Regulatory Floodplain Hydraulic Report Barrie Creeks – Bunkers, Dyments, Hotchkiss, Kidds, Whiskey and Sophia

City of Barrie, Ontario

Body Document Only

D.M. Wills Project Number 23-5611

D.M. Wills Associates Limited
Partners in Engineering
Peterborough

April 2024

Prepared for:
Lake Simcoe Region
Conservation Authority

Summary of Revisions

Revision	Revision Title	Date of Release	Summary of Revisions
1	Draft Regulatory Floodplain Report	February 7, 2024	Issued for Client Review
2	Final Regulatory Floodplain Report	February 15, 2024	Issued for Provincial Review
3	Final Regulatory Floodplain Report	March 26, 2024	Final Submission
4	Final Regulatory Floodplain Report	April 5, 2024	AODA Review

This report / proposal has been formatted considering the requirements of the Accessibility for Ontarians with Disabilities Act.

This project is funded in part by the Government of Canada.

This project was made possible in part by the Province of Ontario.

Table of Contents

Figures

Tables

Appendices

Note: All Appendices are found in a separate appendix document.

Appendix A - Hydraulic Structure and Bathymetric Survey Data
Appendix B - Hydrology
Appendix C - Hydraulic Modelling
Appendix D - Floodplain Mapping

1.0 Introduction

1.1 Background

The Lake Simcoe Region Conservation Authority (LSRCA) is responsible for the regulation of development within hazardous lands, as well as flood forecasting and flood warning for areas under their jurisdiction. In order to effectively meet their mandate, and to ensure the best level of protection for the public, it is critical that the technical studies that support decision-making are regularly reviewed and updated.

LSRCA has recognized the need for a comprehensive update to the hydrologic and hydraulic modelling and regulatory floodplain mapping for six creeks within the City of Barrie (City). The subject creeks include Bunkers Creek, Dyments Creek, Hotchkiss Creek, Kidds Creek, Sophia Creek, and Whiskey Creek.

The updated studies will take advantage of advances in land use data, topographic and bathymetric data, hydrometric monitoring and data collection, procedures for predicting the potential impacts of climate change, and urban planning policies. The revisions within the technical reports will also capture changes within the watersheds, including infrastructure improvements (e.g. culverts/bridges).

The relevant hydrologic analysis and modelling have been completed by others. LSRCA staff provided Wills with updated peak flows, including locations of significant flow changes, for all creeks.

In a time where flood emergencies are becoming more common, the impacts of climate change are being realized, and development pressures are steadily growing, a fulsome understanding of floodplain limits is critically important. The Federal and Provincial governments have identified the importance of having updated floodplain mapping and have implemented several programs to assist Municipalities and Conservation Authorities to gain better understanding of flood risks and to prepare up-to-date floodplain mapping.

The previous modelling and floodplain mapping for the six creeks vary in origin but were generally established between 1998 and 2010. Funding for this project is provided, in part, through the Government of Canada's Flood Hazard Identification Mapping Program (FHIMP), which, in Ontario, is administered by the Ministry of Natural Resources and Forestry (MNRF).

1.2 Objective

The objective of this project is to provide updated regulatory floodplain mapping for six creeks within the City of Barrie, including Bunkers Creek, Dyment Creek, Hotchkiss Creek, Kidds Creek, Sophia Creek, and Whiskey Creek. The cumulative length of floodplain mapping that has been completed is 23.3 km: all creeks outlet into Lake Simcoe.

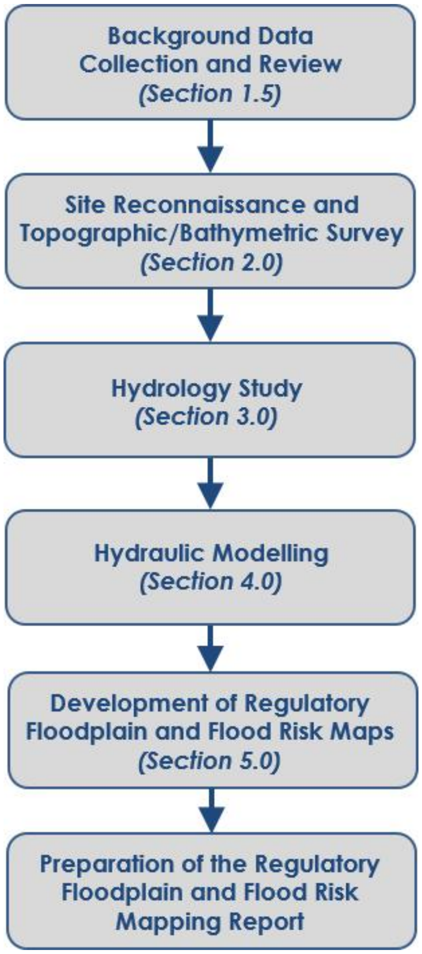
The scope of this study includes the development of technical hydraulic modelling, and the creation of detailed flood maps for each of the six creeks. The peak flows used in this study were developed by others and provided by LSRCA staff.

1.3 Study Process and Report Organization

The regulatory floodplain study process is documented in **Figure 1** and generally involves the following key phases:

- **Background Data Collection and Review** – The background data collection and review involved the collection and review of available background information from LSRCA and the City of Barrie. The available information, along with the applicable sources and collection methods, are summarized in **Section 1.5**.
- **Site Reconnaissance and Topographic/Bathymetric Survey** – Wills staff completed site reconnaissance and topographic/bathymetric survey of select existing bridge and culvert structures and to supplement the LiDAR data on which the majority of the topographic inputs were based. The outputs from the site reconnaissance are used as inputs into the hydraulic modelling and were provided to LRSCA and City staff to support their inventory records. The site reconnaissance and topographic/bathymetric survey is described in **Section 2.0**.
- **Hydrology Study** – The hydrology studies for each of the six creeks were completed by others. LSRCA staff provided Wills with peak flow rates and locations of significant flow changes for three applicable flow events. Based on the information provided by LSRCA, the Regulatory Flow is either the 100-year uncontrolled flow (Bunkers Creek, Sophia Creek) or the Regional (Hazel) flow (Dyments Creek, Hotchkiss Creek, Kidds, and Whiskey Creek). A summary of the peak flows and flow change locations used in this study is described in **Section 3.0.**
- **Hydraulic Modelling** – The hydraulic modelling includes the preparation of the base topographic data and the development of a one-dimensional (1D) steady-state HEC-RAS model, with detailed consideration to the sensitivity of a wide variety of input parameters, and with due consideration to past studies and available flow records. The model has been created using HEC-RAS (Version 6.3.1). The development of the hydraulic modelling is described in **Section 4.0**.
- **Development of Regulatory Floodplain Maps** – The development of regulatory floodplain maps involves using the outputs from the hydraulic modelling to create the final mapping products in GIS software. The outputs from this phase of the project include both paper/pdf maps as well as digital floodlines. The development of the regulatory floodplain and flood risk maps is described in **Section 5.0**.
- **Preparation of the Regulatory Floodplain and Flood Risk Mapping Report** – This report documents the inputs, processes, and decision-making rationale of all analyses associated with the project as well as the final results.

Figure 1 – Study Process



*By others – Data provided by LSRCA

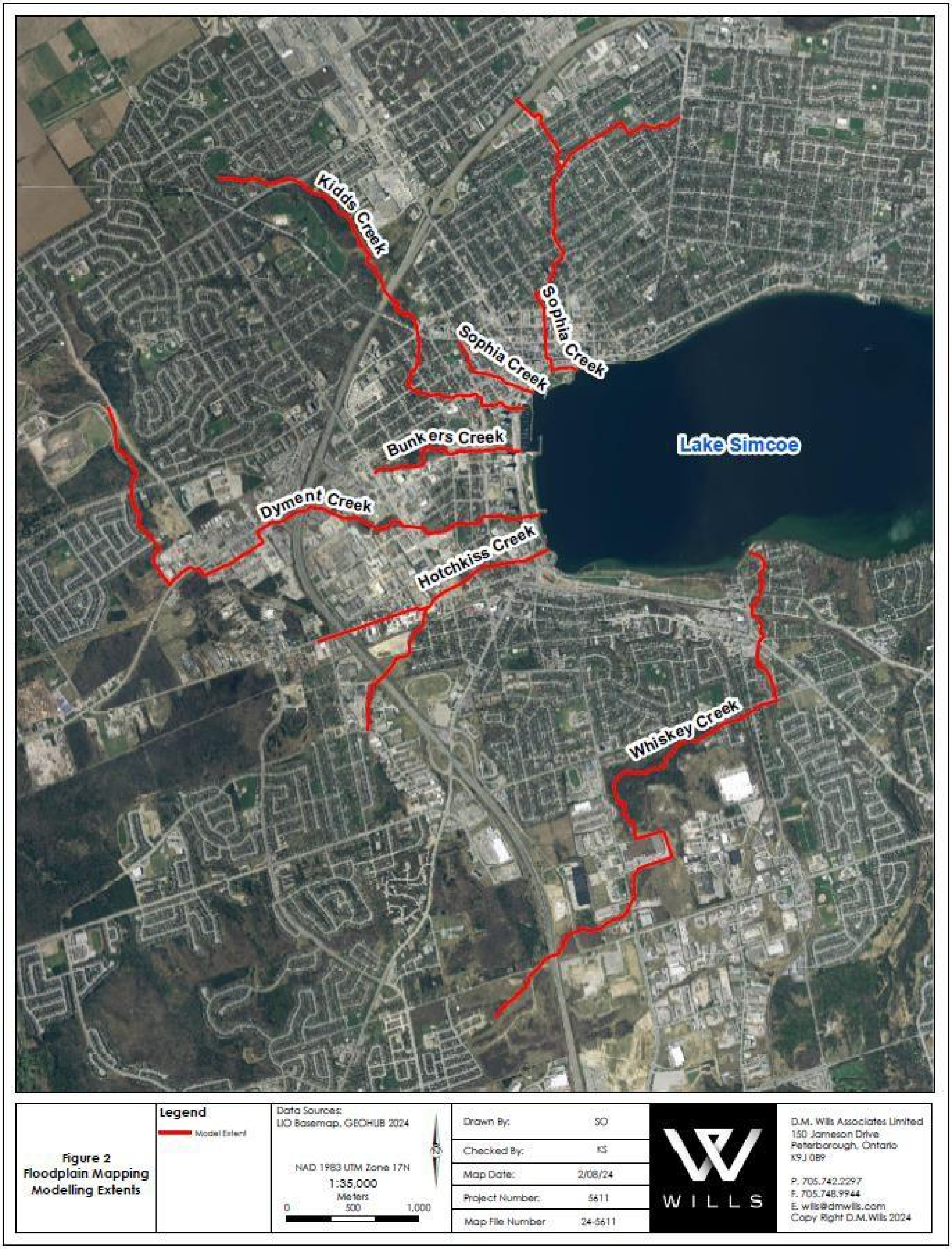
1.4 Study Area

The primary focus of this study is on the following six creeks within the City of Barrie: Bunkers Creek (single reach, 1.3 km), Dyments Creek (single reach, 5.0 km), Hotchkiss Creek (single reach, 2.2 km), Kidds Creek (single reach, 3.9 km), Whiskey Creek (single reach, 6.5 km), and Sophia Creek (three reaches, totalling 4.4 km).

All six creeks outlet to Kempenfelt Bay, on the west side of Lake Simcoe. The creeks drain lands from west of Lake Simcoe, including a significant portion of the developed areas within the City of Barrie. The extents of the Regulatory Mapping that has been produced is consistent with the limits of previous studies, and are generally bounded at the upstream limit by Highway 400 (Hotchkiss Creek, Whiskey Creek, and Sophia Creek East); Anne Street (Bunkers Creek); Ferndale Road (Dyments Creek); Cundles Road West (Kidds Creek); and Ross Street (Sophia Creek West)

The full extent of the study area is shown in **Figure 2**.

Figure 2 – Project Study Area



There are 59 locations where bridges, culverts, and weirs have been included as discrete entities within the hydraulic models, and additional locations where subsurface flow through extended culverts and/or sewer systems have been addressed through supplementary modelling practices, as described within **Section 4.5.**

Bridge, culvert, and weir data were collected from available construction records, as provided by the City and LSRCA, wherever said data were available. Wills staff conducted in-field measurements at 30 locations to capture all outstanding data. Bathymetric information was collected by Wills for all structures located at Lakeshore Drive and downstream. Additional discussion on the site reconnaissance and topographic/bathymetric survey is provided in **Section 2.0**.

1.5 Available Information

There have been several past projects and initiatives which have investigated the hydrologic and hydraulic characteristics of the subject creeks and have informed the development of this Regulatory Floodplain Mapping project.

Table 1 shows a list of the background studies, previous technical modelling, and mapping, supporting GIS data, and construction drawings provided by LSRCA as background for this project. Included within **Table 1** are the supplementary and publicly available data that were used to supplement the project.

Table 1 – Background Information

Report / Model / Data		
Information Provided by LSRCA and the City	**Description**	**Date**
Bunkers Creek Construction Plans	A selection of 24 relevant construction plans within the limits of Bunkers Creek; intended to provide culvert and bridge crossing data.	1963 - 2022
Dyments Creek Construction Plans	A selection of 28 relevant construction plans within the limits of Dyments Creek; intended to provide culvert and bridge crossing data.	1972 - 2016
Hotchkiss Creek Construction Plans	A selection of 23 relevant construction plans within the limits of Hotchkiss Creek; intended to provide culvert and bridge crossing data.	1989 - 2022
Kidds Creek Construction Plans	A selection of 19 relevant construction plans within the limits of Kidds Creek; intended to provide culvert and bridge crossing data.	1977 - 2022
Whiskey Creek Construction Plans	A selection of 26 relevant construction plans within the limits of Whiskey Creek; intended to provide culvert and bridge crossing data.	1973 - 2022

Report / Model / Data		
Information Provided by LSRCA and the City	**Description**	**Date**
Sophia Creek Construction Plans	A selection of 28 relevant construction plans within the limits of Sophia Creek; intended to provide culvert and bridge crossing data.	1963 - 2021
Bunkers Creek Floodplain Mapping	One plan and profile drawing of Bunkers Creek, showing Flood Mapping developed by Giffels Associated Ltd; titled Bunkers Creek Master Drainage Plan – Update.	July 2005
Dyments Creek Floodplain Mapping	Three plan drawings of Dyments Creek showing Flood Mapping developed by Jones Consulting Group; titled Dyments Creek MDP Study– Update.	June 2008
Hotchkiss Creek Floodplain Mapping	Three plan drawings of Hotchkiss Creek showing Flood Mapping developed by the City of Barrie; titled Hotchkiss Creek Floodlines.	October 2010
Kidds Creek Floodplain Mapping	Six plan drawings of Kidds Creek showing Flood Mapping developed by Trow Consulting Engineers Ltd; titled Floodline Mapping.	December 1999
Whiskey Creek Floodplain Mapping	Three plan drawings of Whiskey Creek showing Flood Mapping developed by RG Robinson and Associates Ltd; titled Whiskey Creek Master Drainage Study.	September 2004
Whiskey Creek Floodplain Mapping (Update)	One plan drawing of Whiskey Creek, for ~2.0 km from the outlet extending upstream, showing Updated Flood Mapping developed by AECOM; titled Whiskey Creek Master Drainage Study; and noting Revised Flood Elevation as per LSRCA Model.	August 2011
Sophia Creek Floodplain Mapping	Six plan drawings of Sophia Creek East, upstream of Peel Street, showing Flood Mapping developed by Skelton Brumwell Consulting Engineers; titled Sophia Creek Watercourse Master Drainage Plan.	March 1998
Sophia Creek Floodplain Mapping (Supplementary)	Three plan drawings of Sophia Creek East, downstream of Peel Street, and Sophia Creek West, showing Flood Mapping	February 2008

Report / Model / Data		
Information Provided by LSRCA and the City	**Description**	**Date**
	developed by CC Tatham & Associated Ltd; titled Flood Plain Mapping Plan.	
Digitized Hydraulic Models	HEC-RAS models and select RAS Mapper files provided by LSRCA for all six creeks, aligned with the above reports.	Various
Digitized Regulatory Floodplain Limits	GIS Shapefile provided by LSRCA compiling current Regulatory Floodlines for all six creeks.	Provided August 2023
Barrie Creeks Peak Flows	Excel Table provided by LSRCA, summarizing the 100 Year and Regional (Hazel) Peak Flows, both with and without climate impacts, with reference to applicable Visual Otthymo 6.0 (VO6) hydrograph nodes; developed by others.	December 18, 2023; 100 Year, Regional and Climate Change February 2, 2024
Barrie Creeks Peak Flow Change Locations	GIS Shapefile of flow change locations; aligned with the VO6 hydrograph nodes provided above.	Provided October 28, 2023
City of Barrie Land Use Data	GIS Shapefiles of impervious areas (with sidewalks), wooded areas, cultivated lands, and SWMF; used to develop manning's discretization.	Provided August 2, 2023
Other Background Information and Resources		
Google Satellite Aerial Imagery	Aerial Imagery imported to RAS-Mapper and GIS files to provide orientation and road network IDs	Obtained September 2023
COSINE Online Database	Available online from MNRF, the COSINE database was used to investigate dozens of monuments through the subject area to develop adjustments in vertical datum between CGVD 28:78 and CGVD 2013.	Date of Monuments 1931-1984
Lake Simcoe 2013 LiDAR data	Available online from MNRF, this product is a LiDAR derived Ontario Digital Terrain Model (DTM) which was used to define the majority	Obtained September 2023

Report / Model / Data		
Information Provided by LSRCA and the City	**Description**	**Date**
	of surface profiles and cross sections used in the hydraulic modelling.	
River and Stream Systems: Flooding Hazard Limit Technical Guide	Developed by MNRF in 2002, this guide provides advice and direction to inform planning policies regarding natural hazards, including Flooding Hazards in Ontario. The technical direction contained within the guides informs the standards and approaches to be taken when developing hydrologic and hydraulic models.	2002
Technical Guidelines for Flood Hazard Mapping	Developed by the Environmental Water Resources Group Ltd, and in partnership with six Conservation Authorities in the Greater Horseshoe Area, this guide provides additional technical advice regarding the development of hydrologic and hydraulic models.	March 2017
O. Reg. 179/06	Ontario Regulation: Lake Simcoe Region Conservation Authority: Regulation of Development, Interference with Wetlands, and Alterations to Shorelines and Watercourse.	November 28, 2022

2.0 Site Reconnaissance and Topographic/Bathymetric Survey

2.1 Overview

The development of the hydraulic model and regulatory floodplain / flood risk maps requires the use of topographic and bathymetric survey data. The primary source of topographic data for this project was the LiDAR Digital Terrain Model (DTM) that was provided by the Ministry of Natural Resources and Forestry (MNRF). The LiDAR DTM was supplemented with topographic survey of bridges and culverts in locations where recent construction plans were unavailable or provided limited data.

The LiDAR DTM provided by MNRF does not contain bathymetric information and represents the water surface elevation at the time that the information was collected. Based on their field investigation, Wills recommended that it would be reasonable, and slightly conservative, to accept the LiDAR data as-is for the majority of the length of the reaches, and to therefore neglect the flow from the water surface to the bottom of channel. In general, the creeks were observed to be flowing less than 0.2 m deep, apart from a few ponded areas, and therefore Wills does not anticipate that incorporating detailed bathymetric data throughout the models will significantly change the results.

There are exceptions to the above, which are all located within the areas where some of the creeks begin to interact with the normal water elevation of Lake Simcoe. Bunkers Creek, Dyments Creek, Hotchkiss Creek, and Kidds Creek all become significantly deeper and wider in or around Lakeshore Drive and continue in such a manner to their outlets to Lake Simcoe. For these creeks, Wills staff collected bathymetric cross sections at the Lakeshore Drive crossings and adjacent downstream pedestrian bridges by measuring from the bridge decks to the bottom of the channel. These measurements were used to adjust the channel bottom within the HEC-RAS models to capture the potential additional bathymetric flow area in these areas where it could be more impactful on the model results.

Bathymetric measurements were completed by Wills' staff on November 11, 2023.

2.2 LiDAR Digital Elevation Model

The primary source of topographic data for this project was the LiDAR-derived Ontario Digital Terrain Model (DTM) that was provided by the MNRF through Ontario GeoHub. The DTM represents the bare earth surface and was generated from the classified LiDAR point cloud data. The User Guide, Digital Terrain Model (Lidar Derived) (MNRF, 2023), identifies the coordinate reference systems used as:

> The horizontal datum of the products is the North American Datum of 1983 Canadian Spatial Reference System epoch 2010 (NAD83 (CSRS)). The horizontal unit of measure (coordinate system axis units) for all raster grid cells is metres (m).
>
> The vertical coordinate system of the products is based on the Canadian Geodetic Vertical Datum 2013 (CGVD 2013) of the Geodetic Survey Division and is measured in metres (m).

The User Guide, Digital Terrain Model (Lidar Derived) (MNRF, 2024) indicated that the OMAFRA 2022 Lake Simcoe LiDAR data that was utilized as part of this floodplain mapping project has a non-vegetated vertical accuracy of 5.1 cm at a 95% confidence level (MNRF, 2024). The vegetated vertical accuracy for the Lake Simcoe Lidar Project was 14.95 cm at a 95% confidence level (MNRF, 2024). Further information regarding the accuracy and quality of the DTM can be found in the User Guide, Ontario Digital Terrain Model (LiDAR-Derived) (MNRF, 2024). The DTM was used to create the overbank portions of cross sections for input into the hydraulic model. The DTM will also be used as the base dataset to create the regulatory floodline and flood risk maps.

All future development proposals within the regulated area of these creeks will need to be presented on the same coordinate system, as discussed in **Section 2.4**, to ensure a direct comparison, including referencing a control monument of appropriate accuracy.

2.3 Structure Inventory and Bathymetric Survey

The LiDAR DTM does not include the channel surface below the water level and does not define the hydraulic conveyance characteristics of the bridges, culverts and railway crossing, therefore, some topographic and bathymetric survey was required.

Wills reviewed existing construction plans wherever they were available to determine the relevant information at bridges and culverts. The relevant information that was adopted from the drawings includes the material type (e.g. concrete, steel, HDPE), end treatments and headwalls, invert elevations and resulting slopes, dimensions of the hydraulic openings, and the hydraulic characteristics of the floor of the structure (e.g. open footed culverts).

Structure data that was taken from construction drawings were assumed to be expressed relative to a CGVD 28:78 vertical datum and were adjusted accordingly using the process discussion in **Section 2.4**. In general, adjustments to CGVD 2013 compared well with the LiDAR derived DTM data used to develop the surrounding cross sections.

Inlet configurations and headwalls were modeled based on information available in the construction drawings, wherever possible. In cases where end treatment configurations were not clear, conservative values were used in the model that would represent the absence of any special inlet treatment such as headwalls or wingwalls.

All culverts and bridges were modelled based on their intended, as-constructed function. It was assumed that the culverts would be reasonably maintained and kept clear of the accumulation of sediment and debris. While it is possible that real-world flooding conditions can be significantly influenced by blockages within the hydraulic structures, these situations are both unpredictable and unintended, and therefore are not reflected in the Regulatory mapping process.

For all structures where there was insufficient information within the construction plans, or where construction plans were not available, Wills undertook topographic survey and in-field measurements using a survey grade GPS rover and total station survey equipment. The horizontal datum used in the survey was NAD83 (CSRS), and the vertical datum used in the survey was CGVD 2013 in order to be consistent with the LiDAR data.

As part of the topographic survey, Wills surveyed approximately 30 culverts and weirs. The survey of these structures was performed with the intention of gathering the information required for the development of the hydraulic model. The culvert surveys collected elevations related to inverts, obverts, dimensions, flow obstructions (such as barrier walls) and the overflow surface (weir flow). The weir surveys collected elevations related to the key features of the weir structures related to their hydraulic conveyance.

Bathymetric cross-sections were measured at Lakeshore Drive and the adjacent downstream pedestrian bridges at Bunkers Creek, Dyments Creek, Hotchkiss Creek, and

Kidds Creek. The information was collected by measuring from the bridge decks to the bottom of the channel. These measurements were used to adjust the channel bottom within the HEC-RAS models to capture the potential additional bathymetric flow area in these areas. The locations of the bathymetric cross-sections, along with the relevant field notes, are included in **Appendix A**.

The results of the survey were used to define the structures and channel bathymetry within the hydraulic model. The location of the structures can be found in **Figure 3.**

2.4 Horizontal and Vertical Coordinate Systems

It is critically important during the development and implementation of floodplain mapping that all information be collected in, or transposed to, a consistent horizontal and vertical coordinate system.

All coordinates used throughout this study are expressed using NAD83 (CSRS) horizontal datum and CGVD2013 vertical datum. Additional information regarding the application of the coordinate systems and recommended adjustments between CGVD 2013 and a common past vertical datum (CGVD 28:78) are provided in **Section 2.4.1.**

2.4.1 Vertical Datum Adjustments

CGVD 2013 was selected as the applicable vertical datum for all information used in this study. The existing construction drawings, and the results of past floodplain studies, were generally understood to be expressed relative to the CGVD 28:78 vertical datum, and therefore efforts to transpose some data were required. Given the geographic area covered by the study, the project team was interested in whether the vertical difference between the CGVD 28:78 and CGVD 2013 values would vary from one limit of the project to the other.

Wills reviewed the information available within the COSINE online database and identified 19 monuments within the study area that provided elevations in both CGVD 28:78 and CGVD 2013 data. From one limit of the study area to the other, the difference between the vertical data ranged from 0.358 m to 0.370 m, the average variance was 0.366 m, and 13 of the 19 stations showed values that round to 0.37 m. Therefore, a transposition constant of 0.37 m was adopted for use throughout the study limits, noting that CGVD 2013 is lower than CGVD 28:78. A summary of all COSINE monuments is included in **Appendix A.**

Figure 3 – Study Process

Figure 3
Hydraulic Structure Survey Locations

Data Sources:
SCOOP2013, GEOHUB 2024

NAD 1983 UTM Zone 17N
1:35,000

Drawn By: SO
Checked By: KS
Map Date: 2/08/24
Project Number: 5611
Map File Number 24-5611

D.M. Wills Associates Limited
150 Jameson Drive
Peterborough, Ontario
K9J 0B9

P. 705.742.2297
F. 705.748.9944
E. wills@dmwills.com
Copy Right D.M.Wills 2024

3.0 Hydrology Study

3.1 Peak Flows

The purpose of the hydrology study is to determine the peak flows at key locations through the six creeks, which has a critical impact on the elevation and extents of the flood hazard limits. Wills was not retained under this assignment to complete a hydrologic assessment of the watersheds. The peak flows were provided at numerous nodes throughout the subject area by LSRCA, based on the Barrie Hydrologic Model Updates Report (Tatham Engineering Limited, Dec 2023).

The peak flows that were assessed within the hydraulic models include the 100-Year flow, both with and without climate change impacts, and the Regional (Hazel) flow, both with and without climate change impacts. The selection of the Regulatory Flow is specific to each creek and is subject to O Reg. 41/24, which stipulates a particular Regulatory design storm for each watershed.

As per Tabel 11 of O. Reg. 41/24, the applicable flood event standards used to determine the maximum susceptibility to flooding of lands or areas within the watersheds in the area of jurisdiction of LSRCA are:

1. Butler’s Creek and Sophia Creek – The 100 Year Flood Event Standard; and
2. All other areas – The Hurricane Hazel Flood Event Standard

LSRCA provided a GIS shapefile of flow change node locations. The nodes that were developed within the hydrologic study are not perfectly aligned with the locations of hydraulic cross sections within the HEC-RAS model, and therefore flows were allocated from the information provided by LSRCA based on the following key principles:

- Peak flows were adjusted in the hydraulic model at most hydrologic flow change nodes; and consideration was given to ensure all significant changes in the flows were captured in the hydraulic assessment.
- Peak flow changes were adjusted at cross sections that were located both upstream of, and as close as possible to, the hydrologic flow change nodes.
- In cases where hydrologic flow change nodes occurred in or around a bridge or culvert crossing, which was common when incorporating storm sewer inflows, the peak flow change was introduced into the hydraulic model at a cross section that was at least two sections upstream of the bridge or culvert crossing. This was done to ensure an appropriately conservative approach when assessing the hydraulic capacity of the crossings, which are important to understand the extents of their backwater influences. The decision to move at least two cross sections upstream was made to avoid model instability that can occur by changing peak flows within the sections that are used as part of the bridge or culvert modelling routines (typically the sections immediately adjacent to the crossing).

The peak flows that were provided by LSRCA are summarized in **Table 2.** Additional information is provided in **Appendix B.**

Table 2 – Peak Flow Summary (Regulatory Flow in Bold)

HEC-RAS Station	VO6 Hydrologic Node	1:100 Year Flow (m^3/s)	1:100 Year Flow with CC (m^3/s)	Regional Flow (Hazel) (m^3/s)	Regional Flow (Hazel) with CC (m^3/s)
Bunkers Creek					
1+305	179172	**36.79**	43.50	27.84	33.77
1+055	17918	**39.38**	46.88	29.71	36.02
0+858	17923	**52.31**	62.56	42.22	51.23
0+803	17924	**54.24**	64.90	43.95	53.38
0+621	17933	**56.17**	67.03	47.22	57.38
0+443	17934	**55.96**	66.38	47.46	57.68
0+328	17935	**57.61**	68.41	49.11	59.81
0+184	17936	**55.53**	66.28	49.29	60.08
0+087	17937	**55.83**	66.52	50.08	60.96
Dyments Creek					
4+973	18909	14.52	18.07	**18.09**	22.11
4+531	18911	15.92	19.91	**22.63**	27.68
4+287	18913	16.39	20.60	**25.46**	31.13
3+837	189142	14.79	18.75	**25.63**	31.38
3+535	189143	13.06	16.61	**26.17**	32.07
3+453	18916	14.84	18.73	**29.36**	35.93
2+933	18919	37.12	45.86	**49.85**	64.97
2+600	18922	41.07	50.43	**53.18**	64.66
2+236	189232	43.98	53.67	**55.02**	67.05
2+101	18925	43.24	53.65	**56.35**	67.97
1+959	18926	43.37	53.81	**56.57**	68.30
1+678	18928	44.10	54.29	**58.70**	70.86
1+431	18929	44.28	54.45	**58.89**	71.13
1+153	18931	45.43	55.55	**61.04**	73.74
0+698	18933	44.61	54.30	**61.69**	74.79
0+601	18934	44.48	54.22	**61.78**	74.88

HEC-RAS Station	VO6 Hydrologic Node	1:100 Year Flow (m^3/s)	1:100 Year Flow with CC (m^3/s)	Regional Flow (Hazel) (m^3/s)	Regional Flow (Hazel) with CC (m^3/s)
0+474	18937	45.00	54.74	**63.02**	76.34
0+170	18938	45.80	55.68	**64.16**	77.69
Hotchkiss Creek – Reach 1					
2+233	19929	19.33	23.41	**13.21**	15.92
1+962	19909	20.21	24.46	**14.15**	17.06
1+886	199102	43.17	50.98	**33.69**	39.93
1+606	19917	43.76	51.63	**34.63**	41.05
1+234	19918	52.30	61.74	**40.12**	48.09
Hotchkiss Creek – Reach 3					
1+067	19919	55.14	65.44	**42.03**	50.35
1+053	19920	55.18	65.39	**42.06**	50.46
0+882	199202	72.18	86.26	**51.81**	62.24
0+711	199203	72.83	87.10	**52.29**	62.82
0+648	19922	75.07	89.64	**54.60**	65.64
0+485	19923	75.27	90.45	**55.16**	66.14
0+385	19925	76.69	92.20	**56.25**	67.58
0+162	19927	76.26	91.54	**56.53**	67.77
Kidds Creek					
3+898	16924	31.38	38.52	**27.72**	33.41
3+834	169242	31.58	38.81	**28.02**	33.78
3+615	16905	30.84	38.05	**29.01**	34.98
3+419	16906	32.06	39.55	**30.38**	36.64
3+302	16908	39.51	48.61	**38.51**	46.54
2+641	16909	39.69	48.96	**41.37**	50.07
2+242	16910	46.38	56.25	**48.83**	59.13
2+113	169122	50.22	61.04	**54.47**	65.99
1+509	169132	49.41	59.96	**55.57**	67.28
1+114	169152	49.67	60.24	**55.96**	67.76

HEC-RAS Station	VO6 Hydrologic Node	1:100 Year Flow (m^3/s)	1:100 Year Flow with CC (m^3/s)	Regional Flow (Hazel) (m^3/s)	Regional Flow (Hazel) with CC (m^3/s)
0+953	169262	50.67	61.39	**58.03**	70.30
0+788	16918	50.84	61.61	**58.66**	71.02
0+311	16921	51.60	62.43	**60.23**	72.86
0+080	16923	51.75	62.61	**60.69**	73.53
Whiskey Creek					
6+450	23901	14.25	17.74	**12.15**	14.70
5+704	23905	25.59	31.73	**20.14**	24.34
5+579	23908	32.58	39.16	**24.37**	29.41
4+631	23912	32.66	39.94	**27.16**	32.93
3+392	23915	55.85	65.34	**43.65**	51.91
2+026	23919	50.34	59.90	**47.91**	57.40
1+789	23940	59.73	71.51	**56.69**	67.96
1+544	23928	79.27	96.84	**73.53**	88.45
0+966	23930	76.06	92.89	**75.64**	91.39
0+677	23932	77.30	94.86	**77.76**	94.03
0+487	23935	78.35	95.86	**79.58**	96.33
0+183	23938	78.32	95.88	**80.29**	97.25
Sophia Creek - West					
0+729	15952	**3.70**	4.40	2.26	2.72
0+618	159532	**1.10**	1.36	1.00	1.22
0+436	159533	**1.44**	1.76	1.18	1.43
0+396	159542	**6.17**	7.36	3.87	4.67
0+307	15955	**7.33**	8.72	4.38	5.28
0+191	15956	**11.27**	13.32	6.23	7.50
0+123	159562	**12.17**	14.38	6.62	7.96
Sophia Creek – East 1					
0+675	15901	**13.03**	15.69	7.93	9.50
0+156	15903	**18.12**	21.97	11.15	13.36

HEC-RAS Station	VO6 Hydrologic Node	1:100 Year Flow (m^3/s)	1:100 Year Flow with CC (m^3/s)	Regional Flow (Hazel) (m^3/s)	Regional Flow (Hazel) with CC (m^3/s)
0+082	159072	**23.92**	28.98	15.19	18.21
Sophia Creek – East 2					
3+041	15121	**13.11**	15.82	8.39	10.08
2+967	159082	**13.32**	16.05	8.62	10.38
2+862	15910	**15.97**	19.35	10.27	12.36
2+647	15911	**17.71**	21.45	11.35	13.64
2+519	15913	**20.72**	24.96	13.32	15.97
2+319	15915	**29.85**	35.84	19.42	23.27
2+038	15916	**29.09**	34.97	19.79	23.98
1+921	15917	**51.77**	62.56	34.98	42.31
1+820	159192	**55.40**	66.83	37.94	45.66
1+568	159202	**55.39**	66.74	38.42	46.27
1+225	15923	**61.95**	74.25	44.02	53.16
1+206	15924	**65.17**	78.21	47.73	57.68
0+973	159252	**66.88**	80.64	50.03	60.49
0+585	15929	**70.57**	85.10	54.37	65.83
0+335	15934	**73.11**	88.57	57.50	69.67
0+236	15935	**73.37**	88.86	57.76	70.00

3.2 Recorded Hydrometric Data

As discussed in **Section 3.1**, the peak flows used to develop the Regulatory Floodplain were provided by LSRCA based on the result of the Barrie Hydrologic Model Updates Report (Tatham Engineering Limited, Dec 2023)

Part of the process of a Regulatory flood mapping study is to calibrate and validate the results of the hydraulic model using available site records and hydrometric data. These data typically include in-stream gauge records, monitored rating curves, measured high-water marks, historical flood records, etc.

Wills reviewed the watershed monitoring data that is available online at the link below and identified three data stations within the study area.

https://data.lsrca.on.ca/wiski/applications/public.html?publicuser=Public#waterdata/stationoverview

The data stations described below provide discharges and stages at 5-minute increments for the majority of the duration of their reporting durations. A review of the datasets indicates that the quality of the data has been evaluated, noting periods that are labelled 'Good', 'Fair', 'Estimated', and 'Ice'.

It is noted that gauged flow data are not available on Dyments Creek, Whiskey Creek, or Sophia Creek. Wills reviewed the National Water Data Archive (HYDAT) and confirmed that the database does not contain any additional information within, or immediately adjacent to, the subject area.
https://wateroffice.ec.gc.ca/map/index_e.html?type=historical

A summary of the data stations available from LSRCA is provided in **Table 3.**

Table 3 – Recorded Hydrometric Data

Creek and Location	Station ID	Co-ordinates	Vertical Datum CGVD 2013	Period of Record (years)	Max Recorded Discharge (m^3/s)	As % of Regulatory Flow
Bunkers Creek at Innisfil St	LS0112	44.38294 N -79.69731 W	219.48	8	6.17	9.0%
Kidds Creek at Eccles St N	LS0113	44.37492 N -79.6946 W	223.91	8	3.90	6.6%
Hotchkiss Creek at Innisfil St	LS0203	44.37492 N -79.6946 W	221.15	4	3.35	6.4%

The process of applying hydrometric data to calibrate or validate the hydraulic models is explained in detail within **Section 4.7**. In order to support the hydraulic calibration process, consideration was given to selecting appropriate peak flow events, which would be most reliable and applicable to the study. A selection of representative flow events is summarised in **Table 4**, based on the following key criteria:

- As seen in **Table 3**, the max recorded discharges are significantly lower than the Regulatory Flow in each creek, which will limit the effectiveness of any calibration efforts since conveyance characteristics of the creeks may vary between high flows and low flows. Specifically, the channel roughness, backwater impacts, access to overbank areas, obstructions, and majority flow direction (valley flow vs. channel meander flow) will likely change with depth. Therefore, priority is placed on the higher flow records within the dataset to align with the Regulatory Flow condition as much as possible.
- Notwithstanding the above, flow events were chosen to represent roughly the 80th percentile in measured flow rates, since there are multiple occurrences of such flows and Wills has verified that the stages and flows are represented reasonably consistently at this flow level. There is concern that an outlier level (ie. the single highest recorded flow) would offer little opportunity to verify the proper and consistent function of the measurement systems.

- Events were chosen to represent the spring season, where ice jamming will not influence the results and the vegetation will be representative of rougher, leaf-on conditions.
- Events were chosen from the periods of 'Good' data (or unchecked for Kidds Creek), which is shown in green in the bottom band of the web-based data and in the appendix material.
- At Kidds Creek at Eccles St N, there was a significant channel improvement project completed just downstream of Station LS0113 in or around October 2021. Furthermore, LSRCA noted that the data after September 2022 may not be accurate, given channel morphology and erosion issues. Therefore, at this station, the representative events will be selected from 2022 data.

Based on our review of the available data, Wills recommends the following flow events be used in the calibration and/or validation efforts, as described further in **Section 4.7**.

Table 4 – Summary of Representative Flow Events

Creek and Location	Station ID	Co-ordinates	Date of Event	Peak Flow (m^3/s)	Measured Stage	Gauged Elevation CGVD 2013
Bunkers Creek at Innisfil St	LS0112	44.38294 N -79.69731 W	06/05/2016	1.45	0.76	220.24
			04/13/2018	1.14	0.69	220.17
			06/12/2022	1.59	0.89	220.37
Hotchkiss Creek at Innisfil St	LS0203	44.37492 N -79.6946 W	05/30/2017	1.69	0.64	221.79
			06/20/2017	1.74	0.65	221.80
			06/13/2018	1.18	0.54	221.69
Kidds Creek at Eccles St N	LS0113	44.37492 N -79.6946 W	03/06/2022	1.19	0.44	224.35
			04/13/2022	1.43	0.48	224.39
			06/12/2022	1.60	0.50	224.41

3.3 Comparison to Past Study Results

Previous floodplain mapping studies for the six creeks were completed between 1998 and 2010 and it is reasonable to expect that the regulatory flood limits that are developed within this study will differ in some ways from previous studies.

There are a number of factors that contribute to the extents of floodplain mapping that are produced by any given technical study. Some factors are influenced by changes in the hydraulic characteristics of the terrain, such as improved structures and channels, or by advances in the quality and accuracy of the data. Other factors are driven by hydrologic changes that impact the magnitude of the peak flows that are used in the modelling.

In order to demonstrate the influence of the latest hydrology study on the flood extents produced by this study, a comparison has been provided below highlighting the differences between the peak flows used in this study and the peak flows considered in the past. The average change in Regulatory peak flow, along with the most significant increase in Regulatory peak flow, are summarized in **Table 5**.

Table 5 – Peak Flow Comparison to Previous Studies

Creek	Previous Study Date	Previous Max Flow (m3/s)	Current Max Flow (m3/s)	Average % Change	Max Increase (m3/s)	Max occurs @ Station
Bunkers Creek	July 2005	62.0	57.6	-5.5%	7.9	0+858
Dyments Creek	June 2008	59.3	64.2	4.3%	5.3	3+837
Hotchkiss Creek	Oct 2010	63.6	56.9	11.2%	15.3	0+882
Kidds Creek	Dec 1999	62.8	60.7	-3.9%	5.5	0+311
Whiskey Creek	Sept 2004 (Aug 2011)	65.7	80.3	8.6%	10.8	0+183
Sophia Creek	Mar 1998 (Feb 2008)	35.9	48.3*	109.1%	29.7	1+206

*This value represents the maximum flow within the limits of the previous model. Additional flow nodes exist in the updated model, downstream of Peel St., with a maximum flow of 57.8 m^3/s at Station 0+236

The comparison to previous studies indicates that the current peak flows are generally greater than the flows that were used in the past, with the exception of Bunkers Creek and Kidds Creek. The increases are most pronounced throughout Sophia Creek, and at select locations within Hotchkiss Creek, and Whiskey Creek. The change in peak flow is modest throughout Dyments Creek, Kidds Creek and Bunkers Creek.

4.0 Hydraulics

4.1 Regulatory Framework and Modelling Approach

Floodplain mapping in Ontario is guided by both planning and technical considerations; the goal is to ensure the safety and well-being of the public and to minimize economic loss and property damage due to floods. The Lake Simcoe Region Conservation Authority, the City of Barrie, and the Ministry of Natural Resources and Forestry are all partners in ensuring that natural flooding hazards are well understood, and that development and land use policies are effectively managed and enforced.

Policies for land development and land use are influenced and guided by the Provincial Policy Statement (PPS, 2020) Section 3.1, which describes that "development shall generally be directed… to areas outside of b) hazardous lands adjacent to river, stream and small inland lake systems which are impacted by flooding hazards."

Development with the Lake Simcoe Watershed is further regulated by O. Reg. 179/06, Lake Simcoe Region Conservation Authority: Regulation of Development, Interference with Wetlands, and Alterations to Shorelines and Watercourses. Under this O. Reg. LSRCA has authority to regulate development within a certain distance of the maximum extent of the floodplain under the applicable flood event standard.

Both above documents require a robust understanding of the limits of flood hazards, developed based on fair and consistent technical standards. To be consistent with current best practices in Ontario, the development of the flood hazard limit within this study is based on the River and Stream Systems: Flooding Hazard Limit Technical Guide (MNRF, 2002). In keeping with the Technical Guide, the following key decisions and approaches have been adopted within this study:

- In keeping with Appendix F: Computations – Open Water, Section 2; steady flow conditions have been assumed along the length of the creeks and the water surface profile computations are based primarily on the solution of the one-dimensional energy equations for gradually varied flow.
- The computations were completed based on the Standard Step Method, assuming subcritical flow; the calculations began with a known water surface elevation at the downstream limit of each reach.
- There were no significant flood routing elements introduced in the hydraulic model (peak flow attenuation due to natural flood routing may have been included in the hydrology model, completed by others).
- There were no 'operable' elements included in the hydraulic model, including any dams, gates, sluiceways, or variable weirs and spillways.
- The creeks were modelled in such a manner so as to apply a One-Zone policy approach as defined in the Technical Guide (MNRF 2022); where the entire floodplain was treated as the 'floodway'.

4.2 Model Selection

The HEC-RAS (Version 6.3.1) hydraulic model was selected by the project team and the LSRCA as the preferred hydraulic model to be used for this project. HEC-RAS is a free hydraulic modeling software developed and maintained by the U.S. Army Corps of Engineers' (USACE) Hydrologic Engineering Centre (HEC) with a long history of use in Canada and internationally. The software can perform hydraulic calculations in one-dimensional steady flow, one-dimensional (1D) unsteady flow, two-dimensional (2D) unsteady flow, and coupled one-dimensional/two-dimensional (1D/2D) flow conditions for a full range of natural and constructed channels. The software is suitable for many applications including floodplain mapping, open channel and hydraulic structure design, dam breach analysis, rain on grid, and sediment transport modeling. HEC-RAS includes built in GIS tools with which a significant portion of the hydraulic model can be developed, and the modeling results viewed.

The following information is required to calculate the input parameters for HEC-RAS to compute water surface elevation and velocity:

- Topographic, bathymetric, and aerial imagery information for the channel and overbanks to define the physical characteristics of the watercourse including slope, length, geometry, and Manning's roughness.
- Bridge, culvert, inline structure, and lateral structure information including geometry, construction material, alignment, and operating rules (if applicable).
- Location and geometry of obstructions to flow such dwellings and auxiliary structures.
- Peak flows are required for a steady flow model and a hydrograph for an unsteady flow model.
- Flow and water surface elevations of past events for calibration and verification of model parameters.

The objective of the hydraulic model is to compute accurate water surface elevations and floodplain extents for the Regulatory flow event throughout the six creeks. Wills reviewed the topography, historic floodplain mapping, available background information from LSRCA including construction drawings, previous hydraulic models, and available flow rate and flow depth records in our effort to develop robust and defensible hydraulic models.

4.3 Supplemental Modelling and Flood Mapping Approaches

As discussed in **Section 4.1**, the Regulatory flood limits have been developed using HEC-RAS software, assuming steady-state, one-dimensional flow conditions. The majority of the lengths of each creek lend themselves well to this approach, as the natural flood valley systems promote unidirectional and gradually varying flow patterns. These natural corridors are well suited to be represented by consecutive cross sections that are perpendicular to the flow and generate results without significant abrupt transitions and energy losses.

However, within most of the creeks there are sections that are not easily represented within the constraints of a one-dimensional HEC-RAS model. Each of these complex locations are discussed in detail within **Section 4.5**, and the general rationale for supplemental modelling is provided below.

While HEC-RAS includes routines to assess typical hydraulic features, such as road crossing, bridges, and culverts, the influence of development has resulted in more complex flow patterns in some locations; some examples include:

- Open creeks which transition to closed, piped systems for an elongated stretch of the creek, beyond a typical culvert crossing under a roadway. These locations are difficult to model since HEC-RAS allows a single road profile to be modelled above a bridge/culvert structure. The typical approach to modelling a road crossing may lack an accurate depiction of the changing terrain above a pipe that is buried for an extended length.
- The construction of a road crossing, rail line, street network, or other altered grading which cause a significant split flow condition. In these locations some portion of the flow continues to the downstream channel, while some portion of the flow spills elsewhere. The spills are generally towards a poorly defined or two-dimensional flow route (e.g. a residential street network), towards an adjacent watershed, or along an alternate flow path which eventually rejoins the creek at a downstream location.
- Locations where the flow has an opportunity to access lands that are adjacent to the creek, and are at a lower elevation, if an intermediate berm is overwhelmed. In these cases, HEC-RAS will allow flow to equalize laterally with a cross section and, in some cases, will show that all flow has left the channel of the creek.

The following Supplemental Modelling and Flood Mapping Approaches were considered and adopted:

Supplemental Approach 1

Complex Flow Challenge: Elongated culverts where the terrain above the pipe cannot reasonably be represented as a single road profile.

Approach: The hydraulic model was initially created with the pipe and road in place as a typical bridge/culvert crossing and the results were reviewed to determine the quantity of flow that would be conveyed through the pipe. The pipe was removed from the model and the terrain above the bridge/culvert was modelled in additional detail using multiple cross section. The peak flows within the sections in question were reduced by the amount calculated as pipe flow when the bridge/culvert were in the model.

Supplemental Approach 2

Complex Flow Challenge: Elongated culverts where the terrain above the pipe would ideally not be represented as a single road profile.

Approach: The model was developed with the culvert in place, all flow intact, and a simplified representation of the surface terrain using a single road profile (typical modelling approach). The inundation boundaries between the upstream and downstream sides of these structures were manually adjusted on the floodplain map to create a smooth transition based on the topography data.

Supplemental Approach 3

Complex Flow Challenge: Elongated culverts where the terrain above the pipe would ideally not be represented as a single road profile, and where a manual adjustment of the upstream and downstream inundation boundaries was not practical due to the complexity of the topography.

Approach: A Local Surface Model was created to represent only the surface terrain in order to understand the potential shape and extent of the floodplain. The final model was developed with the culvert in place and therefore flows were not removed from the model; this resulted in the most accurate assessment of the upstream impacts, but provided a simplified representation of the surface terrain above the culvert as only a single road profile could be used. To mitigate this the flood line was compared to the local surface model and adjusted using GIS tools to align with the results. The local surface model cross sections are shown in dark red within the floodmaps and are saved as [CreekName]_Supl01 plan files within the HEC-RAS models.

Supplemental Approach 4

Complex Flow Challenge: Potentially due to the presence of a structure, grading changes, or other interference with the floodway, a portion of the flow would be diverted away from the downstream channel.

Approach: An arrow was added to the flood maps indicating a ‘spill’ from the main channel. On the basis that the spill represents less than 10% of the total peak flow in the creek, the spill route was not mapped, and the peak flows were carried downstream through the remainder of the hydraulic model.

Supplemental Approach 5

Complex Flow Challenge: Due to the nature of the terrain, and potential development impacts, once a small internal berm is overwhelmed a significant portion of the flow would escape the channel to lower terrain, and flow out of the model in a pattern that would be difficult to model (e.g. 2-D flow).

Approach: Levees were introduced to the hydraulic model, even in some areas where it is expected that the internal berms would be overtopped. The purpose of this approach is to contain the channel flow in the model somewhat, to ensure that the floodplain in an around the creeks is not understated. The flood limits are represented as a green dashed line on the flood maps to represent the potential for escaping flow. The peak flows were not reduced through the remainder of the hydraulic model.

Supplemental Approach 6

Complex Flow Challenge: Flow has an opportunity to spill laterally over a well-defined structure (e.g. rail line) to a secondary flow path. The secondary flow path lends itself well to 1D modelling and rejoins the creek at a downstream location.

Approach: A lateral spill was introduced to the hydraulic model to a separate river reach. The model determined the extent to which flows were retained in the main creek and a junction was placed at the downstream location to re-integrate the flow.

4.4 Hydraulic Model Development

4.4.1 Hydraulic Model References and Inputs

The hydraulic modelling approach and model parameters have been developed with consideration to the following key references:

- River and Stream Systems: Flooding Hazard Limit Technical Guide (MNRF 2002).
- Technical Guidelines for Flood Hazard Mapping (Environmental Water Resources Group EWRG, March 2017).
- HEC-RAS Hydraulic Reference Manual (USACE, 2024).

The requirements for data inputs for a steady-state HEC-RAS model are summarized in the Technical Guide (MNRF, 2002 – Page 61) as “discharge, starting water surface elevation, cross section geometry, roughness coefficients, other coefficients, plan of channel alignment, cross section coordinates, and distances between cross sections”.

The Technical Guide (EWRG, 2017), Section 4.7.3.1 lists the requirements of one-dimensional models as including “cross sections, hydraulic structures, ineffective flow areas, expansion and contraction coefficients, weir coefficients, manning ‘n’ values, starting water surface elevations, flow interpolation between points of interest, and spills and split flows”.

The key inputs and parameters that were used to develop the hydraulic models are presented in the following sections.

4.4.2 Topographic and Bathymetric Data

Wills used the 0.5 m LiDAR DTM discussed in **Section 2.2** as the terrain file for the hydraulic model. The LiDAR DTM does not include points for the ground surface below the water surface. In the case of these six creeks, where baseflow represents a small proportion of flow compared to flood flows, the LiDAR DTM was found to produce satisfactory representation of the channel in most locations. However, supplemental bathymetric measurements were collected and applied to sections downstream of Lakeshore Drive, as discussed in **Section 2.3**.

Data sources generated by different entities were placed into the same projection and datum for consistency in processing. Data collected from field measurements were collected in CGVD 2013, and previous construction drawings were converted from CGVD 28:78, vertical datum to align with the LiDAR DTM, as per **Section 2.4**.

Road and rail crossings can have one of the most significant impacts on the regulatory floodplain. Considerable backwater conditions may be present upstream of a crossing that is unable to convey the regulatory flow, causing a widespread floodplain. There are a significant number of structures that span these six creeks. Wills completed field surveys of all hydraulic structures within the study area where previous construction plans were not available or did not contain sufficient information. Detailed structure data sheets and photos for each crossing are available digitally, as part of **Appendix A**.

4.4.3 Watercourse Centre line and Bank Stations

The watercourse centreline and bank stations were digitized by Wills in RAS-Mapper using aerial imagery and the DTM. The bank stations were further refined manually using HEC-RAS's cross section editor.

Bank stations generally represent the top of a stream bank at a location where, if flow exceeded the bank elevation, it would spread within the floodplain. Bank stations are used by HEC-RAS to subdivide the cross-section into channel and overbank areas, for the purpose of establishing the slopes used to determine conveyance, and to discretize the reporting tools. In some hydraulic models, bank stations may identify the locations where the roughness coefficient changes. In the case of all six creeks, the roughness coefficient was not dependant on the location of the bank stations as a 'horizontal variation in manning's' was used for all cross sections.

Bank station locations within the model are based on collected survey data, aerial imagery, and elevation data along with available pictures of the channel.

4.4.4 Cross Section Locations and Spacing

The cross-section geometry for the hydraulic model was extracted from the LiDAR DEM using HEC-RAS's internal GIS module (RAS Mapper). The use of RAS Mapper ensures a properly georeferenced HEC-RAS model.

The location and spacing of cross sections were generally implemented in keeping with the Technical Guide (EWRG, 2017), Pages 91-93. Some key considerations that were implemented by the project team include:

- Cross sections were positioned to be perpendicular to the direction of flow, to the greatest extent possible.
- Cross sections were extended to be long enough to contain all of the flow, with some local and intentional exceptions such as flow junctions or at watershed boundaries.
- Cross sections were cropped at the edge of each creek's watershed boundary (provided by others) to avoid double-counting areas of flow conveyance. At the downstream end of Bunkers, Dyments, Hotchkiss and Kidds creeks, the floodplain

boundaries often connected, and each individual flood map has been drawn to the extent of its watershed.

- Cross sections were placed in intentional locations adjacent to bridges and culverts, with the use of ineffective flow areas to model the transition from fully expanded to fully contracted flow.
- Cross sections were spaced to capture all abrupt changes in channel geometry, bed and valley slope, land use, obstructions, and variations in roughness. In essence, Wills considered the average parameter values that would result between sections, and assessed the degree to which they were appropriate.
- Generally, spacing was implemented in 30-40 m increments. While unsteady models can be significantly more sensitive to spacing due to model stability and flow routing issues, spacing is still an important consideration in steady models. Of particular note, the project team sought to ensure that the results were indicative of gradually varied flow and gave consideration to spacing sections so that most land parcels interacted directly with at least one section.

4.4.5 Manning's Roughness Values

Manning's roughness values are used to represent the nature of the terrain and culvert crossings, and their influence on resistance to flow. Higher manning's roughness values typically result in deeper, slower flow regimes. Manning's is an important parameter, particularly because it can affect the results throughout the length of the hydraulic model, as opposed to some parameters that have isolated impacts, such as tailwater assumptions or coefficients used only at bridge and culvert crossings.

By default, HEC-RAS requires users to input distinct Manning's roughness values for the channel and overbank areas. However, for these six creeks, a more robust assessment of manning's roughness value was used using the 'horizontal variation in 'n'' option, allowing multiple bands of roughness to be assessed within each cross section.

In order to develop the variation in roughness throughout the models, Wills imported a landcover GIS layer provided by the City. The GIS layer discretizes all impervious areas, lawns, woods, and wetland/SWM ponds. Wills manually added the creek alignments, with an appropriate offset, into the GIS layer and imported the shapefile into RAS-Mapper. Culvert roughness parameters were assessed based on the material type as per the construction drawings or field investigation.

The Manning's roughness values were then further refined as needed using aerial imagery and the cross-section editor within HEC-RAS. Particular effort was required at long cross sections where the total number of Manning's bands exceeded the HEC-RAS limit of 20 per cross section. The limit of 20 Manning's bands was typically exceeded along cross sections that intersected numerous driveways in residential areas. To reduce the number of Manning's bands to the HEC-RAS allowable limit, the bands were reduced manually. Efforts were made to focus the changes in the high areas of the cross sections that were above the Regulatory flow, and to maintain the overall total width of each manning's value.

There is a relationship between the roughness value of any given terrain and the depth of flow; Manning's values should be significantly higher during very shallow flow. Generally, the relationship between Manning's values and depth stabilizes once the flow depth exceeds three to five times the height of a typical obstruction (eg. average cobble in a creek). Throughout the hydraulic models, the Manning's values were chosen to represent stabilized values in keeping with published literature.

Manning's values were selected based on the Technical Guide (EWRG, 2017) Page 119 – Table 4.1. Wills selected Manning's roughness values throughout the models that fall within the typical values provided by the Technical Guide (EWRG, 2017), as shown in **Table 6**. In select locations, Manning's was adjusted to improve model performance and avoid errors and warnings related to unsolved iterative calculations, in order to prevent the model from defaulting to critical depth.

Table 6 – Standard Manning's Roughness Coefficients

		Suggested Range	**Suggested Range**
Land Use / Material	**'n' Standard**	**Minimum**	**Maximum**
Terrain			
Channel - Natural	0.035	0.025	0.045
Woods	0.080	0.040	0.120
Lawn	0.045	0.030	0.055
Impervious	0.015	0.011	0.017
Range / Meadow	0.055	0.035	0.70
SWM Pond	0.035	0.025	0.045
Culverts			
Concrete	0.013	0.011	0.015
HDPE / PVC	0.013	0.011	0.015
Steel – 3"x1" Corrugation	0.024	0.021	0.027
Steel – 6"x2" Corrugation	0.032	0.026	0.038

4.4.6 Hydraulic Structures

Information regarding the hydraulic structures throughout the six creeks was gathered from available construction drawings and supplemented by field measures and survey completed by Wills staff. The study area did not contain any dams, concrete weirs, gates, sluiceways, or spillways. All road crossings were included in the model as bridges or culverts using HEC-RAS's bridge and culvert tools, with the exception of some complex flow locations that are described in **Section 4.5**. Private foot bridge structures were not included in the model as they are likely to wash away during a high magnitude flood event. The pedestrian bridges downstream of Lakeshore Drive that exist on most creeks were included in the model.

All road crossings were modelled using the most conservative representation of the road crossing; in most cases this was the crown or raised boulevard. In some cases, particular attention was paid to concrete barriers or parapet walls, which were modeled as solid portions of the bridge/culvert structure. Steel tube railings with 1 m or greater between vertical posts were assumed to still convey flow and were therefore not included in the bridge/culvert structures. Wills selected weir coefficients throughout the models that fall within the typical values provided by the Technical Guide (EWRG, 2017), as shown in **Table 7**.

Table 7 – Standard Wier Coefficients

		Suggested Range	Suggested Range
Weir Flow Coefficients	**'C' Standard**	**Minimum**	**Maximum**
Broad Crested (i.e., Road Embankments)	1.5	1.4	1.7

4.4.7 Ineffective Flow Areas, and Expansion and Contraction Coefficients

Ineffective flow areas were applied to the model in all areas where water is expected to pond, but where no significant conveyance is available due to the adjacent structures or terrain. The following are key areas where ineffective flow areas were used in the model.

- For sections immediately upstream and downstream of road crossings, ineffective flow areas were applied for the full length of the section below the elevation of the road, with a gap approximately the width of the culvert or bridge opening.
- With consideration to the above, the next adjacent upstream and downstream sections were generally located at a point where flow had fully expanded. In select locations where the adjacent section was required to be closer to the bridge/culvert structures, additional ineffective flow areas were applied to model partial expansion/contraction.
- In locations that were hydraulically connected to the floodway, but due to the terrain would obviously not provide flow conveyance, ineffective flow areas were applied to the height of the adjacent terrain, or the highest point in the cross section. These included significant valleys perpendicular to the channel (usually due to an incoming tributary), areas where significant backwater ponding would occur, and other select SWM features or excavated areas that were 'dug' into the surrounding terrain.

Expansion and contraction coefficients were used to adjust the extent to which minor energy losses are recognized, due to turbulence during expanding or contracting flows. Expansion and contraction losses occur through the model due to natural changes in the topography but are most pronounced at sudden transitions such as bridge and culvert structures. Wills selected expansion and contraction coefficients throughout the models that fall within the typical values provided by the Technical Guide (EWRG, 2017), as shown in **Table 8**.

Table 8 – Standard Expansion and Contraction Coefficients

	Standard Parameters	**Standard Parameters**
Expansion/Contraction Coefficient	**Contraction**	**Expansion**
Gradual Transitions	0.1	0.3
Bridges/Culverts	0.3	0.5

4.4.8 Obstructions

Barriers to flow such as dwellings or auxiliary structures have been included in the model as obstructions using a GIS layer provided by the City. The obstruction function within HEC-RAS allows the user to define areas of the cross section that will be unavailable for flow conveyance or storage. Wills imported the available building data using RAS-Mapper, including the 'top of building' elevations which were available in the database. In some cases, particularly for tall buildings, the height of the obstruction was reduced to align with the highest point in the cross section in order to maintain an appropriate scale in the cross-section view.

4.4.9 Boundary Conditions

The six creeks all discharge into Lake Simcoe and were run under subcritical conditions; therefore, one comprehensive boundary condition was used for all the hydraulic models. The downstream boundary condition was set at 219.13 masl in CGVD 2013 (219.50 in CGVD 28:78), the maximum high-water level recorded for Lake Simcoe, as provided by LSRCA.

4.4.10 Lateral Spills and Levees

There are some locations throughout the creeks where internal high points within a cross section limit the opportunity for flows to equalize laterally. In some cases, these are isolated high points that are picked up within a cross section and the areas beyond the high point are hydraulically connected and should be modelled to convey flow. In other cases, however, the high points represent a continuous barrier between sections.

By default, HEC-RAS distributes flow laterally to any low area within cross sections and will neglect that local high points could prevent water from reaching certain areas. Wills reviewed the flood map results throughout the development of the model to identify locations where 'pockets' of flow were evident. To ensure that the regulatory flood elevations adjacent to the main channel were not understated, levees were introduced to eliminate the isolated area from the hydraulic model, unless the internal high points were overtopped.

In one location, a lateral spill was used as an alternative to a levee in order to measure the extent to which flows left the main channel to an alternate flow route. Additional details regarding lateral spills and levees are included in **Section 4.5.**

4.5 Complex Flow Locations and Supplemental Approaches

As discussed in **Section 4.3**, there are a number of locations where the nature of the flow is not conducive to a one-dimensional, steady state model. Whether influenced by development, or as a product of the natural terrain, the following locations require supplemental consideration to provide additional confidence in the results of the hydraulic models.

4.5.1 Bunkers Creek

Station 0+087 to 0+000 – Lakeshore Drive

At the downstream end of Bunkers Creek, near Lakeshore Drive, the flows begin to spread out into the low-lying terrain adjacent to Lake Simcoe. As Bunkers Creek begins to flow closer to Kidds Creek, the extent of the floodplain begins to encroach on the adjacent watershed boundary. Upstream and downstream of Lakeshore Drive, the floodplain is capped at an artificial vertical wall to avoid double counting the flow area between the Bunkers Creek and Kidds Creek models.

This challenge was addressed using Supplemental Approach 4; a spill arrow was used to indicate that some of the flows could leave the watershed on the north side of Bunkers Creek, contributing to the flow in Kidds Creek.

4.5.2 Dyments Creek

Station 4+368 to 3+155 – Edgehill Drive to Dunlop Street

Beginning upstream of Edgehill Drive, there is a local high point located approximately 100 m east of Dyments Creek. Lands to the west of the high point drain directly into Dyments Creek, while lands to the east flow towards the intersection of Ferndale Drive and Dunlop Street. The hydraulic model indicates that some flow from Dyments Creek could overtop this high point; and the result would be a poorly defined flow route through developed lands. It is expected that flows would re-intersect the creek somewhere near Dunlop Street and Sarjeant Drive.

This challenge was addressed using Supplemental Approach 5; levees were introduced into the model on the left overbank from Station 4+368 to Station 3+155. In some cases, the height of the levees were extended above the grade to contain flow within the creek. The uncertainty that is raised by this approach is indicated by a dashed line within the floodplain map, and an arrow indicating that a spill is expected in the area.

Station 2+574 to 2+358 – Sarjeant Drive

Dyments Creek is conveyed under Sarjeant Drive via twin 1.2 m CSP culverts in an irregular fashion. The culverts are 215 m long and have two 90° bends to follow the perimeter of a commercial development on the downstream side of Sarjeant Drive. Given the length of the pipes, it is difficult to be confident that the interpolated water surface elevation is accurately reflected on the terrain in the floodplain maps.

This challenge was addressed using Supplemental Approach 2; given that the terrain is fairly regular downstream of Sarjeant to the end of the culvert, the inundation boundaries between the upstream and downstream sides of the structure were manually adjusted on the floodplain map to create a smooth transition based on the topography data.

Station 1+113 to 0+957 – Anne Street

Dyments Creek is conveyed under Anne Street via twin 2.12 m x 1.73 m CSP arch culverts in an irregular fashion. The culverts are installed on a skew and extend for approximately 140 m under the intersection of Anne Street and John Street, and then under a commercial property. Given the length of the pipes and the variable terrain, it is difficult to accurately represent the topography over the culverts in a single profile.

This challenge was addressed using Supplemental Approach 3; a local surface model scenario (Dyments_Supl_01) was created in HEC-RAS to explore the limits of the floodplain in a surface-only model, modelling the overland flow using multiple cross sections. The supplemental flood limits were then stitched into the production of the floodplain maps using GIS tools.

4.5.3 Hotchkiss Creek

Station 1+925 to 1+050 – Hwy 400 Crossing to Rail Trail

Hotchkiss Creek is conveyed under Highway 400 via a 2.2 m CSP culvert and a 1.05 m CSP culvert, which is expected to cause a significant backwater effect during extreme flow events. As the headwater increases, it is expected that a portion of the flow will overtop the rail trail to the northwest of Hotchkiss Creek and will subsequently flow down the rail trail ditches, and down Tiffin Street. These flows are expected to remain substantially contained within the Hotchkiss Creek watershed and will re-intercept the channel approximately 150 m west of Anne Street. It is expected that the peak flows will be split between the two definable flow routes in a manner that will vary with the magnitude of flow.

This challenge was addressed using Supplemental Approach 6; a lateral spill was developed in the model to represent the rail trail upstream of Highway 400. Flow over the rail was predicted by the model and removed from the main reach. A second reach was developed along Tiffin Street to the confluence. The flow route along Tiffin Street also required select levees to avoid spills to the north; the uncertainty that is raised by this approach is indicated by a dashed line within the floodplain map, and an arrow indicating that a spill is expected in the area.

Station 1+573 to 1+375 – Wood Street

Hotchkiss Creek to the west of Wood Street is currently under development. The channel is buried in a pipe for a distance of 165 m. Based on field investigation, the upstream end of the pipe is a 1200 mm CSP. At some point underground, the pipe transitions to a 900 mm concrete pipe. It is expected that this pipe would convey a small percentage of the Regulatory Flow; the overland route remains poorly defined.

This challenge was addressed using Supplemental Approach 2; given that the flow is contained in a fairly consistent width and direction downstream of the rail culvert inlet, the inundation boundaries between the upstream and downstream sides of the structure were manually adjusted to create a smooth transition based on the topography data.

Station 1+203 to 1+186 – Rail Trail

Hotchkiss Creek is conveyed under the rail trail via a 1.2 m CSP culvert; a second 1.2 m CSP culvert is available to provide relief flow at a higher elevation. The culvert extends under industrial lands for a distance of 135 m. Given the length of the pipe and the variable terrain, it is difficult to accurately represent the topography over the culvert in a single profile.

This challenge was addressed using Supplemental Approach 2; given that the flow is contained in a fairly consistent width and direction downstream of the rail trail, the inundation boundaries between the upstream and downstream sides of the structure were manually adjusted on the floodplain map to create a smooth transition based on the topography data. Based on a review of the topography and hydraulic results, it was also noted that some portion of the flow that overtops the Rail Trail will spill to the east towards the intersection of Jacobs Terrace and Anne Street. This additional challenge was addressed using Supplemental Approach 4; a spill arrow was added to indicate the risk that some of the flow may leave the watershed.

Station 0+882 to 0+316 – Anne Street

Hotchkiss Creek is conveyed under Anne Street via a twin 4.27 m x 2.44 m concrete box culvert. The culvert is installed under the road and remains underground for approximately 130 m. Upstream of Anne Street the channel daylights briefly and intermittently, creating a challenging series of short sections terrain to model as bridge / culverts structures in HEC-RAS.

This challenge was addressed using Supplemental Approach 3; a local surface model scenario (Hotchkiss_Supl_01) was created in HEC-RAS to explore the limits of the floodplain in a surface-only model, modelling the overland flow using multiple cross sections. The supplemental flood limits were then stitched into the production of the floodplain maps using GIS tools. During the review of the results, a spill arrow was used to indicate that some of the flows could leave the watershed on the north side of Hotchkiss Creek at Anne Street.

Station 0+182 to 0+135 – Lakeshore Drive

At the downstream end of Hotchkiss Creek, near Lakeshore Drive, the flows begin to spread out into the low-lying terrain adjacent to Lake Simcoe. As Hotchkiss Creek begins to flow closer to Dyments Creek, the extent of the floodplain begins to encroach on the adjacent watershed boundary during the 100 year flow. Upstream of Lakeshore Drive, the floodplain is capped at an artificial vertical wall to avoid double counting the flow area between the Hotchkiss Creek and Dyments Creek models.

This challenge was addressed using Supplemental Approach 4; a spill arrow was used to indicate that some of the flows could leave the watershed on the north side of Hotchkiss Creek, contributing to the flow in Dyments Creek.

4.5.4 Kidds Creek

Station 1+412 to 0+993 – Wellington Street to Donald Street

Beginning downstream of Wellington Street, there is a local high point located approximately 20 m east of Kidds Creek that defines the edge of the Kidds Creek watershed. Lands to the west of the high point drain directly into Kidds Creek, while lands to the east flow towards Sophia Creek. The hydraulic model indicates that some flow from Kidds Creek could overtop this high point; and the result would be a poorly defined flow route through residential and park lands. It is expected that flows would intersect with the Sophia Creek west reach somewhere near Park Street.

This challenge was addressed using Supplemental Approach 5; levees were introduced into the model on the left overbank from Station 1+412 to Station 0+993. In some cases, the height of the levees was extended above the grade to contain flow within the creek. The uncertainty that is raised by this approach is indicated by a dashed line within the floodplain map, and an arrow indicating that a spill is expected in the area.

Station 1+412 to 1+130 – Thomson Street

Kidds Creek is conveyed under Thomson Street via a 1.8 m x 1.2 m concrete box culvert in an irregular fashion. The culvert is installed on a skew and extends for approximately 75 m under Thomson Street and a number of private entrances. Given the length of the pipe and the variable terrain, it is difficult to accurately represent the topography over the culverts in a single profile.

This challenge was addressed using Supplemental Approach 2; given that the floodplain width is fairly regular downstream of Thomson Street, the inundation boundaries between the upstream and downstream sides of the structure were manually adjusted on the floodplain map to create a smooth transition based on the topography data.

Station 0+373 to 0+116 – Bradford Street

Kidds Creek transitions from an open channel to a closed 6.1 m x 1.5 x concrete box at Bradford Street. The creek remains underground along Simcoe Street and Toronto

Street, a distance of 310 m, before emerging approximately 100 m west of Lake Simcoe. Given the length of the underground system, it is infeasible to include the pipe in the hydraulic model and provide an accurate assessment of the overland flow.

This challenge was addressed using Supplemental Approach 1. The capacity of the piped system was estimated by temporarily entering a short, representative inlet pipe at Station 0+373 and allowing HEC-RAS to balance the split between overland and piped flow. Based on those results, the flows were adjusted, and the pipe was removed from the model. During the Regulatory Flow event (Hazel) the peak flow that was removed from the model was 24.2 m3/s (41% of a total 58.7 m3/s).

Upon review of the results, it became apparent that flows that overtop Bradford Street will, in part, spill out of the watershed towards Bunkers Creek. The cross sections on Bradford Street were extended to the watershed limit and a spill arrow was used to indicate that some of the flows could leave the watershed on the south side of Kidds Creek, contributing to the flow in Bunkers Creek.

4.5.5 Whiskey Creek

Station 5+548 to 5+300 – Hwy 400

Whiskey Creek is conveyed under Hwy 400 via a 2.25 m concrete culvert in an irregular fashion. The culvert is 240 m long, includes 90° bends, and conveys flow under Highway 400 and Harvie Road into the northeast interchange loop. Given the length and slope of the pipe, and the distance from the inlet of the pipe to Highway 400, RAS-Mapper did not reflect overtopping flow on Highway 400, which is expected when reviewing the water profile in HEC-RAS.

This challenge was addressed using Supplemental Approach 2; the inundation boundaries between the upstream and downstream sides of the structure were manually adjusted on the floodplain map to create a smooth transition based on the topography data. While implementing this strategy, it was recognized that Highway 400 slopes continuously to the north. It is likely that overtopping flow, at least in part, would spill from Whiskey Creek. A spill arrow was used to indicate that some of the flows could leave the watershed on the north side of Whiskey Creek, eventually contributing to the Hotchkiss Creek watershed.

Station 4+609 to 4+559 – Bayview Drive

Whiskey Creek is conveyed under Bayview Drive at a significant skew angle via twin 1050 mm by 1290 mm CSP arch pipes. On the east side of Bayview Drive, at the location of the creek, there is an existing 22 m long dead-end entrance. It is expected that some of the flows that overtop Bayview Drive will be conveyed to the east end of the entrance and will discharge into the natural area and out of the sub-watershed. It is expected that the spill flow would re-intercept Whiskey Creek approximately 500 m downstream.

This challenge was addressed using Supplemental Approach 4; a spill arrow was used to indicate that some of the flows could leave the watershed on the east side of Whiskey Creek at the Bayview Drive crossing.

Station 0+966 to 0+574 – Rail Line

Whiskey Creek is conveyed under a rail line located between Lakeshore Drive and Burton Avenue via a 1.6 m CSP culvert. On the upstream side of the rail line, and approximately 200 m to the west, there is a local high point. Beyond the high point, the rail line and Lakeshore Drive slope continuously to the west. It is expected that flows that overtop the high point would leave the watershed on the west side of Whiskey Creek, eventually contributing to the Hotchkiss Creek watershed.

This challenge was addressed using Supplemental Approach 5; levees were introduced into the model on the left overbank from Station 0+966 to Station 0+655. In some cases, the height of the levees was extended above the grade to contain flow within the creek. The uncertainty that is raised by this approach is indicated by a dashed line within the floodplain map, and an arrow indicating that a spill is expected in the area.

4.5.6 Sophia Creek

Station 1+113 to 0+957 (Reach 1) – Ottaway Street

Sophia Creek is conveyed under a network of streets and residential properties from Ottaway Street to Laurie Crescent via a 3.0 m x 1.5 m concrete box culvert for approximately 190 m. Given the length of the pipes and the variable terrain, it is difficult to accurately represent the topography over the culverts in a single profile.

This challenge was addressed using Supplemental Approach 3; a local surface model scenario (Sophia_Supl_01) was created in HEC-RAS to explore the limits of the floodplain in a surface-only model, modelling the overland flow using multiple cross sections. The supplemental flood limits were then stitched into the production of the floodplain maps using GIS tools.

Station 1+477 to 1+391 (Reach 2) – Davidson Street

Sophia Creek is conveyed under Davidson Street via twin 1.67 m x 1.06 m CSP arch culverts in an irregular fashion. The culvert is installed on a skew and extends for approximately 80 m under Davidson Street and then Gunn Street. Given the length of the pipe and the awkward orientation of Davidson Street and Gunn Street, it is difficult to accurately represent the topography over the culverts in a single profile.

This challenge was addressed using Supplemental Approach 2; given that the floodplain width is fairly regular downstream of Davidson Street, the inundation boundaries between the upstream and downstream sides of the structure were reviewed on the floodplain map to ensure the results reasonable aligned with the topography data.

Station 0+973 to 0+017 (Reach 2) – Peel Street

Sophia Creek transitions from an open channel to a closed system at Peel Street. The creek remains underground for 950 m, as part of the storm sewer network following Sophia Street, Owen Street, Bayfield Street, Dunlop Street, and Simcoe Street before emerging into Lake Simcoe. Given the length of the underground system, it is infeasible to include the pipe in the hydraulic model and provide an accurate assessment of the overland flow.

This challenge was addressed using Supplemental Approach 1. The capacity of the piped system was estimated by temporarily entering a short, representative inlet pipe at Station 0+973 and allowing HEC-RAS to balance the split between overland and piped flow. The nature of the storm sewer is complex and varied; the flows were removed based on the capacity of a 1650 mm concrete pipe (Bayview Trunk).

Based on those results, the flows were adjusted, and the pipe was removed from the model. During the Regulatory Flow event (100 Year) the peak flow that was removed from the model was 4.73 m3/s (6.4% of a total 73.4 m^3/s).

It is apparent that flows through the network of streets between Peel Street and Lake Simcoe are difficult to model as one-dimensional flow. Some of the surface flow is expected to spill out of the east branch watershed towards Sophia Creek's west branch. Levees were used to contain the flow within the Sophia Creek east streetscape to a reasonable extent. A spill arrow was used to indicate that some of the flows could leave the watershed on the west side of Sophia Creek East, contributing to the flow in Sophia Creek West.

4.6 Sensitivity Analysis

Wills completed a sensitivity analysis of the hydraulic models in order to determine the extent to which changes in common parameters could influence the model results.

Wills reviewed parameters that are listed in Technical Guide (EWRG, 2017) Page 119 – Table 4.1 that would be expected to have an impact throughout the length of the models, and not simply at select locations. To that end, adjustments were made universally to the manning's roughness values and the expansion and contraction coefficients.

Manning's roughness is usually a sensitive parameter and generally impacts all sections in a hydraulic model; with the possible exceptions of areas under significant tailwater effects and sections that have defaulted to critical depth (in a subcritical model). Manning's roughness is variable and subjective, noting that the appropriate value can increase sharply at low flow depths. Therefore, it is necessary to assess the sensitivity of computed water surface elevations to changes in manning's roughness values. The typical range for sensitivity analysis for floodplain mapping is 125% to 75% of the estimated parameter values (EWRG, 2017).

The adjustment to manning's roughness coefficient were applied to the Regulatory Flow scenario within each model. A summary of the results of the manning's sensitivity analysis can be found in **Table 9** and **Table 10.** The model summary output tables for both scenarios have been included in **Appendix C**.

Table 9 – 125% of Manning's Roughness Value

Change in Water Surface Elevation	**Bunkers Creek**		**Dyments Creek**		**Hotchkiss Creek**	
	XS Count	**Percent of Total**	**XS Count**	**Percent of Total**	**XS Count**	**Percent of Total**
more than +0.3 m	0	0.0%	1	0.8%	0	0.0%
+0.29 m to +0.20 m	2	3.1%	1	0.8%	0	0.0%
+0.19 m to +0.10 m	26	40.6%	7	5.4%	4	5.1%
+0.09 m to +0.01 m	25	39.1%	73	56.6%	35	44.3%
No Change	9	14.1%	42	32.6%	36	45.6%
-0.01 m to -0.09 m	2	3.1%	5	3.9%	4	5.1%
-0.10 m to -0.19 m	0	0.0%	0	0.0%	0	0.0%
-0.20 m to -0.29 m	0	0.0%	0	0.0%	0	0.0%
less than -0.30 m	0	0.0%	0	0.0%	0	0.0%
Total	64	100.0%	129	100.0%	79	100.0%
Max Increase (m)	0.21		0.49		0.17	
Max Decrease (m)	(-)0.05		(-)0.01		(-)0.01	

Change in Water Surface Elevation	**Kidds Creek**		**Whiskey Creek**		**Sophia Creek**	
	XS Count	**Percent of Total**	**XS Count**	**Percent of Total**	**XS Count**	**Percent of Total**
more than +0.3 m	0	0.0%	0	0.0%	0	0.0%
+0.29 m to +0.20 m	0	0.0%	1	0.4%	0	0.0%
+0.19 m to +0.10 m	19	15.7%	33	13.9%	9	7.0%
+0.09 m to +0.01 m	50	41.3%	107	45.1%	64	49.6%
No Change	33	27.3%	83	35.0%	50	38.8%
-0.01 m to -0.09 m	19	15.7%	13	5.5%	6	4.7%
-0.10 m to -0.19 m	0	0.0%	0	0.0%	0	0.0%
-0.20 m to -0.29 m	0	0.0%	0	0.0%	0	0.0%
less than -0.30 m	0	0.0%	0	0.0%	0	0.0%
Total	121	100.0%	237	100.0%	129	100.0%
Max Increase (m)	0.18		0.21		0.20	
Max Decrease (m)	(-)0.01		(-)0.02		(-)0.07	

A review of **Table 9** indicates that the majority of sections experience no change or a small increase in water surface elevation due to an increase in manning's roughness coefficient. This is aligned with the general expectations of the parameter and provides confidence that the model is responding well to the input variables.

Table 10 – 75% of Manning's Roughness Value

Change in Water Surface Elevation	**Bunkers Creek**		**Dyments Creek**		**Hotchkiss Creek**	
	XS Count	**Percent of Total**	**XS Count**	**Percent of Total**	**XS Count**	**Percent of Total**
more than +0.3 m	0	0.0%	0	0.0%	0	0.0%
+0.29 m to +0.20 m	0	0.0%	0	0.0%	0	0.0%
+0.19 m to +0.10 m	0	0.0%	0	0.0%	0	0.0%
+0.09 m to +0.01 m	1	1.6%	2	1.6%	9	11.4%
No Change	16	25.0%	49	38.0%	38	48.1%
-0.01 m to -0.09 m	27	42.2%	74	57.4%	27	34.2%
-0.10 m to -0.19 m	18	28.1%	3	2.3%	5	6.3%
-0.20 m to -0.29 m	2	3.1%	0	0.0%	0	0.0%
less than -0.30 m	0	0.0%	1	0.8%	0	0.0%
Total	64	100.0%	129	99.2%	79	100.0%
Max Increase (m)	0.01		0.02		0.01	
Max Decrease (m)	(-)0.28		(-)0.44		(-)0.18	

Change in Water Surface Elevation	**Kidds Creek**		**Whiskey Creek**		**Sophia Creek**	
	XS Count	**Percent of Total**	**XS Count**	**Percent of Total**	**XS Count**	**Percent of Total**
more than +0.3 m	0	0.0%	0	0.0%	0	0.0%
+0.29 m to +0.20 m	0	0.0%	0	0.0%	0	0.0%
+0.19 m to +0.10 m	0	0.0%	0	0.0%	0	0.0%
+0.09 m to +0.01 m	11	9.1%	1	0.4%	4	3.1%
No Change	38	31.4%	105	44.3%	61	47.3%
-0.01 m to -0.09 m	58	47.9%	100	42.2%	59	45.7%
-0.10 m to -0.19 m	13	10.7%	30	12.7%	5	3.9%
-0.20 m to -0.29 m	1	0.8%	1	0.4%	0	0.0%
less than -0.30 m	0	0.0%	0	0.0%	0	0.0%
Total	121	100.0%	237	100.0%	129	100.0%
Max Increase (m)	0.07		0.01		0.01	
Max Decrease (m)	(-)0.24		(-)0.27		(-)0.15	

A review of **Table 10** indicates that the majority of sections experience no change or a small decrease in water surface elevation due to a decrease in manning's roughness coefficient. This is aligned with the general expectations of the parameter and provides confidence that the model is responding well to the input variables.

With respect to both **Table 9** and **Table 10**, the most significant impact (+0.49 to -0.44 m) occurred at Lakeshore Drive at Dyments Creek. At this location the Regulatory flow is close to overtopping the road. This is usually a somewhat unstable flow condition in that changes in various parameters can alter the results from low-flow to high-flow bridge hydraulic analysis methods.

In a similar manner, adjustment to expansion and contraction coefficients were applied to the Regulatory Flow scenario within each model. The coefficients were adjusted from 150% to 50% of the estimated parameter values. A larger variation was applied, noting the significant variation in the suggested coefficient range A summary of the results of the sensitivity analysis can be found in **Table 11** and Table 12**.** The model summary output tables for both scenarios have been included in **Appendix C**.

Table 11 – 150% of Expansion / Contraction Coefficients

Change in Water Surface Elevation	**Bunkers Creek**		**Dyments Creek**		**Hotchkiss Creek**	
	XS Count	**Percent of Total**	**XS Count**	**Percent of Total**	**XS Count**	**Percent of Total**
more than +0.3 m	0	0.0%	0	0.0%	0	0.0%
+0.29 m to +0.20 m	0	0.0%	1	0.8%	0	0.0%
+0.19 m to +0.10 m	0	0.0%	9	7.0%	2	2.5%
+0.09 m to +0.01 m	45	70.3%	52	40.3%	33	41.8%
No Change	18	28.1%	66	51.2%	43	54.4%
-0.01 m to -0.09 m	1	1.6%	1	0.8%	1	1.3%
-0.10 m to -0.19 m	0	0.0%	0	0.0%	0	0.0%
-0.20 m to -0.29 m	0	0.0%	0	0.0%	0	0.0%
less than -0.30 m	0	0.0%	0	0.0%	0	0.0%
Total	64	100.0%	129	100.0%	79	100.0%
Max Increase (m)	0.09		0.21		0.15	
Max Decrease (m)	(-)0.02		(-)0.01		(-)0.01	

Change in Water Surface Elevation	**Kidds Creek**		**Whiskey Creek**		**Sophia Creek**	
	XS Count	**Percent of Total**	**XS Count**	**Percent of Total**	**XS Count**	**Percent of Total**
more than +0.3 m	0	0.0%	0	0.0%	0	0.0%
+0.29 m to +0.20 m	9	7.4%	0	0.0%	0	0.0%
+0.19 m to +0.10 m	1	0.8%	1	0.4%	0	0.0%
+0.09 m to +0.01 m	48	39.7%	124	52.3%	39	30.2%
No Change	62	51.2%	110	46.4%	88	68.2%
-0.01 m to -0.09 m	1	0.8%	2	0.8%	2	1.6%
-0.10 m to -0.19 m	0	0.0%	0	0.0%	0	0.0%
-0.20 m to -0.29 m	0	0.0%	0	0.0%	0	0.0%
less than -0.30 m	0	0.0%	0	0.0%	0	0.0%
Total	121	100.0%	237	100.0%	129	100.0%
Max Increase (m)	0.24		0.11		0.07	
Max Decrease (m)	(-)0.03		(-)0.01		(-)0.02	

A review of **Table 11** indicates that the majority of sections experience no change or a small increase in water surface elevation due to an increase in expansion / contraction coefficients. This is aligned with the general expectations of the parameter and provides confidence that the model is responding well to the input variables.

Table 12 – 50% of Expansion / Contraction Coefficients

Change in Water Surface Elevation	Bunkers Creek		Dyments Creek		Hotchkiss Creek	
	XS Count	Percent of Total	XS Count	Percent of Total	XS Count	Percent of Total
greater than +0.3 m	0	0.0%	0	0.0%	0	0.0%
+0.29 m to +0.20 m	0	0.0%	0	0.0%	0	0.0%
+0.19 m to +0.10 m	0	0.0%	0	0.0%	0	0.0%
+0.09 m to +0.01 m	0	0.0%	2	1.6%	0	0.0%
No Change	22	34.4%	66	51.2%	46	58.2%
-0.01 m to -0.09 m	42	65.6%	52	40.3%	30	38.0%
-0.10 m to -0.19 m	0	0.0%	8	6.2%	2	2.5%
-0.20 m to -0.29 m	0	0.0%	1	0.8%	1	1.3%
less than -0.30 m	0	0.0%	0	0.0%	0	0.0%
Total	64	100.0%	129	100.0%	79	100.0%
Max Increase (m)	0.00		0.02		0.00	
Max Decrease (m)	(-)0.08		(-)0.29		(-)0.21	
Change in Water Surface Elevation	**Kidds Creek**		**Whiskey Creek**		**Sophia Creek**	
	XS Count	**Percent of Total**	**XS Count**	**Percent of Total**	**XS Count**	**Percent of Total**
greater than +0.3 m	0	0.0%	0	0.0%	0	0.0%
+0.29 m to +0.20 m	0	0.0%	0	0.0%	0	0.0%
+0.19 m to +0.10 m	0	0.0%	0	0.0%	0	0.0%
+0.09 m to +0.01 m	0	0.0%	2	0.8%	4	3.1%
No Change	66	54.5%	101	42.6%	61	47.3%
-0.01 m to -0.09 m	44	36.4%	132	55.7%	59	45.7%
-0.10 m to -0.19 m	2	1.7%	1	0.4%	5	3.9%
-0.20 m to -0.29 m	9	7.4%	1	0.4%	0	0.0%
less than -0.30 m	0	0.0%	0	0.0%	0	0.0%
Total	121	100.0%	237	100.0%	129	100.0%
Max Increase (m)	0.00		0.01		0.01	
Max Decrease (m)	(-)0.25		(-)0.21		(-)0.15	

A review of **Table 12** indicates that the majority of sections experience no change or a small decrease in water surface elevation due to a decrease in expansion /

contraction coefficients. This is aligned with the general expectations of the parameter and provides confidence that the model is responding well to the input variables.

With respect to both **Table 11** and **Table 12**, the most significant impact (+0.21 to -0.29 m) occurred at Lakeshore Drive at Dyments Creek. At this location the Regulatory flow is close to overtopping the road. This is usually a somewhat unstable flow condition in that changes in various parameters can alter the results from low-flow to high-flow bridge hydraulic analysis methods.

An additional input parameter that significantly impacts the results of any hydraulic model is the peak flow rates. In general, the models responded well to changes in peak flows; increased peak flows resulted in higher water surface elevations. Wills reviewed the models in detail to eliminate, to the greatest extent, any ‘crosses’ in the water surface profile lines between the various flow events that were assessed.

The sensitivity analysis provides encouraging and reasonable results, building credibility with respect to the reliability of the models. In general, the models respond to changes in key parameters in a manner that would be expected: water surface elevations rise appropriately with increases in roughness and higher energy loss coefficients. Furthermore, the impacts are reasonably small and consistent throughout the models. The majority of cross sections experience no change or a modest change (less than 0.10 m) when subjected to significant variations in input parameters.

4.7 Calibration/Validation

The development of a hydraulic model requires several input parameters. Some of the parameters are based on field measurements (i.e., survey, measurements of bridges and culverts, etc.), while other parameters are left to engineering experience, reference material, and judgement based on available information (Manning’s n, loss coefficients, etc.). For this reason, it is ideal to compare computed water levels to those observed in the field wherever possible. Model parameters can then be adjusted to replicate the observed water levels more accurately during a historic event.

Three hydrometric data stations exist within the watersheds, located within Bunkers Creek, Hotchkiss Creek and Kidds Creek. A total of nine flow events were used to correlate the flow rate to the flow depth within each creek. Consideration was given to choosing flow events in or around the 80th percentile of recorded data, in order to rely on results that had been verified by multiple occurrences. The hydrologic significance and limitations of the flow data is discussed in **Section 3.2.**

In order to understand the hydraulic variables that may impact the precision of the model relative to the flow gauge data, it is important to review the characteristics of the floodplain at the locations of the data stations. That is to say, for example, that gauged data that is located within the tailwater influence of a bridge or culvert may be significantly dependant on the performance of the culvert, whereas a station that is located in a long and un-interrupted stretch of open channel may be most significantly influenced by the selection of manning’s roughness values.

Additional flow scenarios were developed for the three creeks, representing the flow events outlined in **Table 3** in **Section 3.2**. The locations of the data stations are closest to Bunkers Creek - Section 0+577; Hotchkess Creek – Section 0+572; and Kidds Creek - Section 0+848 The hydraulic profiles near the data stations, for both floodplain mapping events and based on the gauged data, are shown in **Figure 4** to **Figure 6**.

Figure 4 – Bunkers Creek Gauged Flow Profile

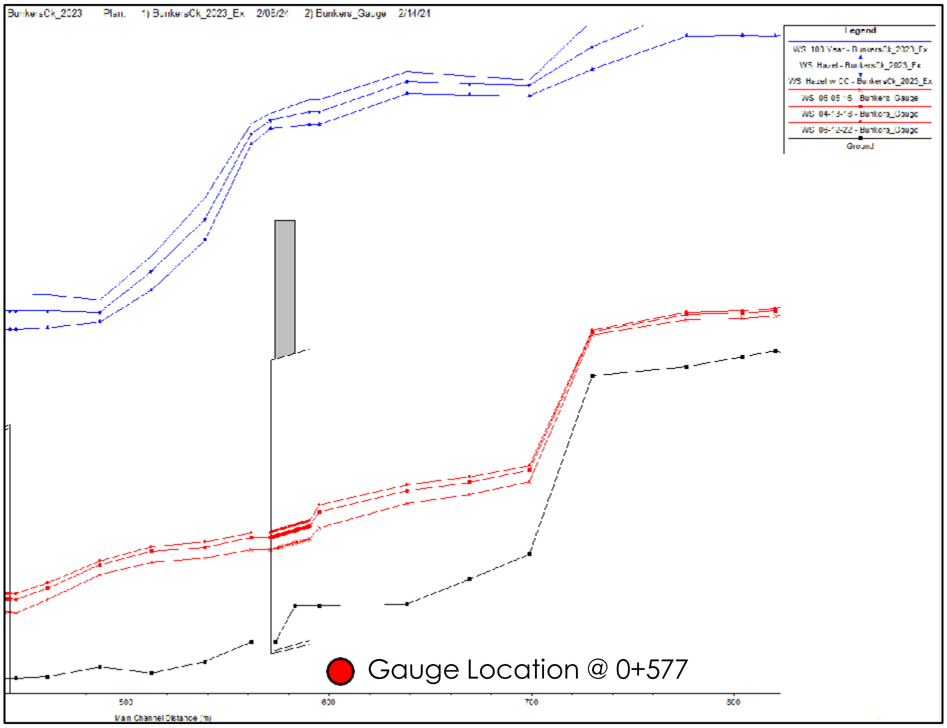


Figure 5 - Hotchkiss Creek Gauged Flow Profile

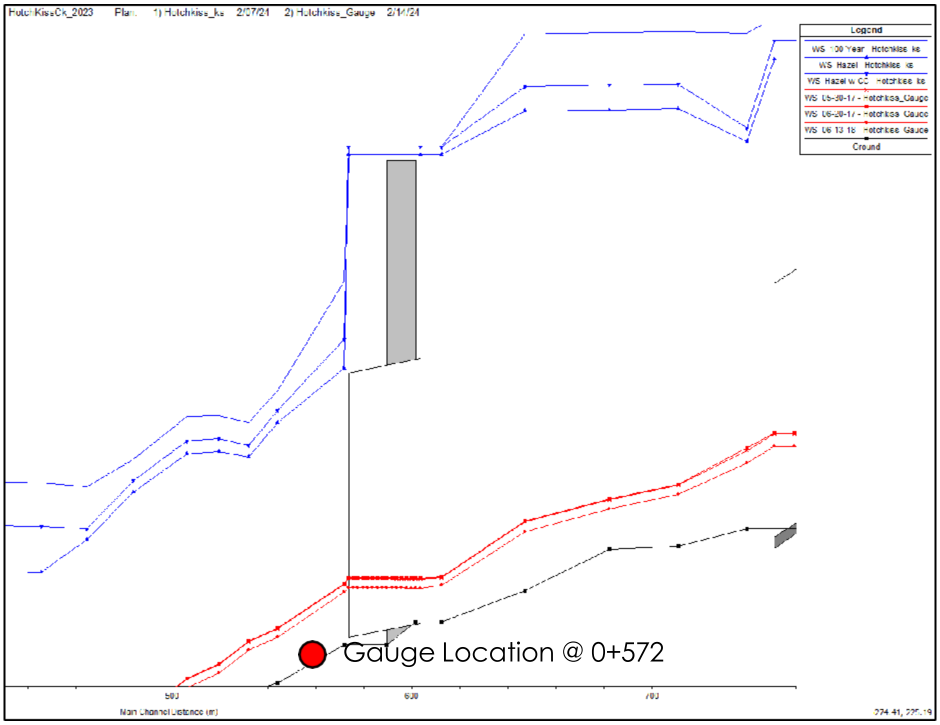
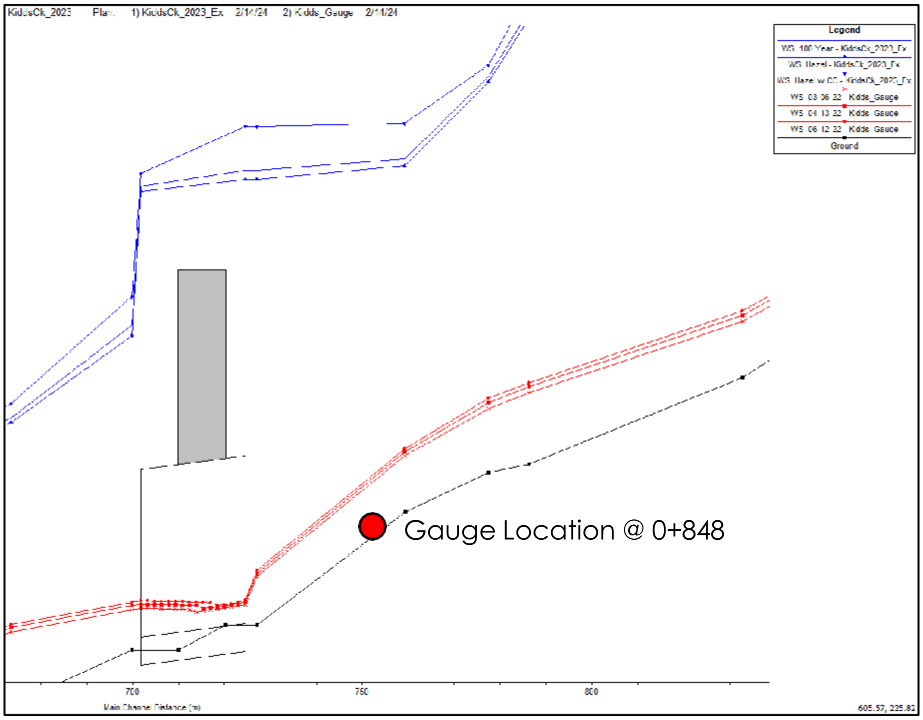


Figure 6 - Kidds Creek Gauged Flow Profile



A review of **Figure 4** to **Figure 6** indicates that, during the gauged flows events, the water surface profile is roughly parallel to the channel profile. This indicates that the flow depth results are not obviously influenced by the adjacent culvert crossings. It is noteworthy that during the flood mapping flow events, the gauged locations do appear to be under the tailwater influence of Innisfil Street (Bunkers Creek) and Eccles St N (Kidds Creek).

The elevation of the water surface during each of the nine flow events were compared to the results of the hydraulic models. A summary of the results is provided in **Table 13**.

Table 13 – Water Surface Elevation Comparison

Creek and Location	Station ID	Co-ordinates	Date of Event	Peak Flow (m^3/s)	Gauged Elevation CGVD 2013	Modelled Elevation CGVD 2013	Difference Model – Gauged (m)
Bunkers Creek at Innisfil St	LS0112	44.38294 N -79.69731 W	06/05/2016	1.45	220.24	220.14	-0.10
			04/13/2018	1.14	220.17	220.06	-0.11
			06/12/2022	1.59	220.37	220.18	-0.19
Hotchkiss Creek at Innisfil St	LS0203	44.37492 N -79.6946 W	05/30/2017	1.69	221.79	221.67	-0.12
			06/20/2017	1.74	221.80	221.67	-0.13
			06/13/2018	1.18	221.69	221.59	-0.10
Kidds Creek at Eccles St N	LS0113	44.38703 N -79.69928 W	03/06/2022	1.19	224.35	224.33	-0.02
			04/13/2022	1.43	224.39	224.36	-0.03
			06/12/2022	1.60	224.41	224.38	-0.03

A review of **Table 13** indicates that the modelled results are moderately lower than the gauged data. The depth of flow in each of the creeks during the gauged events is in the range of 0.40 m to 0.60 m. Therefore, relative to the flow depth, the variation in depth between the gauged results and the model results is very minor in Kidds Creek, and more significant in Hotchkiss Creek and Bunkers Creek.

The gauged elevations and modelled elevations vary with flow in a consistent manner, with the exception of the 06/12/2022 event at Bunkers Creek, which measured unusually high-water surface elevations. This could be due to a number of unforeseen factors, including a partial blockage of the Innisfil Street culvert.

The results of the calibration review and sensitivity analysis indicate that the gauged data and model results could likely be made to align precisely by adjusting manning's roughness and/or expansion and contraction coefficients, while remaining within standard modelling parameter ranges.

Ultimately, we do not recommend making adjustments to the hydraulic models on the basis of this calibration review due to the significant difference between the magnitude of the available gauged flow data and the proposed flood mapping flow events.

If additional flow data become available in the future, it may be appropriate to revisit this calibration review. Based on the review of the flow profiles during the gauged flow events, the resulting water surface elevations, and the sensitivity analysis described in **Section 4.6**, we recommend using manning's roughness value as the key parameter for adjustment, in order to align the model results to future gauged data.

4.8 Hydraulic Model Results

4.8.1 Water Surface Elevations

The hydraulic models included a cumulative length of 23.3 km and incorporated 59 discrete bridge / culvert crossings. A variety of complex flow locations, spills, and supplemental modelling and flood mapping approaches were adopted throughout the models to best represent the urban landscape.

Summary output tables of the results for each cross section for each of the modelling scenarios can be found in **Appendix C**. The results of this study can be interpreted on the basis of the engineered flood maps, which are included in **Appendix D.**

4.8.2 Hydraulic Model Comparisons

Wills reviewed the historic floodplain mapping against the computed inundation boundaries for the Regulatory storm as part of this study. Wills noted that the previously developed floodplain extents generally compare well in overall shape and extents. Noting that the Regulatory peak flows generally increased from previous studies, as detailed in **Section 3.3**, it was expected that the results of this study would indicate a general increase in the extents of the floodplain.

It is expected that there will be some degree of variation from previous studies due to a variety of changes in the underlying data and information, including but not limited to newer modelling technology, higher resolution topographic and roughness information, updated peak flows, updated infrastructure including culvert and bridge replacements, differing modelling assumptions including tailwater assumptions, and different approaches to complex flow scenarios.

Some of the above changes may result in flood extents that are less than those predicted by previous studies. The most likely variables that would lead to reduced flood extents include lower peak flow rates, and/or increased culvert and bridge capacities due to infrastructure improvement projects.

Notable differences from the previous Regulatory Flood Map extents include:

Bunkers Creek

- The updated mapping indicates reduced flood extents from Ellen Street to Lake Simcoe, particularly on the south side of Bunkers Creek.

Dyments Creek

- The updated mapping indicates potential spill locations to the east of Dyments Creek, from Edgehill Drive to Dunlop Street
- The updated mapping indicates increased flood extents on the south side of Dyments Creek from Dunlop Street West to Sarjeant Drive.
- The updated mapping indicates increased flood extents on the east side of Dyments Creek, downstream of Highway 400.
- The updated mapping indicates reduced flood extents from Lakeshore Drive to Lake Simcoe, on both sides of Dyments Creek.

Hotchkiss Creek

- The updated mapping indicates increased flood extents upstream of Highway 400, which includes a lateral spill and a secondary flow route along Tiffin Street.
- The updated mapping indicates reduced flood extents from Lakeshore Drive to Lake Simcoe, particularly on the north side of Hotchkiss Creek.

Kidds Creek

- The updated mapping indicates slightly reduced flood extents for extended portions of the model; but generally, aligns closely with previous mapping.

Whiskey Creek

- The updated mapping extends approximately 500 m further upstream than the previous mapping.
- The updated mapping indicates that a large industrial building fronting Bayview Drive, near Mollard Court, is within the Regulatory Floodplain, which was not reflected in previous mapping.
- The updated mapping indicates increased flood extents upstream of Yonge Street and the Rail Line that is located between Yonge Street and Lakeshore Drive

Sophia Creek

- The updated mapping indicates increased flood extents between Highway 400 and MacMorrison Park, noting the consideration for surface flow.

- The updated mapping includes results between Peel Street and Lake Simcoe, which is not reflected in the digital Regulatory Floodline provided by LSRCA. We note that a supplemental assessment was completed by CC Tatham in 2008 and that the results compare well, particularly considering the complex nature of the flow and significant number of potential spill locations.

5.0 Mapping

5.1 Overview

The regulatory floodplain and flood risk mapping is the final product produced after the water surface elevations are determined using the hydraulic model. The mapping was produced using RAS-Mapper to create inundation boundaries, and the following adjustments were made using GIS tools:

- Dry areas with an area of less than 50 m^2 that were completely surrounded by floodplain (i.e. islands) were deleted from the flood mapping using automated tools. Any additional islands were reviewed manually and substantially removed, with the exception a few outliers that were particularly large.
- Wet areas with an area of less than 100 m^2 that were completely isolated from the rest of the floodplain (i.e. wet pockets and puddles) were deleted from the flood mapping using automated tools. Any additional pockets were reviewed manually to confirm there was no connection to the floodplain and were subsequently deleted.
- All road crossings were reviewed to ensure that the floodplain extents were drawn correctly over the road, based on the results of the HEC-RAS flow profile. In most cases, the roads are overtopped during the Regulatory Flow.
- The supplemental mapping approaches discussed in **Section 4.3** and **Section 4.5** were implemented on the flood maps, including some manual interpolation and indicators for potential spill areas.

The Floodplain Maps are included in **Appendix D.**

6.0 Conclusion

The Lake Simcoe Region Conservation Authority (LSRCA) has recognized the need for a comprehensive update to the hydrologic and hydraulic modelling and regulatory floodplain mapping for six creeks in the City of Barrie. The objective of this project is to provide updated regulatory floodplain for Bunkers Creek, Dyments Creek, Hotchkiss Creek, Kidds Creek, Whiskey Creek and Sophia Creek. The intent of this hydraulics report is to provide the hydraulic inputs for floodplain mapping and mapping results. This hydraulics report included the following key phases:

- **Background Data Collection and Review** – Wills reviewed all available background information provided by the LSRCA.
- **Site Reconnaissance and Topographic/Bathymetric Survey** – Wills undertook a site reconnaissance and collected topographic and bathymetric survey data to define numerous structures crossing the creeks and validate the LiDAR DTM. The quality and accuracy of the DTM was validated.
- **Hydrology Study** – Wills did not complete a hydrology study as part of this assignment. Peak flows were provided by LSRCA on the basis of the Barrie Hydrologic Model Updates Report (Tatham Engineering Limited, Dec 2023).
- **Hydraulics Study** - Wills undertook a hydraulics study to develop a hydraulic model to compute water surface elevations for the 100 Year, Hazel, and Hazel with climate change scenarios. The hydraulics study was completed using HEC-RAS (Version 6.3.1). The development of the hydraulic model included sensitivity analyses and calibration review efforts.
- **Floodplain Mapping** – Wills developed comprehensive floodplain maps for each of the flow scenarios provided.

Respectfully submitted,

LICENSED PROFESSIONAL ENGINEER
K.P.SMITH
100149006
April 5/24
PROVINCE OF ONTARIO

Sarah Ormel, P.Eng.
Project Engineer
Water Resources Engineering

Ken Smith, P.Eng.
Manager
Water Resources Engineering

KS/SO/dg

References

Hager, W. H. (1987). Lateral Outflow Over Side Weirs. Journal of Hydraulic Engineering, Volume 113, Issue 4.

MNR. (2002). Technical Guide: River and Stream Systems - Flooding Hazard Limit. Ontario.

Enviromental Water Resource Group Ltd. (EWRG). (2017) Technical Guidelines for Flood Hazard Mapping

Natural Resources Canada (NRCAN) (2019). Federal Hydrologic and Hydraulic Procedures for Flood Hazard Delineation

Minstry of Natural Resources and Forestry (MNRF)(2019), Southern Ontario Land Resource Information System (SOLRIS) Version 3.0: Frequently asked questions

Minstry of Natural Resources and Forestry (MNRF) (2019), Southern Ontario Land Resource Information System (SOLRIS) Version 3.0: Data Specifications

Ministry of Natural Resources and Forestry (MNRF) (2023), Ontario Digital Terrain Model (LiDAR Dervied) User Guide

Appendix

All Appendices are found in a separate appendix document