
72	Box	7995.78	89.81	89.48	2.60	6.00	25.50	51.12
73	Arch	8228.87	91.29	91.01	2.70	3.80	20.00	58.55
74	Arch	818.05	89.07	88.52	3.14	12.83	40.00	66.20
75	Not Modelled – No crossing exists at this location.							
78	Elliptical	256.07	77.85	77.00	2.15	2.75	19.50	156.13
81	Arch	3869.81	81.29	81.03	3.66	12.83	26.00	28.15
82	Circular	5838.67	85.51	85.38	2.40	N/A	12.00	20.40
87	Box	1616.71	82.13	81.66	1.80	8.00	138.00	160.67
88	Box	1093.15	80.10	79.85	2.20	3.50	20.90	40.00
90[1]	Circular	277.41	73.87 (all)	73.82 (all)	1.20, 1.40, 1.20	N/A	6.00	6.80
92	Arch	6758.22	254.43	254.49	1.80	1.85	8.50	37.71
93	Box	2291.93	268.67	268.63	1.40	1.90	3.50	5.66
94	Box	8990.55	259.77	259.80	2.30	3.05	5.81	5.81
96[2]	Arch	6969	87.70 (W) & 87.74 (E)	87.55 (W) & 87.76 (E)	4.40 (W) & 4.40 (E)	4.00 (W) & 4.00 (E)	12.00	28.97 (W) & 28.57 (E)
98	Arch	2180.92	98.20	97.98	3.80	12.80	5.60	16.93
99	Circular	9054.77	96.37	96.22	3.00	N/A	4.30	27.14
101	Circular	2232.36	76.88	75.93	3.00	N/A	31.00	108.64
102	Circular	1450.292	81.94	81.48	1.20	N/A	31.00	27.21
103	Box	2865.58	96.69	96.61	1.50	5.60	22.50	49.00
104[3]	Arch (W) Circular (E)	3277.59	97.81 (W) & 98.61 (E)	97.76 (W) & 98.36 (E)	1.60 (W) & 1.20 (E)	1.80 (W)	5.60	10.70
105	Box	4111.75	101.22	100.73	1.10	8.00	25.80	44.29

Structure ID	Shape	Cross Section ID	US Invert (m)	DS Invert (m)	Diameter or Rise (m)	Width or Span (m)	Deck Roadway Width (m)	Culvert Length (m)
106	Circular	5092.15	107.81	107.57	1.20	N/A	35.00	55.00
107	Circular	2807.84	274.91	274.40	0.45	N/A	9.50	16.12
108	Not Modelled – Beginning of the channel.							
109	Box	1333.25	180.36	180.32	1.50	1.85	13.50	16.93
110	Circular	524.91	109.85	109.54	1.20	N/A	11.00	23.47
111	Not Modelled – Beginning of the channel.							
112	Not Modelled – Upstream contributing area is less than 125Ha							
113	Not Modelled – Upstream contributing area is less than 125Ha							
114	Not Modelled – Upstream contributing area is less than 125Ha							
115	Box	1051.74	79.78	79.63	1.20	2.40	11.40	18.50

[1] *Culvert has three pipe openings.*

[2] *Culvert has two pipe openings.*

[3] *Includes the relief culvert (circular) located on the east side of the main culvert (arch).*

Table 9: Hydraulic Characteristics of Bridges

Structure ID	Cross Section ID	Number of Piers	Bridge Span (m)	Deck Roadway Width (m)
23	11.9	1	10.00	6.40
28	16408.9	0	8.30	6.95
31	22914.49	0	22.20	22.00
32	22760.01	0	12.20	6.25
33	21989.04	0	10.40	6.20
34	21717.49	0	20.60	19.50
35	21348.56	0	12.10	10.00
36	21068.76	0	14.10	13.75
40[1]	19569.3	2	130.00	23.00
	19502.85	2	130.00	23.00
41[1]	1928.3	0	25.00	14.50
	1871.81	0	25.00	14.50
42	Not Modelled – The deck elevation is higher than the WSE.			
43	1887.05	0	46.60	55.00
44	15064.71	0	45.90	63.00
45	15107.82	0	45.90	13.00
51	908.12	0	45.90	25.00
52	348.05	0	3.11	7.35
54	13765.76	0	9.95	23.00
61	4771.64	0	41.02	48.00

Structure ID	Cross Section ID	Number of Piers	Bridge Span (m)	Deck Roadway Width (m)
63	9678.64	0	12.20	9.70
64	5917.58	0	26.30	22.37
68	9647.5	0	16.55	13.35
69	7928.42	0	15.55	20.93
70	2331.55	0	15.50	20.95
76	969.62	0	14.80	17.20
77	6551.59	0	14.75	17.00
79	4877.17	0	18.60	17.90
80	4594.22	2	30.50	12.20
83	3402.27	2	68.65 (US) & 68.90 (DS)	42.24
84	3339.7	2	58.28 (US) & 59.67 (DS)	12.00
85	2518.02	2	74.00	12.50
86	2402.24	2	72.00	37.55
89	804.55	0	11.00	21.83
91	1923.56	0	26.79	22.16
95	Not Modelled – Beginning of the channel.			
97	2071.52	0	36.10	5.58
100 - North	3313.6	0	14.44	9.00
100 - South	3293.01	0	13.25 (US) & 10.37 (DS)	9.00

[1] *Modelled as two separate crossings.*

8.3.3 Ineffective Areas

Ineffective areas are used by the model to allow water to occupy areas within cross sections without allowing for channel conveyance (i.e., no velocity). This is required to simulate the contraction and expansion effects of hydraulic structures at the upstream and downstream bounding cross sections and to simulate floodplain storage effects where water velocities are expected to be very low or negligible as the water fills these floodplains laterally.

Ineffective areas were applied at hydraulic structures represented by the upstream bounding cross sections on a 1:1 ratio which placed the ineffective area at the same distance laterally from the side of the hydraulic structure opening to the distance from the structure to the bounding cross sections. For the downstream cross section, the ratio was at 1:2. Ineffective areas at the upstream and downstream cross sections of a hydraulic crossing were set to the lowest elevation of the road deck (also referred to as the spill elevation).

8.4 Model Parameters

8.4.1 Boundary Conditions

Upstream and downstream boundary conditions are required to tie the model into the conditions of flow entering the system and water levels as it exits the Lynde Creek watercourse system and enters Lake Ontario.

Upstream Boundary Conditions

The upstream boundary conditions consist of flow values that were assigned to each channel reach at its first cross section. These flow values were estimated using the results of the hydrologic model, as mentioned in **Section 8.4.3**. For cases where no available information existed for upstream flow values ten percent (10%) of the downstream flow value was assumed. This assumption was based on the requirement for flow at flow change locations not to increase more than ten percent (10%).

Downstream Boundary Conditions

The application of the downstream boundary conditions was based on the Flood Hazard Guidelines (MNRF, 2002). The water level in Lake Ontario was taken as the downstream boundary condition in the hydraulic model with a fixed elevation. This is considered a reasonable assumption based on the long-term fluctuations in water elevations in Lake Ontario which can take weeks or even months to change significantly.

It was established by CLOCA that, as per the most recently completed floodplain model for Corbett Creek (also in their jurisdiction), a water level at Lake Ontario of 74.77 m (Vertical Datum: IGLD85) to be applied to this model as the downstream boundary condition. A conversion of the IGLD85 vertical datum to the project datum (CGVD2013) was undertaken by subtracting 0.46 m from the IGLD85 value to obtain a fixed water level at Lake Ontario of 74.31 m (CGVD2013) based on the elevation difference identified by Natural Resources Canada (Geodetic tools and data) at the station (Number: 18U927) located near the Lynde creek outlet at Lake Ontario. The selection of a fixed water level at Lake Ontario is also adequate because the flood events are short in duration when compared to the long-term water elevation trends in the lake.

8.4.2 Manning’s n Coefficient

The land cover data for the Lynde Creek watershed was provided by CLOCA as part of the background information. This information was utilized to classify the study area based on different land cover types, and therefore assign the preliminary Manning’s n roughness coefficient values accordingly. Roughness coefficient for each land cover type were assigned using the HEC-RAS Hydraulic Reference Manual published by the US Army Corps of Engineers (USACE, 2023) as the data source **Table 10** summarizes the land use and associated Manning’s n assigned to the Lynde Creek watershed.

Table 10: Manning's n Coefficient Applied to Lynde Creek Land Use

Land Cover ID	Land Cover Type	Recommended Manning’s N Range	Assigned Manning’s N Coefficient
1	Clear Open Water	0.025 – 0.05	0.03
5	Marsh	0.045 – 0.15	0.06
6	Swamp		
7	Fen		
12	Treed Upland	0.08 – 0.20	0.08
13	Deciduous Treed		
14	Mixed Treed		
15	Coniferous Treed		
16	Plantations - Treed Cultivated	0.02-0.05	0.04
17	Hedge Rows	0.02-0.05	0.04

Land Cover ID	Land Cover Type	Recommended Manning's N Range	Assigned Manning's N Coefficient
25	Sand/Gravel/Mine Tailings/Extraction	0.023 – 0.03	0.03
27	Community/Infrastructure	0.04	0.04
28	Agriculture and Undifferentiated Rural Land Use	0.02 – 0.05	0.03

Note: Manning's n values adapted from Chow (1959), excluding "Developed" land type. These n values are for appreciable depths of flow and are not meant for shallow overland flow. Shallow, overland flow Manning's n values are generally much higher, due to the relative roughness compared to the flow depth.

The Manning's n coefficient assigned to all channels is consistent throughout model domain. This was achieved by creating a polygon of the channel within the bank lines and integrating it into the land use layer to assign Manning's n coefficients over the cross sections. The Manning's n values are assigned to each cross section using the land use layer and an automated procedure in RAS Mapper.

8.4.3 Flow Change Locations

As mentioned in **Section 8.4.3**, the flow change locations along each river and reach within the Lynde Creek watershed were defined based on the VO simulation results and percentage of contributing area contributing to the respective river and reach. Furthermore, to interpret the flows at cross sections between flow change locations and ensure smooth transition, interpolation was completed along all the rivers based on the ratio of upstream and downstream flow values, and the relative distance between the downstream cross section and the flow change location. The uncontrolled 100-year, Regional Storm and Climate Change flow inputs along with the corresponding HEC-RAS cross sections are provided in **Appendix C**.

8.4.4 Additional Inputs

Additional inputs were made to the hydraulic model and were not previously discussed in the above sections. These inputs are summarized below.

Contraction and Expansion Coefficients

Contraction and expansion coefficients were assigned to each cross-section in the model based on the guidelines provided for subcritical flows in the HEC-RAS Hydraulic Reference Manual (USACE, 2023). It is assumed that transition is abrupt, upstream and downstream of culverts; therefore, for the subcritical flow, values of 0.3 and 0.5 were given as the contraction and expansion coefficients, respectively. For all the bridge crossings, the contraction and expansion coefficients were also increased to 0.3 and 0.5, respectively, for two cross sections upstream and one cross section downstream of the bridge.

Artificial Levees

The preliminary results from the hydraulic model indicated a few areas within the Lynde Creek reach where flooding appears without any lateral connection to the watercourse. In these cases, the LiDAR information was reviewed at each location to confirm whether there was a hydraulic connection. For places where no hydraulic connection was identified, an artificial levee was added to the cross section to avoid lateral flooding that otherwise would not occur. For those areas where a hydraulic connection was identified, no modifications were made to the cross section. Refer to **Appendix D.1** for the locations where artificial levees were added to the hydraulic model.

High Flow Methods

When the bridge deck or road was overtopped the pressure and/or weir method was used. For small obstructions where flow depth was below the bridge soffit, the energy-based method was utilized.

Highway Noise Barrier

As instructed by CLOCA, noise barriers were not modelled as an obstruction because it is not anticipated the fence could withstand the hydrodynamic force from any significant depth of floodwater. However, the concrete barriers were modelled where high-water flow and overtopping was observed (i.e., Structure 83 on Highway 401).

8.5 Sensitivity Analysis

The Manning's n coefficient represents the roughness of a channel, which influences the flow velocity and water depth. Sensitivity analysis on the Manning's n coefficient is a critical step in hydraulic modeling to ensure reliability and robustness of the model outputs.

To assess the impact of changes to Manning’s n coefficient on the resulting water levels, a sensitivity analysis was completed to understand the numerical properties of the model and how reasonable it is for a range of different parameters to affect model results.

The Manning’s n coefficients are values based on land cover characteristics to reflect friction forces applied on the flow and were discussed in **Section 8.4.2**. The values in the model were increased by 20% for all land cover types. The revised Manning’s n coefficients applied for the sensitivity analysis are presented in **Table 11** with the original coefficients also presented for reference.

Table 11: Revised Manning's n Coefficients for Sensitivity Analysis

<table>
<tr><th>Land Cover ID</th><th>Land Cover Type</th><th>Recommended Manning’s n Range</th><th>Assigned Manning’s n Coefficient</th><th>Increase of 20%</th></tr>
<tr><td>1</td><td>Clear Open Water</td><td>0.025 – 0.05</td><td>0.03</td><td>0.036</td></tr>
<tr><td>5</td><td>Marsh</td><td rowspan="3">0.045 – 0.15</td><td rowspan="3">0.06</td><td rowspan="3">0.072</td></tr>
<tr><td>6</td><td>Swamp</td></tr>
<tr><td>7</td><td>Fen</td></tr>
<tr><td>12</td><td>Treed Upland</td><td rowspan="4">0.08 – 0.20</td><td rowspan="4">0.08</td><td rowspan="4">0.096</td></tr>
<tr><td>13</td><td>Deciduous Treed</td></tr>
<tr><td>14</td><td>Mixed Treed</td></tr>
<tr><td>15</td><td>Coniferous Treed</td></tr>
<tr><td>16</td><td>Plantations - Treed Cultivated</td><td>0.02-0.05</td><td>0.04</td><td>0.048</td></tr>
<tr><td>17</td><td>Hedge Rows</td><td>0.02-0.05</td><td>0.04</td><td>0.048</td></tr>
<tr><td>25</td><td>Sand/Gravel/Mine Tailings/Extraction</td><td>0.023 – 0.03</td><td>0.03</td><td>0.036</td></tr>
<tr><td>27</td><td>Community/Infrastructure</td><td>0.04</td><td>0.04</td><td>0.048</td></tr>
<tr><td>28</td><td>Agriculture and Undifferentiated Rural Land Use</td><td>0.02 – 0.05</td><td>0.03</td><td>0.036</td></tr>
</table>

The water levels differences throughout the Lynde Creek System (Reach 1 and 2) as a result of increasing the Manning's n coefficient are shown in **Table 12**.

Table 12: Water Level Differences (Lynde 1 and Lynde 2) - Manning's n Coefficient Sensitivity Analysis

Storm Event	Difference in Water Surface Elevation (m)		
	Average	Minimum	Maximum
100-year Uncontrolled	0.01	0.00	0.56
Regional Storm	0.08	0.00	0.23
Regional + Climate Change	0.09	0.00	0.28

The results of the sensitivity analysis on water elevations indicate that the increase in Manning's n coefficients by 20% has impact across the Lynde Creek model (Reach 1 and 2) with an average difference of 0.08 m for Regional Storm event. The increase in Manning's n coefficients did not have an impact on hydraulic control points nor changed the conveyance through the hydraulic structures.

8.6 Review of Model Results

Due to the size of the Lynde Creek catchment and hydraulic model as well as the number of flow simulations run, there are numerous results that could be presented. The focus of this section is to provide observations and analysis of the results for 'uncontrolled' 100-year and the Regional Storm event. The tabular format of these results is provided in **Appendix D.2**. Model results the Regional Storm event under Climate Change effect is also included in **Appendix D.2**.

8.6.1 Longitudinal Profile

The stream longitudinal profile for Lynde Creek corresponding to the Regional Storm is included in **Figure 8** and includes reaches Lynde 1 to 5. There are several hydraulic control points that are governed by either hydraulic structures or terrain throughout the system. It was also observed that the hydraulic regime remains within subcritical flow, especially at the downstream reaches which have lower terrain slopes as Lynde Creek approaches Lake Ontario. Lake Ontario was set at a constant elevation of 74.31 m which, in combination with watershed flows, control the lower floodplain boundaries of Lynde Creek. Velocities within the river during the 100 year (uncontrolled) and Regional Storm events simulation range between 0.24 to 6.09 m/s and 0.45 to 7.37 m/s with an average of 2.04 and 2.72 m/s, respectively.

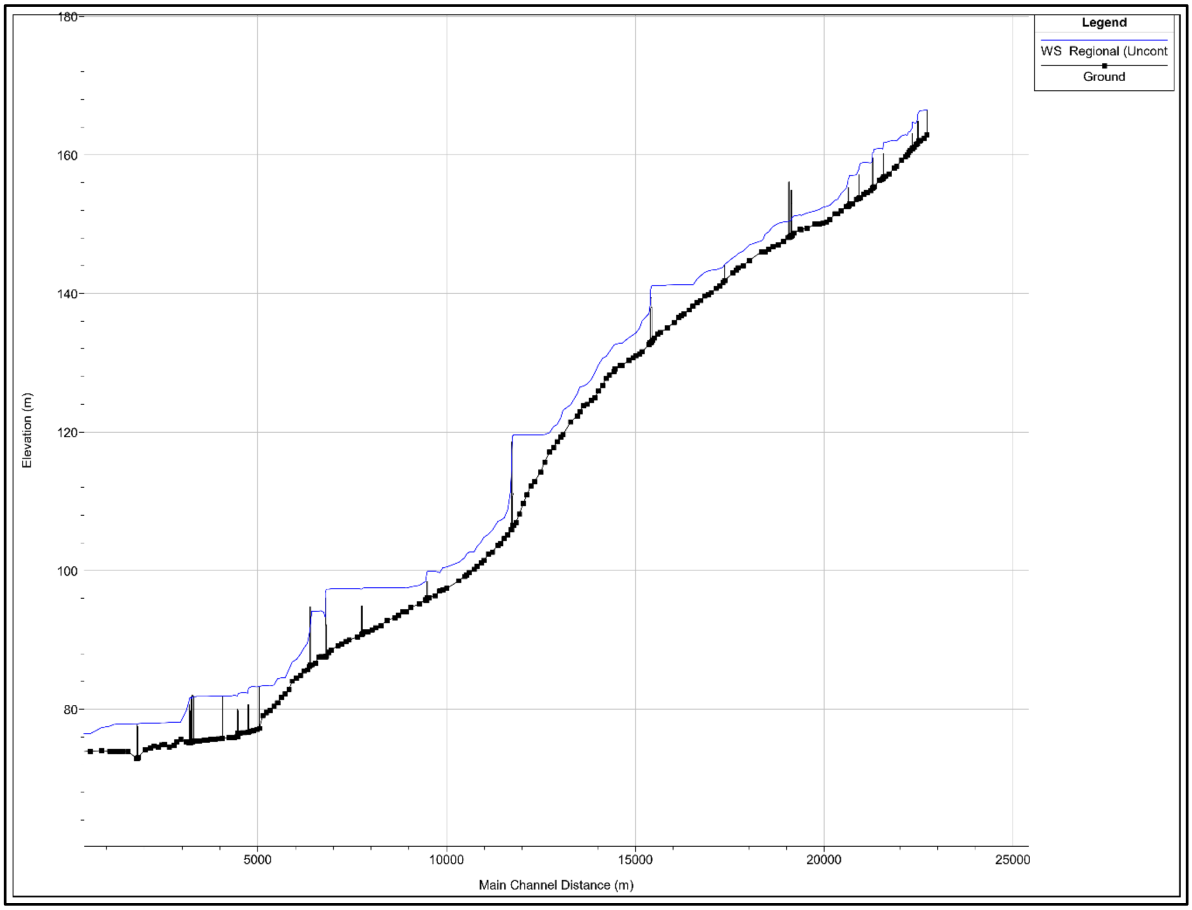

Figure 8: Longitudinal Profile Lynde Creek - Regional Storm

8.6.2 Comparison to Previous Floodplain Mapping Studies

The last floodplain analysis of Lynde Creek was completed in 2008 by Earth Tech. A comparison of the resulting floodplain boundaries was undertaken between the current hydraulic model results and the previous 2008 study. Overall, the results from the two models agree for most of the study area. However, differences between flood boundaries were noted. The differences between floodplain boundaries from both studies are generally related to updates to the hydrology including an increase in flow rates as a direct result of a changes in impervious areas and modifying CN Number to reflect AMCIII as discussed in **Section 6**. Also, the current hydraulic model was built using LiDAR and bathymetric data that was unavailable in 2008 and allows for a more detailed representation of terrain characteristics.

In addition to the above, since 2008 new highway and road alignments, urban developments and channel realignments have occurred in the Lynde Creek watershed. These changes have significantly impacted conveyance, potentially extending the floodplain boundaries. A representation of the flood plain boundary varying between the 2008 and the current model, resulted from these changes, was observed in the area between Highway 412 and Des Newman Boulevard, south of Taunton Road and the CPKC, as shown in **Figure 9**. The major differences between the current model and the 2008 model in this area are due to the construction of Highway 412 and Des Newman Boulevard, resulting in regrading. Additionally, the current study extends the modeling to include the adjacent river reach, Lynde T1, and as per the Comprehensive Floodplain Reduction Report for West Whitby Secondary Plan Area (Candevcon, 2016), a new relief circular culvert of diameter 1.20 m was installed by West Whitby Developers beneath the CPKC on Lynde T1 tributary (refer **Appendix A.7** for construction drawings). It is noteworthy that variation between flood plain boundaries between the 2008 and the current model is consistently observed when compared for other flood events.

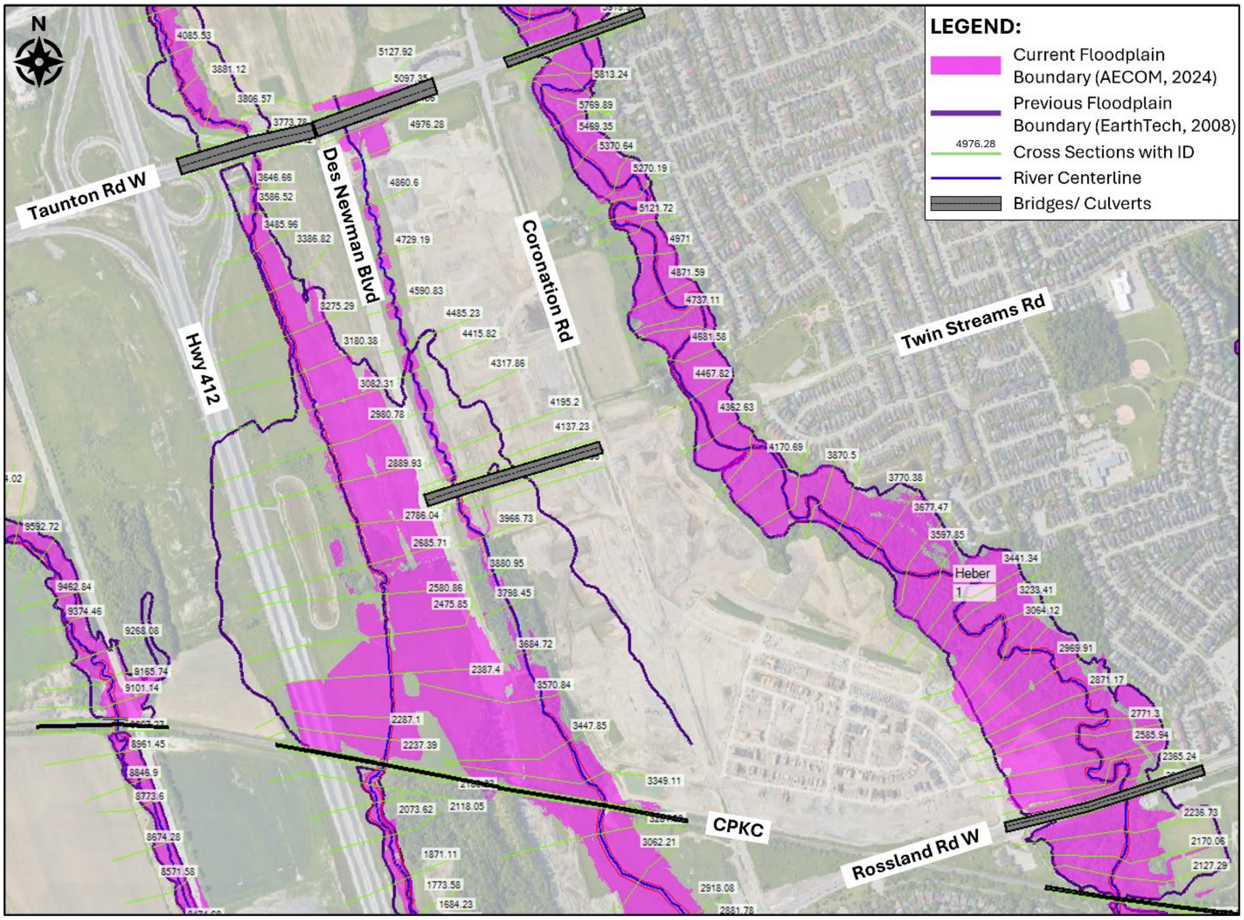

Figure 9: Comparison of Floodplain Boundaries for Regional Storm – 2008 and the Current Models - between Highway 412 and Des Newman Boulevard, south of Taunton Rd W & the CPKC

8.6.3 Area of Interest: Michael Boulevard - Between Dundas Street West and Highway 401

In the 2008 model, significant flooding was observed in the area south of Dundas Street West and north of Highway 401, between Michael Boulevard area and Lynde Creek. Since the development of 2008 model, major changes took placed in this area, including the addition of Highway 412 and ramps to the Highway 401, widening of Highway 401 and Victoria Street West, expansion of the urban area, and the modification and construction of multiple river crossings. The results of the current model show a similar extent of flooding boundaries under the 100 year and the Regional Storm events. It is understood that the river crossings with the railway line along the south of Highway 401 have not been upsized to match the changes, possibly causing a congestion point and resulting in flooding on the 401 and upstream towards Michael Boulevard. The increase in the flood extent could be the result of combined multiple factors including flow change, geometry updates, and new structures. A comparison of the flood plain boundaries between the current and the 2008 study for the area south of Dundas Street West and north of Victoria Street West is shown in **Figure 10**.

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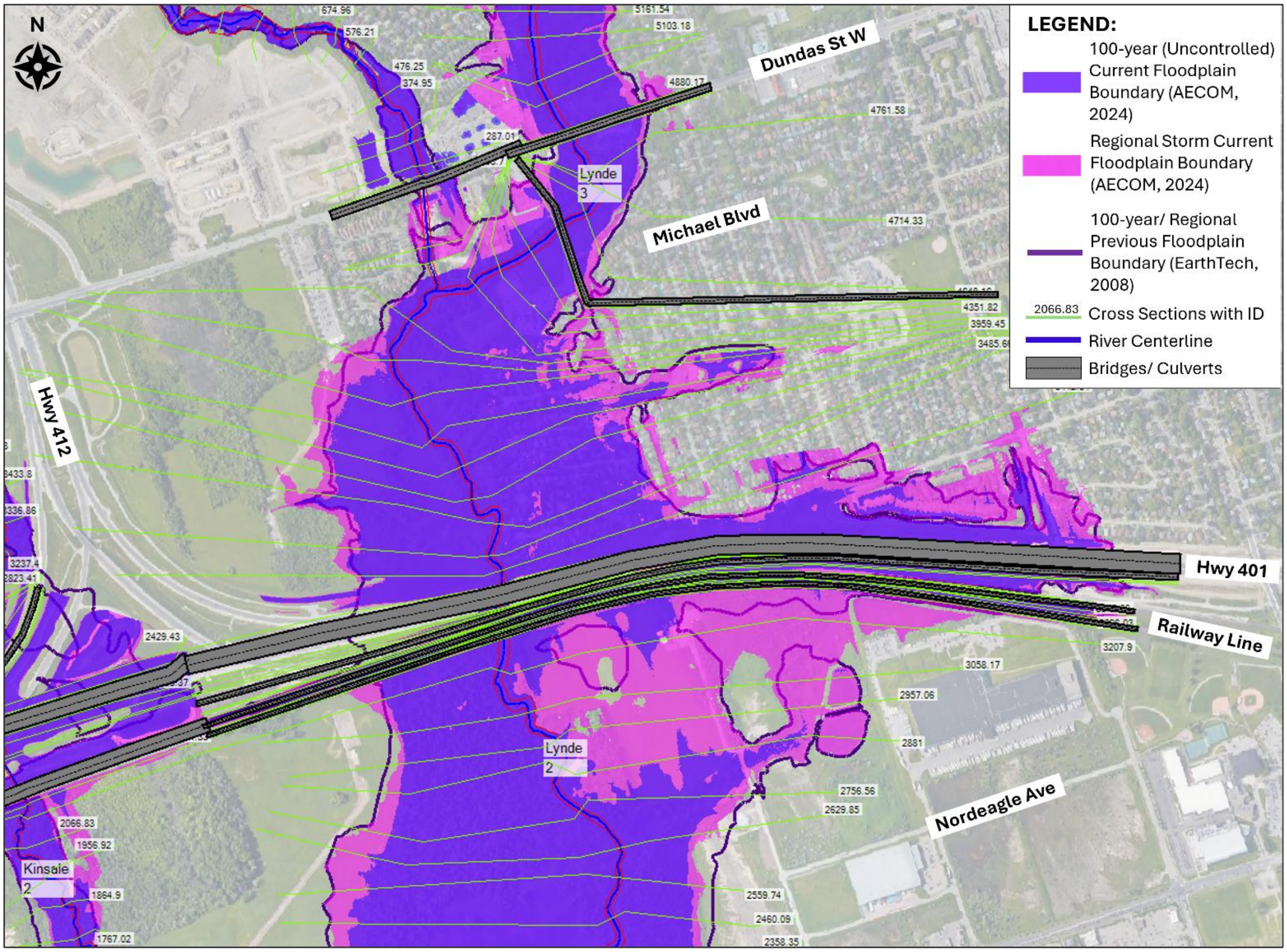

Figure 10: Comparison of Floodplain Boundaries for 100 year and the Regional Storm - 2008 and the Current Models - south of Dundas St W and north of Highway 401

8.6.4 Overtopped Structures

A total of 67 hydraulic structures are shown to be overtopped by either the 100-year or Regional Storm event. These structures are identified in **Table 13** with their location and structure number referred back to the 2008 Floodplain Study (Earth Tech, 2008). Eleven (11) of these are new structures resulting from new road infrastructure. It is to be noted that all the structures that are now overtopped based on the updated floodplain mapping were also overtopped as per the 2008 Floodplain Study.

Additionally, there are nine (9) structures that were overtopped in the 2008 model (in either the 100 year or Regional storm event) that are no longer overtopped based on the updated floodplain mapping. These structures are listed in **Table 14**. In the majority of these cases, the structures were upsized since 2008.

Table 13: Overtopped Structures under 100-year/Regional Storm Event - Current Hydraulic Study

Structure ID	River	Reach	Station	Location	Structure No. 2008 Floodplain Study	Overtopped in Current Hydraulic Study (Yes/No)		Overtopped in 2008 (Yes/No)	
						100-year (Uncontrolled)	Regional Storm Event	100-year	Regional Storm Event
2	Myrtle	4	9497.34	Scugog Line 2	Structure 67	No	Yes	No	Yes
3	MyrtleT3	1	117.65	Bryant Side Rd.	Structure 68	Yes	Yes	Yes	Yes
4	Myrtle	3	7369.54	Townline Rd. W.	Structure 69	No	Yes	No	Yes
5	Ashburn	2	10182.37	Townline Rd. W.	Structure 65	Yes	Yes	Yes	Yes
7	MyrtleT2	1	417.32	Myrtle Rd. W.	Structure 72	No	Yes	No	Yes
9	Ashburn	2	7106.6	Myrtle Rd. W.	Structure 63	Yes	Yes	Yes	Yes
10	Heber	5	22088.94	Myrtle Rd. W.	Structure 62	No	Yes	No	Yes
11	HeberT4	1	6752.61	9th Concession Rd.	Structure 61	No	Yes	Yes	Yes
12	HeberT4	1	6392.251	Sideline Rd. 2	Structure 60	Yes	Yes	Yes	Yes
13	HeberT4	1	3551.74	Sideline Rd. 2	Structure 59	Yes	Yes	Yes	Yes
14	HeberT4	1	3304.39	8th Concession Rd.	Structure 58	No	Yes	Yes	Yes
17	HeberT2	3	6569.4	Brawley Rd. W.	Structure 57	Yes	Yes	Yes	Yes
18	Ashburn	1	2756.72	Ashburn Rd.	Structure 74	No	Yes	Yes	Yes
19	Ashburn	1	1610.5	Brawley Rd. W.	Structure 75	No	Yes	Yes	Yes
20[1]	Myrtle	2	2305.7	Calistoga Dr.	N/A	No	Yes	N/A	N/A
22	Myrtle	1	1539.02	Brawley Rd. W.	Structure 76	No	Yes	No	Yes
23	Ashburn	1	11.9	Cedarbrook Trail	Structure 40	Yes	Yes	Yes	Yes
24	Lynde	6	24188.66	Columbus Rd. W.	Structure 38	No	Yes	No	Yes
25	HeberT2a	2	3886.35	Columbus Rd. W.	Structure 54	Yes	Yes	No	Yes
26	HeberT2	3	3992.19	Columbus Rd. W.	Structure 52	Yes	Yes	No	Yes
27	HeberT2	3	4534.79	Country Lane	Structure 53	Yes	Yes	Yes	Yes
30	LyndeT3	1	814.78	Baldwin St. N.	Structure 39	Yes	Yes	No	Yes
31[1]	Lynde	5	22914.49	Carnwith Dr. W.	N/A	No	Yes	N/A	N/A
32	Lynde	5	22760.01	Way St.	Structure 37	Yes	Yes	No	Yes
33	Lynde	5	21989.04	Way St.	Structure 36	Yes	Yes	No	Yes

Structure ID	River	Reach	Station	Location	Structure No. 2008 Floodplain Study	Overtopped in Current Hydraulic Study (Yes/No)		Overtopped in 2008 (Yes/No)	
						100-year (Uncontrolled)	Regional Storm Event	100-year	Regional Storm Event
34	Lynde	5	21717.49	Baldwin St. N.	Structure 35	No	Yes	No	Yes
35	Lynde	5	21348.56	Cassels Rd. E.	Structure 34	Yes	Yes	No	Yes
36	Lynde	5	21068.76	Winchester Rd. E.	Structure 33	Yes	Yes	No	Yes
38	LyndeT2	1	1704.7	Duggan Ave.	Structure 32	Yes	No	No	No
52[1]	HeberT3	1	348.05	Coronation Rd.	Not Identified	Yes	Yes	N/A	N/A
53	HeberT3	1	85.59	Winchester Rd. W.	Structure 45	No	Yes	No	No
54	Heber	4	13765.76	Winchester Rd. W.	Structure 46	No	Yes	No	Yes
55	HeberT2	2	1089.88	Winchester Rd. W.	Structure 48	No	Yes	No	Yes
56	HeberT2a	2	734.38	Cochrane St.	Structure 49	Yes	Yes	No	Yes
58	Kinsale	4	16493.99	Audley Rd.	Structure 41	Yes	Yes	Yes	Yes
59	KinsaleT3	1	8052.81	Halls Rd. N.	Structure 43	Yes	Yes	Yes	Yes
60	Kinsale	4	10853.73	Taunton Rd. E.	Structure 13	No	Yes	No	Yes
63	Heber	2	9678.64	Lyndebrook Rd.	Structure 47	Yes	Yes	No	Yes
65	Lynde	4	11911.29	Taunton Rd. W.	Structure 9	No	Yes	No	Yes
66	Lynde	4	15584.74	Baldwin St. S.	Structure 30	No	Yes	No	Yes
67	LyndeT2	1	535.26	St. Thomas St.	Structure 31	Yes	Yes	Yes	Yes
68	Lynde	4	9647.5	Cochrane St.	Structure 10	Yes	Yes	No	Yes
69	Lynde	4	7928.42	Rossland Rd. W.	Structure 1	Yes	Yes	No	Yes
70	Heber	1	2331.55	Rossland Rd. W.	Structure 2	Yes	Yes	No	Yes
72	Kinsale	4	7995.78	Rossland Rd. W.	Structure 6[2]	No	Yes	No	Yes
73[1]	Kinsale	4	8228.87	Lake Ridge Rd. N.	N/A	No	Yes	N/A	N/A
76	Heber	1	969.62	Bonacord Ave.	Structure 22	No	Yes	No	Yes
78	LyndeT1	1	256.07	Dundas St. W.	Structure 26	Yes	Yes	No	Yes
79	Lynde	3	4877.17	Dundas St. W.	Structure 24	Yes	Yes	Yes	Yes
80	Lynde	3	4594.22	Jeffery St.	Structure 25	Yes	Yes	Yes	Yes
81	Kinsale	3	3869.81	Dundas St. W.	Structure 29	No	Yes	Yes	Yes
82	Kinsale	3	5838.67	Halls Rd. N.	Structure 21	Yes	Yes	Yes	Yes
83	Lynde	2	3402.27	Highway 401	Structure 16[2]	Yes	Yes	Yes	Yes

Structure ID	River	Reach	Station	Location	Structure No. 2008 Floodplain Study	Overtopped in Current Hydraulic Study (Yes/No)		Overtopped in 2008 (Yes/No)	
						100-year (Uncontrolled)	Regional Storm Event	100-year	Regional Storm Event
84	Lynde	2	3339.7	Highway 401	Structure 15[2]	Yes	Yes	No	Yes
86[1]	Kinsale	2	2402.24	Highway 401	N/A	Yes	Yes	N/A	N/A
89	Kinsale	1	804.55	Victoria St. W.	Structure 19	Yes	Yes	Yes	Yes
90	Kinsale	1	277.41	Eastbourne Beach Rd.	Structure 18	Yes	Yes	Yes	Yes
91	Lynde	2	1923.56	Victoria St. W.	Structure 17	Yes	Yes	Yes	Yes
92	Myrtle	3	6758.22	Railway Line	Structure 70	No	Yes	No	Yes
93	MyrtleT2	1	2291.93	Railway Line	Structure 66	No	Yes	Yes	Yes
94	Ashburn	2	8990.55	Railway Line	Structure 64	No	Yes	No	Yes
96	Lynde	4	6969	Railway Line	Structure 4	No	Yes	No	Yes
100	Lynde	2	3313.6 & 3293.01	Railway Line	Structure 14	Yes	Yes	No	Yes
101	Kinsale	2	2232.36	Railway Line	Structure 28[2]	Yes	Yes	Yes	Yes
107[1]	MyrtleT2	1	2807.84	Townline Rd. W.	N/A	Yes	Yes	N/A	N/A
109[1]	LyndeT3	1	1333.25	Columbus Rd. E.	N/A	No	Yes	N/A	N/A
110[1]	HeberT1	1	524.91	Coronation Rd.	N/A	No	Yes	N/A	N/A

[1] *New Structure; Not included in 2008 Floodplain Study.*

[2] *Structure has been upgraded/modified since 2008.*

Table 14: Structures overtopped in 2008 Floodplain Study under either 100-year or Regional Storm Event - Not Overtopped in the Current Hydraulic Study

Structure ID	River	Reach	Location	Structure No. 2008 Floodplain Study
8	AshburnT1	1	Myrtle Rd. W.	Structure 73
64	Heber	1	Taunton Rd. W.	Structure 11
42	HeberT2a	2	Winchester Rd. W.	Structure 50
48	HeberT3	1	Halls Rd. N.	Structure 44
57	Kinsale	4	Winchester Rd. W.	Structure 42
N/A	KinsaleT1	1	Highway 401	Structure 27
62	KinsaleT3	1	Taunton Rd. W.	Structure 12
98	KinsaleT3	1	Railway Line	Structure 8
71	KinsaleT3	1	Rossland Rd. W.	Structure 5

9. Flood Maps

Flood maps have been developed for Lynde Creek and its tributaries in a collection of map tiles that include floodplain boundaries for the 100-year (uncontrolled) event, Regional Storm event, and adjusted Climate Change event to comply with the FHIMP (Federal Hazard Identification and Mapping Program) guidelines (MNRF, 2023). These map tiles have a resolution of 1:2000 metres resulting in 88 map tiles labeled L1 to L86 and arranged in a grid pattern from south to north.

The results of the HEC-RAS model were exported to GIS software (ArcGIS Pro) to generate the flood maps in a template provided by CLOCA. The maps include aerial imagery that show the buildings, infrastructure, vegetation, and other details. The maps also include elevation contours with a resolution of 1 metre, flood lines (future uncontrolled 100-year, Regional, and Climate Change), HEC-RAS cross section ID numbers and the corresponding water elevation for the 100-year and the Regional events, road deck minimum elevation, mapping limits, sheet index number, associated legend, geographic datums, scale and compass rose.

9.1 Regulation Limit

The regulatory flood maps have been developed in compliance with the MNRF Technical Guidelines, based on the results of the hydraulic model from its upstream limits to the outlet of Lynde Creek at Lake Ontario. The Regulatory flood maps have a scale of 1:2000. Buildings, infrastructure, vegetation and other details are shown with aerial imagery from First Base Solutions (2019). The maps also include topographic contours, cross-section ID number and water elevation, sheet index number, legend, geographic datums, scale and compass rose.

Furthermore, the results show areas along the reaches which primarily occupy low-lying terrain or wetland areas due to lateral water movement, or urban areas with some cases of backwater impact causing water to convey laterally. As required by CLOCA the cross-sections were extended to contain all water within the floodplain, however, in some cases cross sections were limited in extent not to include large drainage ditches in main roads and highways.

The floodlines were post-processed to accurately reflect overtopping conditions at each structure. For culverts, the floodlines between the upstream and downstream areas were connected if the road deck surface was higher than the interpolated water surface between these points. For bridges, where the top of the road was not captured in the terrain surface, the floodline polylines were adjusted or cut. However, in cases where overtopping occurred, the floodlines on top of the structure remained intact.

9.2 Spill, Backwater and Flood Prone Areas

Backwater areas were observed at various locations within the model domain where it was observed that constrictions caused by hydraulic structures may cause backwater effects. However, these areas were localized to smaller structures on the northern sections of the model. An example is Structure 28 on Columbus Rd W.

Spills occur when lateral overflows extend beyond the channel limits. To accurately identify these spilling conditions, the cross sections must be extended far enough to capture the entire extent of the lateral flows. The previous flood study report (Earth Tech, 2008) indicated that spill areas were identified but described as continuing for an undetermined distance, suggesting that the 2008 model may not have extended sufficiently beyond the floodplain boundaries. For the current study, efforts were made to extend the cross sections far enough to encompass the entire floodplain.

The modeling results show that where the stream system is located within rural and farmland areas, mainly north of Columbus Road North, spilling is less frequent and less extensive, or, if observed, it often does not cause overtopping. However, in the southern portion of the model, lateral spilling was observed to be wider and more prevalent, primarily due to flow accumulation (as flows increase downstream with the catchment area) and urbanization, which inherently increases the risk of flood exposure. For the southern part of the catchment area, the cross sections needed to be extended significantly longer compared to the northern part. The necessity to extend cross sections to capture the lateral flows highlights the requirement for a 2D or combined 1D/2D modeling approach in the future studies.

Based on floodplain maps and Google aerial photos, significant flooding is observed to threaten residential areas between Dundas Street West and Highway 401 in the Michael Boulevard area towards Lynde Creek. Consistent with the 2008 modeling results, this area is prone to the largest lateral spills within the Lynde Creek Catchment (shown in
Figure 10).

A review of the 11 spill locations that were identified in the previous Floodplain Study (Earth Tech, 2008) was carried out. In the current study the number of major spill locations is updated to 11 locations including three (3) new spill locations and eight (8) locations identified from the 2008 Study as shown in **Table 15.**

Table 15: Summary of Spill Locations from Current Hydraulic Evaluation

Spill No.	River	Reach	Description from 2008 Study (Regional Uncontrolled/100-year)	Current Hydraulic Model
1	Heber	4	N/A	A spill was observed west of Winchester Road West and Country Lane intersection from the north side of Winchester Road West (north of Structure 54). Herber 4 is spilling on the west side towards HerberT3-1.
2	KinsaleT1	1	N/A	A localized spill west of Lake Ridge Road (south of Structure 88) was observed.
3	Kinsale	2	N/A	The 2024 hydraulic model shows a spill toward east at the branch of tributary crossing Highway 401 near the Highway 412 interchanges for an undetermined distance. This spill might be a result of backwater from the smaller downstream outlet at Structure 101 located beneath railway line. The flow is spilling toward Lynde 2 but due to the limitation of 1D modeling and limited extent of the cross sections, this needs further confirmation.
4	Kinsale	3	A small spill was reported at Dundas Street on the west branch.	A localized spill is shown on the West Branch at the intersection of Dundas Street West and Halls Road North (near Structure 81). Flow spills over Dundas St W towards KinsaleT2-1.
5	Lynde	3	Small spill reported north of the intersection of Dundas Street and McQuay Boulevard (parking lot area).	This spill is also shown in the 2024 hydraulic model (north of Structure 79) and includes a lot with parking and commercial buildings, as well as a park area in the northeast corner of the intersection between Dundas Street West and McQuay Boulevard.
6	Kinsale	3	A spill is mentioned on the west side of Halls Road for approximately 800 m.	This spill is shown in the 2024 hydraulic model north of Dundas Street West adjacent to Halls Road North (west of Structure 82).

Spill No.	River	Reach	Description from 2008 Study (Regional Uncontrolled/100-year)	Current Hydraulic Model
7	KinsaleT3	1	A large spill is reported south of Rossland Road which appears to flood the Canadian National Railway.	This part of the floodplain has changed considerably since 2008: New branch (Lynde T1-1) is added to the current model, Highway 412 with ramps is added, and Des Newman Boulevard is extended. A spill is observed at east of the tributary branch, north of the intersection of CPKC and Des Newman Boulevard (north of Structure 98). The floodplain pours into flooding area of the adjacent tributary LyndeT1-1. Also, spill occurs toward west of the tributary to Highway 412 underpass.
8	MyrtleT2	1	This spill was reported at the west branch flooding a part of Myrtle Road.	This spill is shown on the upstream side of Myrtle Road West (north of Structure 7) comprising primarily forested area.
9	MyrtleT2	1	A small spill reported along the railroad just south of Townline Road.	The 2024 hydraulic model shows spill over the railway as well as north and south of the railway (northeast of Structure 93). The area occupied by the floodplain is farming area and forested.
10	Lynde	2	Located at the east branch on Highway 401 for an undetermined distance.	Spill occurs east of Lynde 2 and leave the branch over and the sides of Highway 401. In 2024 flood mapping, cross sections are extended far enough to capture the spilling distance.
11	Heber	1	A medium spill is reported at Taunton Road for approximately 750 m.	No spill observed at this location.
12	KinsaleT3	1	A spill is reported on the west side of Halls Road for an unknown distance.	A spill towards south is seen on the west side of Halls Road North for an unknown distance (near Structure 59).
13	Ashburn	1	This spill was observed on an undeveloped area located on the west side of Cedarbrook Trail.	No spill observed at this location.
14	Ashburn	2	This spill is also upstream of the railway on one of the west branches.	No spill observed at this location.

Other smaller spills and flood prone areas are indicated in the floodplain maps for Lynde Creek and presented in **Appendix E**.

9.3 Remedial Measures

Within the Regulatory flood event limits, the spill areas identified in **Section 9.2** include undeveloped, forested, and rural areas, as well as areas with low, medium, and high-density urban development. Remedial measures could therefore be considered and applied on a site-by-site basis and as flood protection infrastructure projects. These proposed measures require an analysis of cost and benefits to provide a rationale for their validity.

Remedial measures on a site-by-site basis could include:

- The hydraulic structures identified in **Table 13** could be targeted for conveyance improvement measures, to minimize overtopping which in turn will reduce backflow effects and adjust floodplain boundaries.

- Floodproofing any properties within or partially within the floodplain. The existing properties that are presently within the floodplain could be floodproofed with the construction of minor berms and/or ensuring that the low openings are above the flood elevation. The topography and any low openings close to the floodplain should also be reviewed and addressed (raised) if required.

- The construction of berms or retaining walls at key locations (like Michael Boulevard located north of Highway 401) within the Lynde Creek system could be considered to reduce the flood levels in built areas and to protect multiple properties. The Town of Whitby - Michael Boulevard Flood Mitigation Strategy Report (TMIG, 2020) identified the flood control berms as the preliminary preferred solution to be placed in the open space between Highway 401 and the residential slots to prevent floodwater from backing up in this area. The report also included a concept design for the proposed berms to provide protection for up to 100-Year storm event, with a freeboard of 0.30 m.

10. Conclusions and Recommendations

Flood maps have been developed based on the results of the hydraulic evaluation of Lynde Creek and its tributaries where a total of 45 reaches with 1847 cross sections were used to develop a HEC-RAS model. The model extends from the outlet of Lynde Creek with Lake Ontario to upstream tributaries near Chalk Lake Road.

The analysis, documented in this report, was carried out based on the standards found in the Technical Guide River & Stream Systems: Flooding Hazard Limit (MNRF, 2002). A collection of map tiles was produced and include floodplain boundaries for the 100-year event, Regional event, and adjusted Climate Change event to comply with the FHIMP (Federal Hazard Identification and Mapping Program) guidelines. These tiles have a resolution of 1:2000 m with 88 map tiles labeled L1 to L88 and arranged in a grid pattern from south to north.

The maps include aerial orthophotography from First Base Solutions (2019) under license with the Region of Durham and include topographic contours, cross-section ID and water elevation, sheet index number, legend, geographic datums, scale and compass rose.

The resulted floodplain mapping agreed with the previous study completed in 2008 by Earth Tech. According to these models, the largest lateral overflow and spill observed is between Dundas Street West and Highway 401, bounded by Michael Boulevard and the Lynde Creek. The Town of Whitby - Michael Boulevard Flood Mitigation Strategy Report (TMIG, 2020) provides detailed remedial measures and flood control alternatives for this area.

It is recommended that any remedial measures within Lynde Creek focus on improvements to conveyance at targeted locations that would have the greatest impact. Berms may be considered to protect existing flood prone areas, such as within the Michael Boulevard area, however as per provincial guidance, they are not to be implemented to allow for new development. All new development within Lynde Creek and its tributaries should be restricted from being located within the Regulatory floodplain.

Considering the extension of lateral spills and the required extension of the cross sections to capture the floodplain in the southern part of the catchment, it is recommended to develop a 2D or combined 1D/2D HEC-RAS model. Also, all modelling should be updated to reflect any significant changes in land use if they occur.

The Lynde Creek watershed is likely to experience urban land use intensification and boundary expansion. These changes have the potential to increase extents of floodplain. Before these changes are endorsed in municipal Official Plans, it is important to model the potential impacts for the floodplain and determine measures that would mitigate any detrimental impacts on downstream lands and people.

11. References

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