FRENCHMAN'S BAY WATERSHED
HYDROLOGIC MODEL UPDATE

Prepared for:
TORONTO AND REGION CONSERVATION AUTHORITY

Prepared by:
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Prepared for Toronto and Region Conservation Authority, February 2024

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DISCLAIMER

VERSION CONTROL

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EXECUTIVE SUMMARY

Toronto and Region Conservation Authority (TRCA) retained Matrix Solutions Inc. to complete a comprehensive update to hydrologic and hydraulic modelling in the Frenchman's Bay watershed. The objective of this study was to complete watershed-wide delineation of Regulatory floodplain limits using recent topographic and hydrologic data. To complete this objective, a hydrologic model was developed to calculate peak flows throughout the watershed. A comprehensive hydraulic model for the watershed was subsequently built with the new peak flows as well as current topographic and survey data to generate water surface elevations and produce floodplain maps. This report documents the development and application of the hydrologic model.

Frenchman's Bay has a drainage area of approximately 20 km^2, most of which is highly urbanized. There are four major watercourses in the Frenchman's Bay watershed: Pine Creek (8.9 km^2), Krosno Creek (5.6 km^2), Amberlea Creek (3.2 km^2), and Dunbarton Creek (2.3 km^2), which all drain into Frenchman's Bay lagoon. The watershed is entirely within the City of Pickering, Ontario; development in the watershed began as early as the 1840s, but intensified during the 1970s when the Pickering nuclear generating station was established (Eyles et al. 2012). Most of the watershed was fully built prior to the 1980s, leading to minimal stormwater management (SWM) controls to reduce flood volumes and peak flows in its watercourses.

To initiate the project, background data was collected and reviewed, including previously completed reports, flow and rainfall monitoring data, aerial imagery, SWM facility reports, and GIS data to familiarize with the study area. The previously completed hydrology reports were reviewed to understand previous catchment parameterization, calibration approaches, and selection of design storm distributions. Data at two TRCA flow monitoring locations were reviewed to determine duration and frequency characteristics, as well as overlapping monitoring periods. Rainfall data from TRCA were reviewed spatially to try and capture the highest density of rainfall input for the calibration and validation events. Soils data mapping was available for most of the watershed, and surficial geology mapping was used to infill some unclassified areas. Land use mapping identified 20 different land use types within the watershed, with medium density residential, industrial, commercial and roads making up over 60% of the area.

PCSWMM was selected as the preferred modelling platform to represent the hydrologic processes within Frenchman's Bay. The model platform integrates the full United States Environmental Protection Agency Storm Water Management Model Version 5.2.3 (EPA SWMM; EPA 2017) hydrology and hydraulics engine with a powerful GIS platform. PCSWMM was selected as it has built-in capability to represent the detailed hydrologic processes for each catchment, while also being able to represent a variety of SWM features and complex hydraulic routing.

Model catchments were delineated for the Frenchman's Bay watershed using the 2015/2019 spliced LiDAR. Initially, catchments were delineated at the upstream end of each watercourse, at confluences, at watercourse crossings, and for the 4 SWM facilities identified within the watershed. Catchments were refined to ensure that most catchments remained a reasonable size (between 2 and 100 ha). The final delineation resulted in 118 catchments.

Parameters for each catchment were defined from the background spatial datasets, literature values, and professional judgement based on knowledge of the watershed. Initial parameters values were calculated as follows and later refined during the calibration process:

- catchment area: defined through catchment delineation
- catchment flow length: defined by the longest overland flow path
- average catchment slope: defined by smoothed 2015/2019 LiDAR raster
- imperviousness: defined by an aerial image raster analysis
- roughness coefficients for pervious and impervious areas: defined by land use and literature values
- depression storage for pervious and impervious areas: defined by land use and literature values
- soil infiltration parameters: Green and Ampt method defined by soils and surficial geology mapping
- channel routing: defined by simplified HEC-RAS model cross-sections; hydrologically significant structures were reviewed and added to the hydrologic model
- SWM facility parameterization: defined by information provided in the design reports

As per the TRCA guidelines, ten high flow events were selected for model calibration and validation. Events selected for calibration/validation correspond with times where multiple rain gauges and flow monitoring gauges were recording. Emphasis was placed on events that resulted in the greatest peak flows and 15-minute data recording intervals. Antecedent moisture conditions were determined for each event by reviewing the conditions 5 and 3 days prior to the event rainfall and were represented in the model by simulating the pre-event rainfall period.

Several metrics were reviewed for each of the calibration and validation events simulated in the hydrologic model. Through the calibration processes and the TRCA rating curve development, it was determined that emphasis should be placed on the matching flows with more recent (post-2012) flow data. The resulting calibration achieved TRCA's criteria for matching peak flows and volumes for the required number of events at both flow gauges.

The 2- through 100-year and 350-year design storm events, and the 48-hour Hurricane Hazel historic event, were simulated to estimate return period and Regional storm event peak flows for input to the hydraulic model. As the Regional and 350-year flow estimates require that all SWM facilities and structures be removed, and the peak flows needed to consider future conditions, two PCSWMM models were developed with the calibrated hydrologic parameters. An existing conditions PCSWMM model with SWM facilities and structures represented was used to simulate the 2- through 100-year design storm distributions, and a future conditions PCSWMM model without the SWM infrastructure pieces was used to simulate the Regional, 100-year and 350-year events.

Seven different design storm distributions were simulated in the hydrologic model and compared to the flood frequency analysis completed for the key flow gauges located on Krosno Creek (HY040) and Pine Creek (HY052), respectively. Matrix reviewed the results of the analysis and determined that the 1-hour Atmospheric Environmental Service (AES) storm distribution was most suitable to represent the design storm flows in the Frenchman's Bay, as it is applicable to urbanized watersheds, is a City of Pickering standard design storm, produces conservative results, and has a high-intensity and short-duration storm distribution similar to historical events.

To account for saturated conditions, the full 48-hour hyetograph of the Regional storm event (Hurricane Hazel) was simulated in the calibrated hydrologic model. Peak flow results for the Regional storm were compared to the previous studies. Differences in peak flow between models are largely due to refinements with the catchment delineation and refinements in model parameterization and assumptions around major/minor flow splits. In general, the updated Regional flows are lower (average 28% lower) than the previous TRCA model estimates.

A high level of care and professional judgement was used to calibrate and validate the Frenchman's Bay hydrologic model to ensure the physical processes of infiltration, runoff, and routing were properly represented. As with any model, there are sources of inherent uncertainty whether in input data, calibration parameters, or calculation processes within the models themselves. Areas of potential uncertainty with the model, limitations of using the calibrated hydrologic model, and recommendations for potential improvements are provided to assist with future modelling efforts.

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1 INTRODUCTION

The Toronto and Region Conservation Authority (TRCA) retained Matrix Solutions Inc. to complete a comprehensive hydrologic and hydraulic model and flood hazard mapping limit update for the Frenchman's Bay watershed. To complete this objective, an up-to-date hydrologic model of the Frenchman's Bay watershed was required to estimate Regional and 2 through 350-year design storm peak flows throughout the watershed, which was then input to a new comprehensive hydraulic model for the watershed which was developed in parallel with the hydrology model. The hydraulic model was then used to generate water surface elevations and subsequently produce flood hazard mapping limits. This report documents the development and application of the hydrologic model.

Hydrologic flow estimates have historically been completed using the Visual OTTHYMO (Greenland International Consulting Inc. 2001) modelling software platform. To complete the hydrologic update, TRCA selected the PCSWMM (PCSWMM Version 7.6.3695/SWMM Version 5.2.3, CHI 2023) modelling platform to simulate the hydrologic response of the Frenchman's Bay watershed. PCSWMM modelling platform was selected to represent the Frenchman's Bay watershed as it is highly urbanized with more than 75% of its area being designated as urban land use (MMM 2009). The PCSWMM EPASWMM engine was developed to analyze runoff from urban areas and contains modelling capabilities to represent urban elements such as stormwater management (SWM) facilities, drainage system networks, and impervious catchments. Although the EPASWMM engine can also represent non-urban catchments, the hydrologic processes and parameters embedded in the model are tailored toward representing small, urbanized catchments, such as Frenchman's Bay.

PCSWMM has been used on a variety of projects throughout Ontario and Canada, including the latest TRCA hydrology updates for Highland Creek (Matrix 2020), the Rouge River (Wood 2018) and Don River (AECOM 2018) watersheds. Using PCSWMM to represent the hydrology of the Frenchman's Bay watershed provides an opportunity to simulate rainfall-runoff interaction in a more detailed and comprehensive manner than the previous studies. Additional meteorological and hydrometric data that has been collected since the latest updates also provides additional storm events that can be used to calibrate and validate the PCSWMM model. Overall, these refinements help provide a more reliable hydrologic model that is suitable for flood hazard mapping.

This hydrology report outlines the hydrologic model development, parameterization, calibration, and validation results and Regional and design storm simulations results for the Frenchman's Bay watershed.

1.1 Overview of the Frenchman's Bay Watershed

Draining into Lake Ontario at Frenchman's Bay lagoon, the Frenchman's Bay watershed is both relatively small, at 20.0 km^2, and highly urbanized, with more than 75% of its area being designated as urban land use consisting of residential, commercial, and transportation areas (MMM 2009). The watershed is entirely within the City of Pickering, Ontario and is bisected by the approximately 600 m wide transportation corridor containing Highway 401, other roads, and rail lines before draining into the

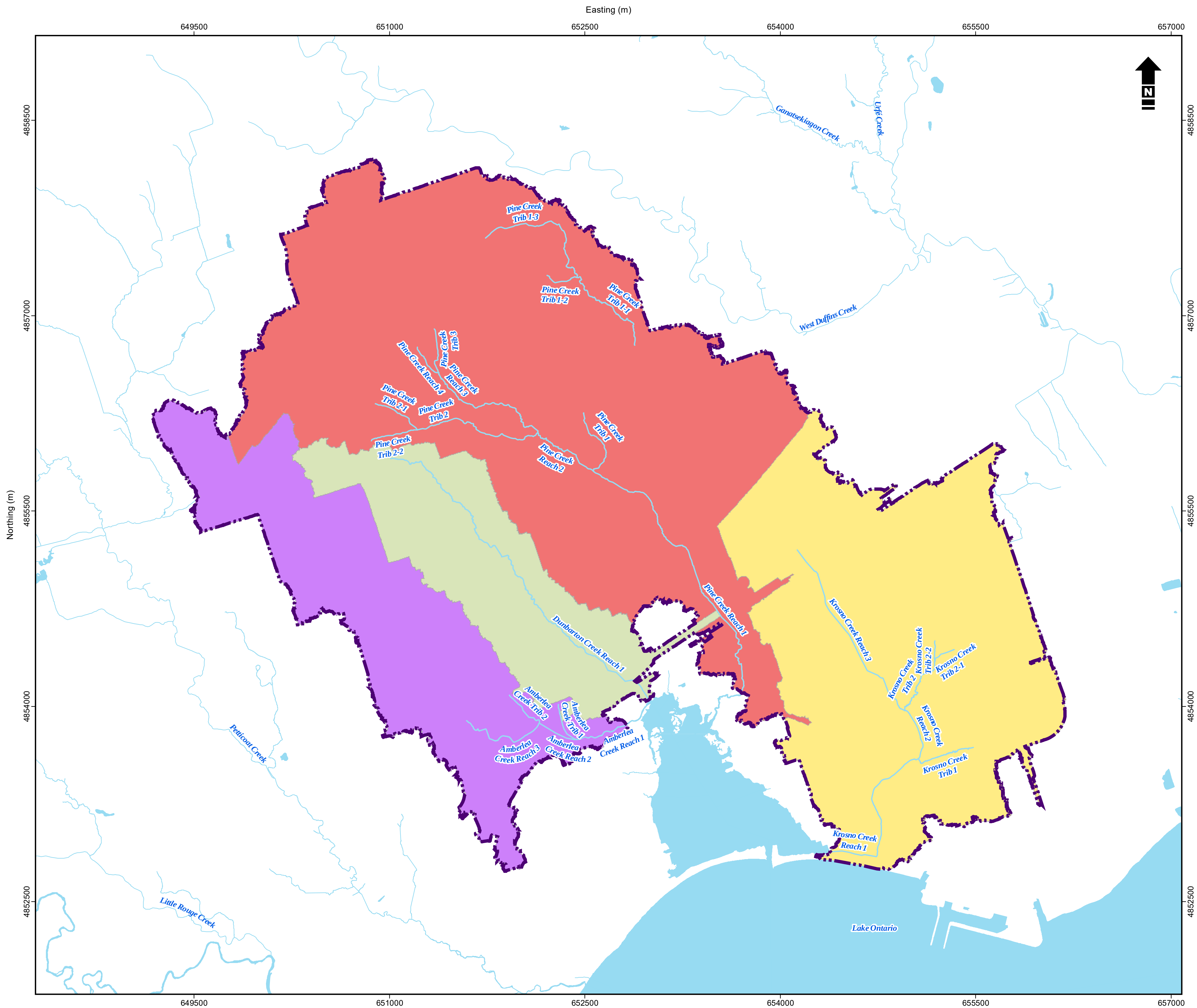
Frenchman's Bay lagoon (Eyles et al. 2012). Development in the watershed began as early as the 1840s, but intensified during the 1970s when the City of Pickering nuclear generating stations was established (Eyles et al. 2012). Most of the watershed was fully built prior to the 1980s, leading to minimal SWM controls to reduce flood volumes and peak flows in its watercourses.

There are four major watercourses in the Frenchman's Bay watershed: Pine Creek (8.9 km^2), Krosno Creek (5.6 km^2), Amberlea Creek (3.2 km^2), and Dunbarton Creek (2.3 km^2), which all drain into Frenchman's Bay lagoon. The watercourses generally drain from north to south. As expected for a watershed of its urbanized characteristic, the hydrology of the system is described as "flashy," with peak flows escalating quickly after rainfall events. Many of the tributaries have been historically altered with many watercourses being heavily armoured or conveyed by pipes (Eyles et al. 2012). Channel erosion and flooding occurs throughout the watershed, but has been noted to be particularly severe in Pine and Amberlea creeks (MMM 2009). There were two significant flooding issues noted in the 2009 Stormwater Master Plan.

1. Krosno Creek near Reytan Boulevard and Streamside Court impacts over 75 properties.

2. Pine Creek upstream of Kingston Road shows flooding within several residential and commercial properties.

The study area, including mapped watercourses and subwatershed boundaries are shown on Figure 1. All geospatial data was referenced to a NAD83 (CSRS) UTM 17 CGVD 1928:1978 datum.



Frenchman's Bay Watershed
Water Body
Watercourse

Subwatershed

Amberlea
Dunbarton
Krosno
Pine

1:30,000 metres
250 0 250 500
NAD 1983 UTM Zone 17N

Reference: Contains information licensed under the Open Government Licence – Ontario.

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Frenchman's Bay Floodplain Mapping Update

Frenchman's Bay Watershed and Mapped Watercourses

Date:	Project:	Submitter:	Reviewer:
February 2024	35765	K. Molnar	A. McKay

Figure 1

2 BACKGROUND REVIEW

2.1 Available Data and Information

Available data and information compiled as part of the background review included the following:

- GIS base data: watercourse centrelines, watershed boundaries, roads, railways, building footprints, land parcels, municipal boundaries, storm sewershed data
- rainfall, water level, and flow monitoring data
- crossing structure locations, shapefiles, as-built drawings
- LiDAR data collected in 2015 and 2019 for the Frenchman's Bay watershed, provided by TRCA
- topographic survey completed by TRCA at various locations within the Frenchman's Bay watershed
- existing HEC-RAS hydraulic models for the four watercourses (various dates)
- existing floodplain mapping sheets
- existing land use data (shapefile format)
- soils and surficial geology data (AAFC 2003, Ontario Geologic Survey, 2010)
- stormwater management facility data (shapefile and report format)
- City of Pickering Official Plan (City of Pickering 2022)

2.2 Previous Reports

2.2.1 Krosno Creek Floodplain Mapping Study (TRCA, 2002)

The Krosno Creek floodplain study was prepared by the TRCA in 2002. Flows for the hydraulic model were developed using the Visual OTTHYMO modelling platform. The model was set up and parameterized as follows:

- Twelve delineated catchments using topographic mapping and field reconnaissance. Total catchment area for Krosno Creek was 650 ha.

- Curve number (CN) parameterization derived from soil types, land cover mapping, and orthoimages; imperviousness was derived based on land use.

- No flow data was available for calibration, however a comparison of model parameters to other TRCA watersheds (Duffin Creek and Highland Creek) was conducted. Regional relationships from the Regional Headwater Hydrology Study were used to predict peaks flow in the watershed based on land use and soils.

- Four-hour Chicago design storm was the selected distribution over the 1 and 6-hour AES distribution.

- Future land use was based on the 2016 City of Pickering Official Plan; there was a 10% increase in urban land coverage for future land use scenarios (71% to 81%).

2.2.2 Amberlea Creek Hydrology and Floodline Mapping Update (Aquafor Beech, 2005)

The Amberlea Creek hydrology and floodplain mapping update report was prepared for the City of Pickering by Aquafor Beech in 2005. The hydrologic update involved the development and application of a numeric model, using the Visual OTTHYMO V1.06 code. The model was set up and parameterized as follows:

- Eleven delineated catchments split into five main subcatchments using topographic mapping and storm sewer data. Total catchment area for Amberlea Creek was approximately 380 ha.
- CN parameterization derived from soil types, land cover mapping, and orthoimages; imperviousness was derived based on land use.
- Standard unit hydrographs were used to simulate runoff from urban catchments.
- Nash unit hydrographs were used to simulate runoff from rural catchments.
- Channel routing using the variable storage coefficient method with channel cross-section representation field survey and topographic mapping.
- No flow data was available for calibration, however regional relationships from the Regional Headwater Hydrology Study were used to predict peaks flow in the watershed based on land use and soils.
- Six-hours AES design storm was the selected distribution over the SCS and Chicago.
- Included minimal increase in urban land coverage for future land use scenarios (88% to 89%).

2.2.3 Pine and Dunbarton Creeks Hydrologic and Hydraulic Study (Greenland Consulting Engineers, 2007)

A hydrologic and hydraulic study was undertaken for the Pine and Dunbarton Creek watersheds for the Toronto and Region Conservation Authority in 2007. The study was needed to update the floodline mapping for the area "due to recent development pressures and structural crossing constructed" within the watersheds. The hydrologic update involved the development and application of a numeric model, using the Visual OTTHYMO code. The model was set up and parameterized as follows:

- Sixteen catchments were delineated for Pine Creek and seven catchments were delineated for Dunbarton Creek using the provided digital elevation model (DEM) and sewershed mapping.
- Standard unit hydrographs were used to simulate runoff from urban catchments.
- Nash unit hydrographs were used to simulate runoff from rural catchments.
- Channel routing using the variable storage coefficient method.
- Two stormwater management facilities were coded into the model, one at Dixie Estates Pond 2 in Pine Creek, and one at the K.S. W subdivision in Dunbarton Creek.

- Eight events were selected for model calibration and validation in Pine Creek. A CN adjustment multiplier was added as an adjustment factor for both the Pine Creek and Dunbarton watersheds as a results of the calibration exercise.
- A 1-hour AES design storm for the selected distribution over the SCS and Chicago.

2.2.4 Frenchman's Bay Stormwater Management Master Plan (MMM, 2009)

A Stormwater Management Master Plan was developed for the City of Pickering by MMM in 2009. The document looked at overall watershed health management issues including controlling quantity and quality of stormwater runoff being conveyed to the local creeks and ultimately Frenchman's Bay. The study looked at implementing a number of stormwater control measures throughout the watershed and assessed the impacts and effectiveness. Following the Class EA Environmental Planning process, the study utilized previously developed hydrology and hydraulic models for most of the analysis. An HSPF model was also developed for the watershed to assess water balance, quality, and ecologic issues that require continuous flow analysis.

2.2.5 Krosno Creek Flood Reduction Project (TMIG, 2015)

The City of Pickering retained TMIG to complete the Krosno Creek Flood Reduction Project in 2015. The study following the Municipal Class EA process to look at solutions that protected people and property from flooding during severe storm events. The study utilized a new PCSWMM/SWMM 5 hydrologic/hydraulic model that was calibrated to water levels for a range of recent flood events. The analysis found that the culverts at the 401/CNR crossing attenuates up to 35% of peak flows. Downstream there are currently impacts to 64 buildings during the 100-year storm event near the Reytan Boulevard culvert. There were six solutions looked at to reduce flooding to in the watershed, with the preferred solution being to replace the existing culverts at Alyssum Street, Reytan Boulevard, and Morden Lane with larger structures.

3 MODEL DEVELOPMENT

The following section outlines the model development process and includes a summary of input data sources, model selection, catchment delineation, catchment parameterization, channel routing, SWM facility representation, and areas of special consideration.

3.1 Input Data Sources

Several data sources were used to develop, calibrate, and verify the hydrologic model. TRCA provided most data sources and supplemented with data available from the City of Pickering. A summary of data sources is listed in the following subsections.

3.1.1 Flow and Rainfall Data

Flow and rainfall data are critical datasets for a hydrologic model. Climate data is the main input that drives the runoff response and observed flow data is used to compare to the simulated flows and confirm the model is replicating observed conditions.

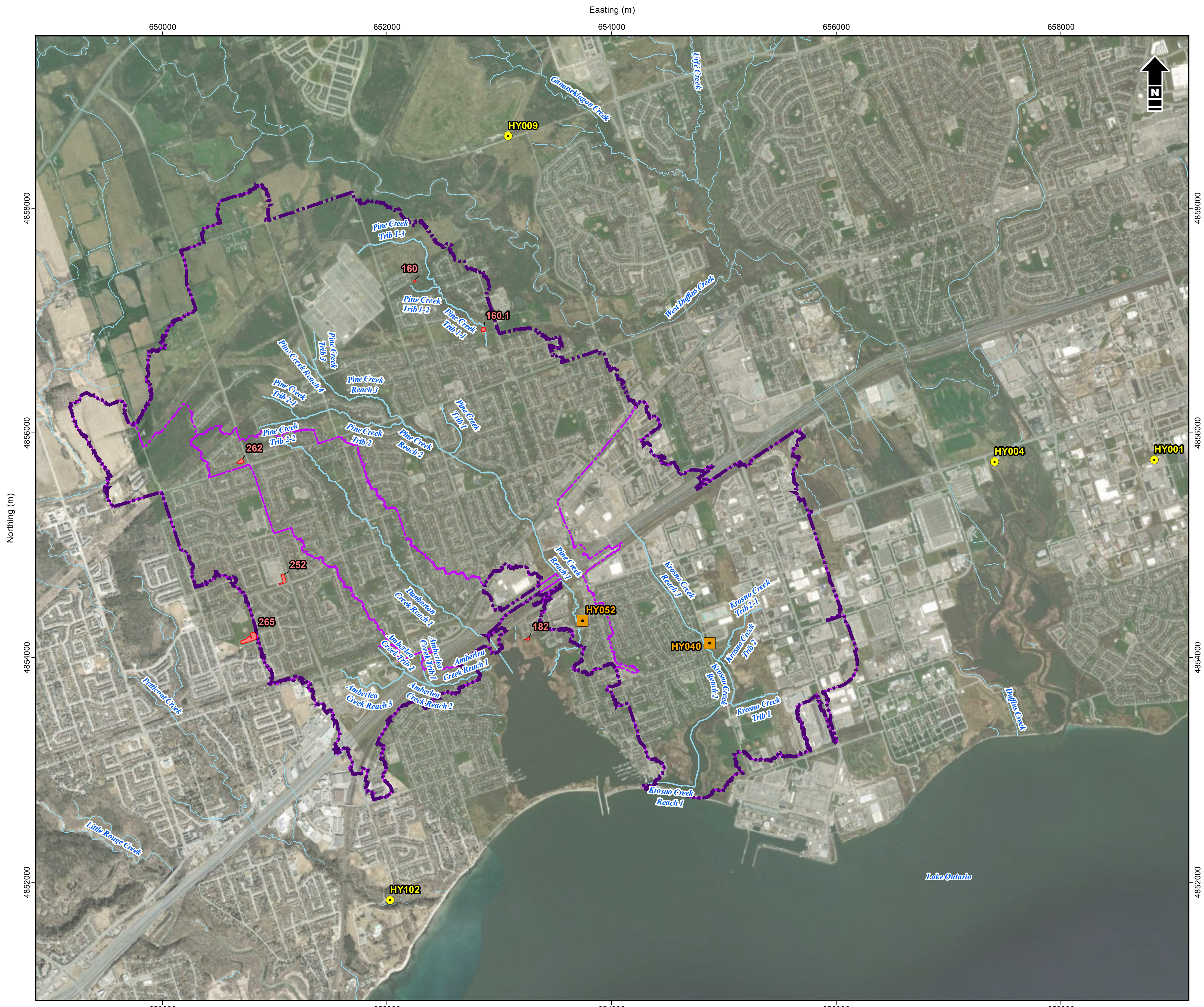
3.1.1.1 Flow Data

Two hydrometric (flow and water level) monitoring stations operated by the TRCA are located within the Frenchman's Bay Creek watershed. Monitoring station HY040 is located on the main branch of Krosno Creek between the Alyssum Street and Sandy Beach Road crossings. The station was installed in 2000 and has been in operation since. Monitoring station HY052 is located on Pine Creek, upstream of Radom Steet. The station was installed in 2001 and continues to record monitoring data. Table 1 provides an overview of the two flow monitoring stations and are shown on Figure 2.

TABLE 1 Flow Gauge Monitoring Stations in Frenchman's Bay

Station ID	Flow Gauge Name	Source	Drainage Area (km^2)	Years of Data Available(1) (Recording Interval)
HY052	Pine Creek	TRCA	8.1	2001-2012 (hourly) 2012-2023 (15-minute)
HY040	Krosno Creek	TRCA	2.8	2000-2007 (hourly) 2008-2023 (15-minute)(2)

Notes:
1. Data may not be continuous through each year.
2. 15-minute data between 2008 and 2012 was provided by TRCA after calibration of the hydrologic model had been carried out. The original data provided for this period was in one-hour intervals.
TRCA - Toronto and Region Conservation Authority



- Frenchman's Bay Watershed
- Subwatershed
- Stormwater Management Facility
- Watercourse
- Climate Monitoring Location
- Flow Monitoring Station

Station ID	Climate Station Name
HY001	Ajax Works Yard
HY004	Bayly Street Weather Station
HY009	Brock West Landfill
HY102	Petticoat Works Yard

Station ID	Flow Station Name
HY040	Krosno Creek
HY052	Pine Creek

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1:35,000 metres
250 0 250 500
NAD 1983 UTM Zone 17N

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Frenchman's Bay Floodplain Mapping Update

Monitoring Station Locations

Date:	Project:	Submitter:	Reviewer:
February 2024	35765	K. Molnar	A. McKay

Figure 2

3.1.1.2 Rainfall Data

Rain gauge data was collected from monitoring stations operated by TRCA. Gauge selection was based on data availability, gauge location, monitoring interval, and quality of data. Table 2 summarizes the rain gauges that were used to assess storm events for calibration and verification of the hydrologic model. Figure 2 shows the spatial extent of the rain gauges relative to the Frenchman's Bay watershed boundary. Most rainfall data were recorded in 5-minute intervals. Since the rainfall/runoff response time in Frenchman's Bay is so rapid, and the subwatershed are small, having a minimum rainfall and flow recorded interval of 15 minutes is required to truly assess the response. Unfortunately, none of the active rainfall gauging stations are located within any of the Frenchman's Bay subwatersheds.

TABLE 2 Rain Gauge Monitoring Stations Surrounding Frenchman's Bay

Station ID	Rain Gauge Name	Source	Available Period	Years of Data Available(1)
HY009	Brock West Landfill	TRCA	2007-2023	17
HY004	Bayly Street	TRCA	2011-2023	13
HY102	Petticoat Works Yard	TRCA	2003-2023	21
HY001	Ajax Works Yard	TRCA	2003-2010	8

Notes:
1. Data may not be continuous through each year.
TRCA - Toronto and Region Conservation Authority

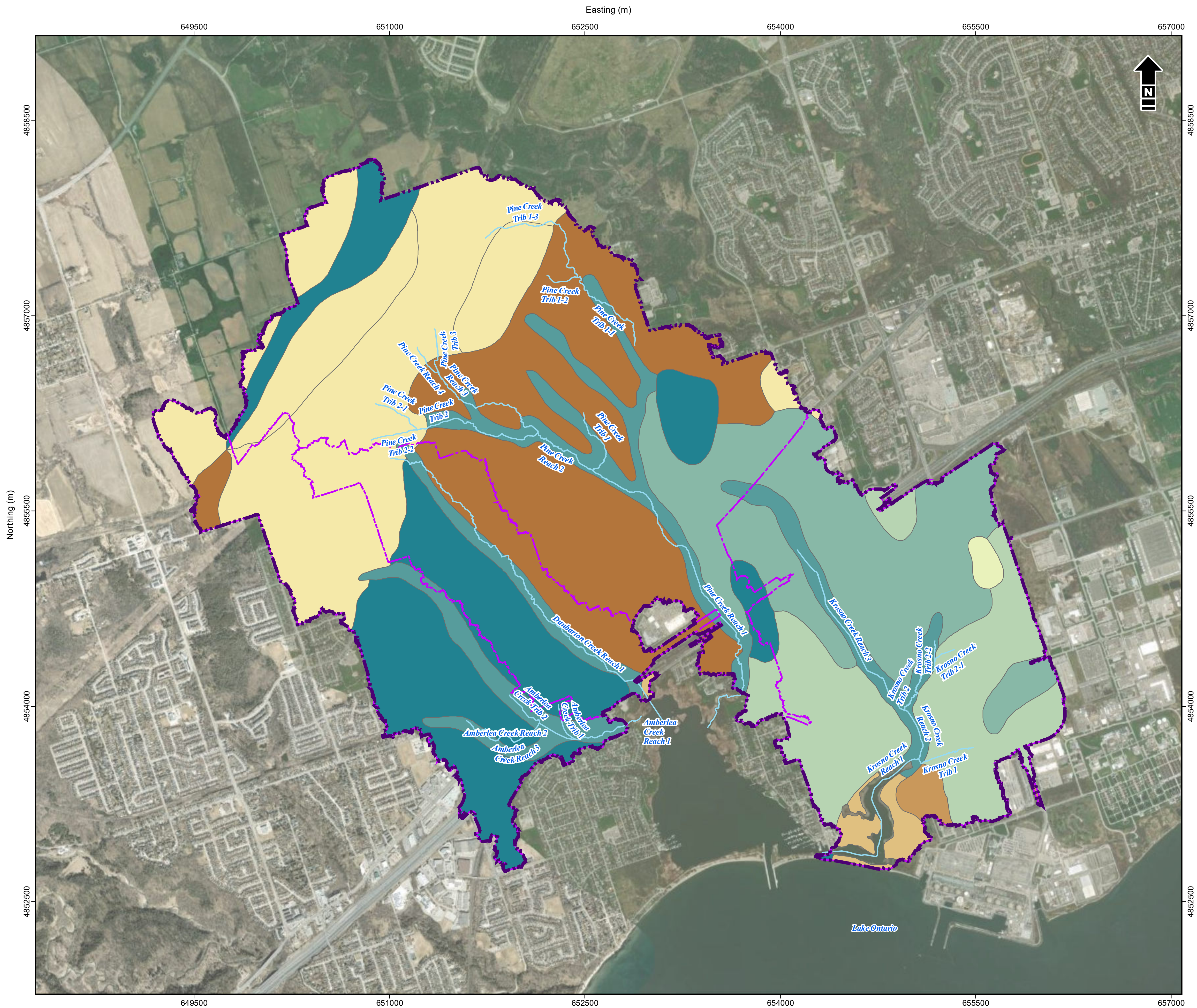
3.1.2 Watercourse Network and Topography

TRCA provided Light detecting and ranging data (LiDAR) data in a 1-m Esri grid format for both 2015 and 2019. The 2019 LiDAR reflects more up-to-date land use and topographic changes. However, the 2015 LiDAR was processed with better vegetation removal which provides a more accurate representation of the creek valley and low flow channel. After comparing the 2015 and 2019 LiDAR datasets, Matrix found that the land use and topographic changes are generally minimal, and the 2015 LiDAR was used as the baseline DTM for creating the hydraulic model. The 2019 LiDAR was used in locations where new urban development has occurred. Splicing of 2019 LiDAR into the 2015 data was completed by TRCA and provided to Matrix. The LiDAR data was used to verify the existing watercourse network, define cross-section dimensions, delineate catchments, and derive hydrologic model parameters.

3.1.3 Soils Mapping

TRCA provided soils mapping and Matrix sourced surficial geology mapping to infill any data gaps. The soils data was originally sourced from the Canadian Soil Information Service and the National Soil Database (AAFC 2023). Surficial geology was sourced from the Ministry of Mine, Surficial Geology and Southern Ontario (Ontario Geologic Survey 2010).

Soils mapping through the watershed generally covers most areas within minimal need to rely on the surficial geology. Figure 3 shows the soils classification within the Frenchman's Bay watershed.



Frenchman's Bay Watershed
Subwatershed
Watercourse

Soil Name

- Brighton
- Darlington
- Marsh
- Milliken
- Muck
- Schomberg
- Smithfield
- Unclassified
- Woburn

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1:30,000 metres
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NAD 1983 UTM Zone 17N

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Frenchman's Bay Floodplain Mapping Update

Soils Mapping

Date: February 2024	Project: 35765	Submitter: K. Molnar	Reviewer: A. McKay

Figure 3

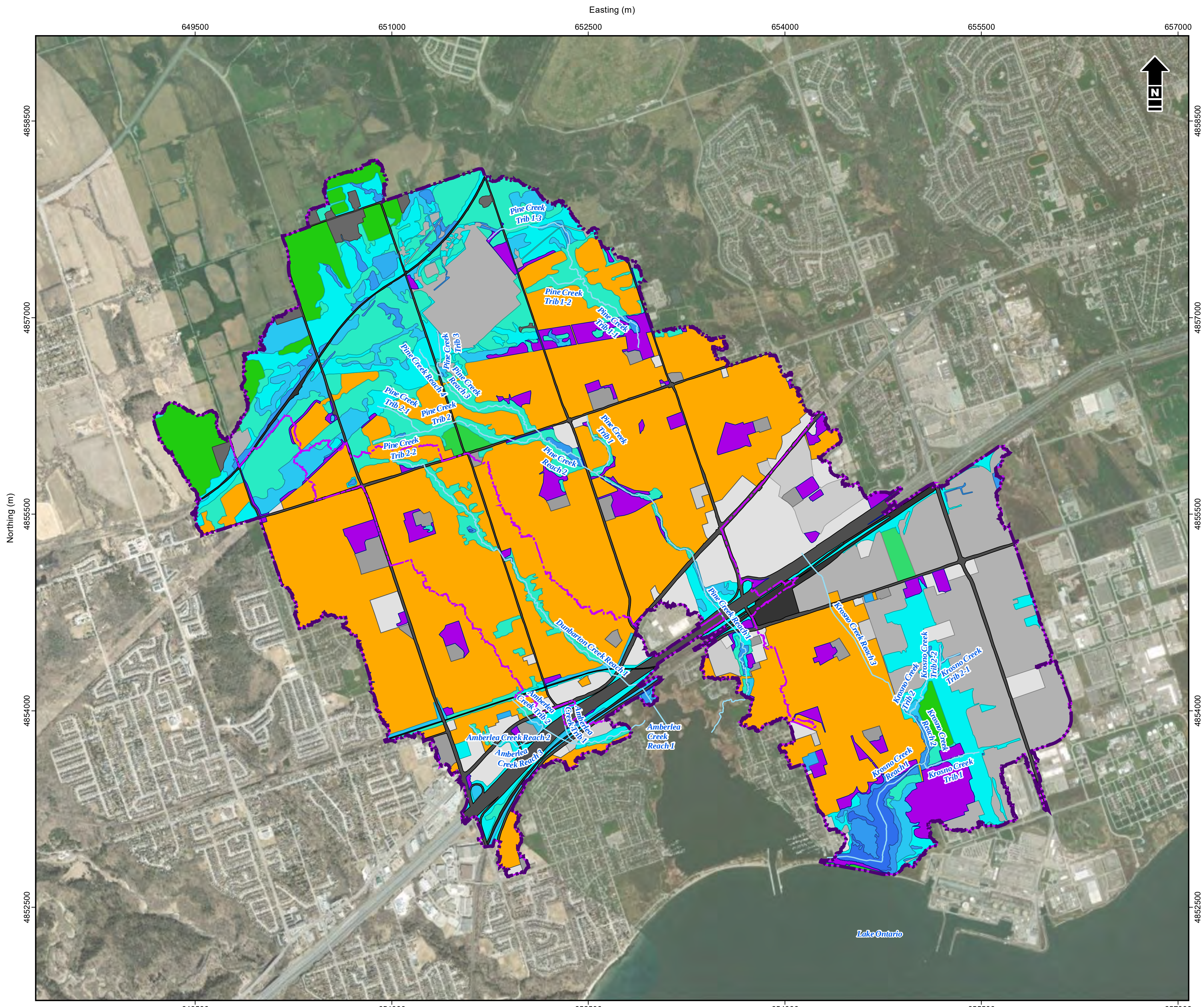
3.1.4 Land Use Mapping

TRCA provided detailed land use mapping for the Frenchman's Bay watershed. Within the watershed, 20 different land use types were identified with the largest portion being medium-density residential (41%) followed by industrial (13%), forest (10%), meadow (8%) and commercial (6%). The remaining land use types each compose less than 5% of the watershed area.

Land use was overlaid with aerial imagery to check specific land use classifications and made minor changes to some land use areas that required reclassification. A breakdown of land use is provided in Table 3 and shown on Figure 4.

TABLE 3 Land Use in Frenchman's Bay Watershed

Land Use Type	Land Use Code	Area (ha)	Percentage of Watershed (%)
Medium Density Residential	MDR	810.1	40.5%
Industrial	IND	251.1	12.6%
Forest	NCF	190.5	9.5%
Meadow	NCM	153.5	7.7%
Commercial	COM	110.9	5.5%
Roads	RDS	94.7	4.7%
Recreational/Open Space	REC	91.7	4.6%
Successional Forest	NCS	70.9	3.5%
Agricultural	AGR	67.9	3.4%
High Density Residential	HDR	34.9	1.7%
Wetland	NCW	32.7	1.6%
Institutional	INS	29.1	1.5%
Railway	RWY	18.6	0.9%
Lacustrine	OWL	12.7	0.6%
Rural Residential	RUR	11.8	0.6%
Golf Course	GC	5.5	0.3%
Cemetery	CEM	4.9	0.2%
Vacant Land	VAL	3.6	0.2%
Riverine	OWR	1.8	0.1%
Beach/Bluff	NCB	0.8	<0.1%
	Grand Total	**1,997.8**	**100%**



Frenchman's Bay Watershed
Subwatershed
Watercourse

Land Use Type

- Commercial
- High Density Residential
- Industrial
- Institutional
- Medium-low Density Residential
- Rural Residential
- Roads
- Railway
- Agriculture
- Beach / Bluff
- Cemetery
- Golf Course
- Forest
- Meadow
- Successional
- Vacant Land
- Wetland
- Open Water
- Recreation or Open Space

1:30,000 metres
250 0 250 500
NAD 1983 UTM Zone 17N

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Frenchman's Bay Floodplain Mapping Update

Land Use Mapping

Date:	Project:	Submitter:	Reviewer:
February 2024	35765	K. Molnar	A. McKay

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Figure 4

3.2 Model Selection

TRCA identified PCSWMM in the Terms of Reference as the preferred model platform for the hydrologic model development. PCSWMM 2018 Professional computer modelling software (CHI 2023) can be used for both single event and continuous simulations. The model platform integrates the full United States Environmental Protection Agency (US EPA) Storm Water Management Model Version 5.2.3 (EPA SWMM; EPA 2017) hydrology and hydraulics engine with a powerful GIS platform. The EPA SWMM engine is a comprehensive dynamic rainfall-runoff model that is used widely throughout the world in the analysis of complex hydrologic, hydraulic, and water quality problems for urban (and rural) areas. EPA SWMM, and its SWMM variants, has been used extensively for the simulation of surface runoff, conveyance through complex open-channel and closed-conduit drainage networks (storm, sanitary, and combined sewer systems), floodplain analysis, and soil erosion and sediment transport.

PCSWMM (Version 7.6.3695) was selected to represent the hydrologic process within the Frenchman's Bay watershed as it has built-in capability to represent the detailed hydrologic processes for each catchment, while also being able to represent a variety of SWM features and complex hydraulic routing.

3.3 Catchment Delineation

Catchment delineation within the Frenchman's Bay was completed using the spliced 2015 and 2019 LiDAR to ensure the catchments represent current conditions and allow sufficient detail (i.e., several flow input locations along each reach) to best inform the hydraulic model.

There are limitations to SWMM-based modelling in representing larger watersheds, particularly as it relates to the representation of sheet flow/overland flow length and the internal catchment routing. In addition to overland flow, routing occurs through the minor system (i.e., stormwater sewer network) and major flow routes (roadways and ditches) which are not explicitly represented in a watershed-scale model. Care was taken to delineate catchments where significant routing elements could be represented without adjusting parameters (e.g., Manning's n) outside of their "typical" ranges (Chin 2006).

3.3.1 Catchment Discretization

Catchments were delineated using the 1 m LiDAR data, with drainage enforced along the mapped watercourse network. To develop initial catchments, pour points (i.e., specific outlet locations where runoff from an upstream area would concentrate to) were placed at the following locations:

- upstream end of watercourses to be mapped
- directly upstream of any confluence
- at each watercourse crossing

A total of 6 SWM facilities were identified within the Frenchman's Bay watershed. To initially assess the drainage to each of the SWM facilities, pour points were added at the location of each SWM pond. The area of each catchment was then refined based on the information from existing reports (if available). A summary of the SWM facility information is provided in Appendix A.

The Frenchman's Bay watershed boundary was manually compared to the watershed boundaries defined in the existing approved Petticoat Creek (WSP 2020) and Duffins Creek (Aquafor Beech Limit 2013) to ensure that areas were not being double counted or missing between the model domains. Any areas with discrepancies were double checked and then discussed with TRCA. Generally, the watershed delineation developed from LiDAR data was followed.

The initial delineation was reviewed for reasonableness based on the scale of the model. There were a few large catchments (>100 ha) and several small (<1 ha) catchments that needed to be refined. Each catchment over 75 ha was reviewed to determine if further delineation could be completed based on a distinct separation in land use at an overland drainage boundary. If possible, pour points were added to overland flow path at the change in land use and additional catchments were delineated. Sewershed information provided by City of Pickering and Region of Durham was used to further refine catchment delineation to account for major/minor flow splits.

The final catchment areas were compared with a histogram analysis to the catchments delineated for the Highland Creek and Petticoat Creek hydrology models. The breakdown shown in Figure 5 shows that size distribution of the Frenchman's Bay catchments are generally smaller than previous hydrologic models developed by TRCA. This aligns with the fact that Frenchman's Bay is separated into four distinct subwatersheds, most of which are highly urbanized. Most the Frenchman's Bay catchments fall within the 5- to 25-ha range.

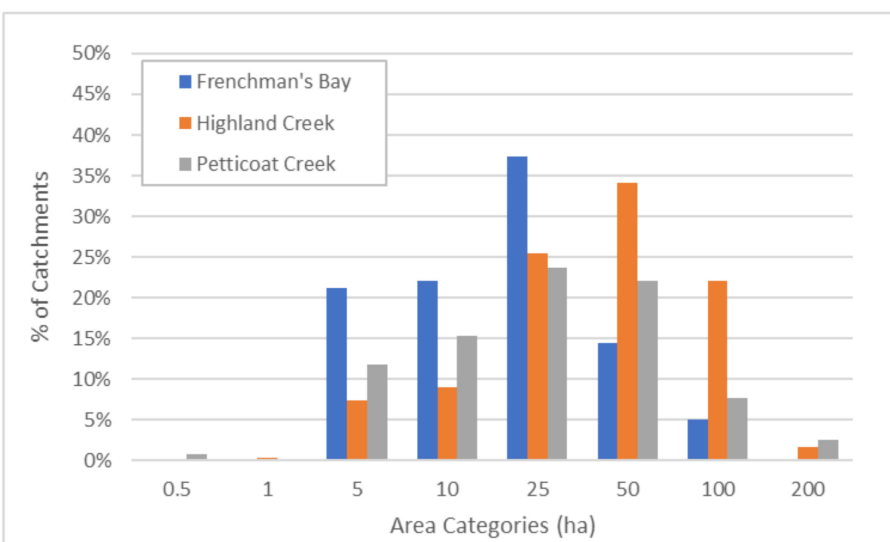
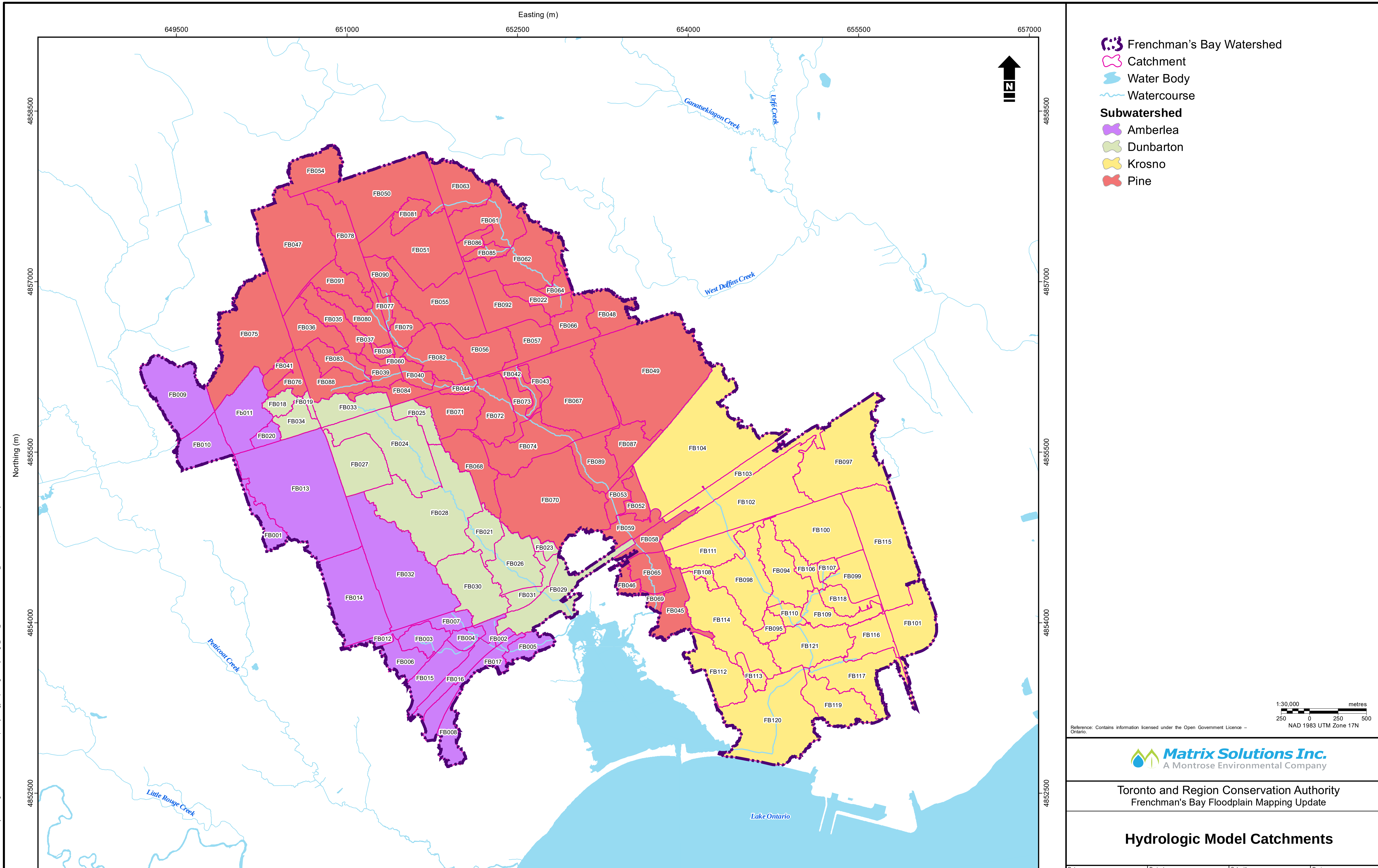


FIGURE 5 Catchment Delineation - Histogram Analysis Comparing Recent Watershed Hydrology Models

Catchments were named sequentially with a unique identifier with the format FBXXX (where XXX is a unique numeric value).

TRCA reviewed the final catchment layer to confirm the general correctness of catchment boundaries and methods used. The final subcatchment discretization is shown on Figure 6. A total of 118 subcatchments were included in the hydrologic model. The catchment areas range from 1.0 to 75.0 ha, with an average area of 16.9 ha.



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Matrix Solutions Inc.
A Montrose Environmental Company

Toronto and Region Conservation Authority
Frenchman's Bay Floodplain Mapping Update

Hydrologic Model Catchments

Date:	Project:	Submitter:	Reviewer:
February 2024	35765	K. Molnar	A. McKay

Figure
6

3.4 Catchment Parameterization

Parameterization of the hydrologic model was completed using the spatial datasets described in Section 2.1, literature values, and professional judgement based on knowledge of the watershed. The following parameters were required for each catchment in the PCSWMM model:

- catchment area
- catchment flow length
- average catchment slope
- imperviousness
- roughness coefficients for pervious and impervious areas
- depression storage for pervious and impervious areas
- catchment routing mechanism, and impervious portion that is routed to pervious areas
- soil infiltration parameters
- channel routing
- SWM facility parameterization

Catchment area was based on the GIS delineation described in Section 3.3. Details on how the remaining catchment parameters were derived is described in the following subsections.

3.4.1 Imperviousness

Imperviousness for each catchment is required to determine the portion of area that will be subjected to the pervious and impervious model routines to determine the runoff from each catchment. The imperviousness was assigned based on the portion of land use type within the watershed.

Matrix conducted an analysis to confirm the typical guidelines for TRCA imperviousness land use assignments (e.g., 95% impervious for commercial areas). For the top three urban land use types in the watershed (medium density residential, commercial and industrial), the pervious (or impervious) areas from selected blocks were traced from orthoimagery. The impervious area was then calculated and the compared to the total area to determine the actual imperviousness. Those estimates were then averaged, and input to the initial model parameterization. The range of imperviousness was then used during model calibration.

A summary of the impervious analysis is provided in Table 4. Overall, the analysis trended towards commercial and industrial areas being classified as more pervious and medium density residential being classified as more impervious compared to TRCA guidelines. Figure 7 shows the tracing for a commercial and medium density residential block.

TABLE 4 Imperviousness Analysis by Land Use Type

Land Use Type	Block 1 (%)	Block 2 (%)	Block 3 (%)	Block 4 (%)	Average (%)	TRCA Guideline (%)
Medium Density Residential	60.6	71.0	66.7	59.1	**64.3**	**60**
Commercial	82.5	83.5	85.7	-	**83.9**	**95**
Industrial	85.7	82.1	-	-	**83.9**	**95**

FIGURE 7 Impervious Analysis Comparison to Imagery (Commercial (Block 2) – left, Medium Density Residential (Block 2) – Right)

3.4.1.1 Percent Routed

The percent routed parameter (i.e., the portion of impervious area whose runoff is routed to pervious areas) is a sensitive parameter in the PCSWMM model, specifically when there is a high proportion of impervious surfaces, such as in the Frenchman's Bay watershed. Newer developments direct portions of impervious areas to pervious areas to help reduce runoff volumes and peaks on stormwater infrastructure. Downspout disconnections and low-impact development measures are now mandatory in new developments; however, during the 1970s when much of the Frenchman's Bay watershed was developed, SWM was not a common practice. Rooftops and parking lots were directly connected into the sewer system, leaving limited opportunities for runoff from impervious areas to flow over adjacent pervious surfaces.

Percent routed within each catchment was based on land use following TRCA or City Pickering standards and refined during the calibration process. To determine the percent routed, the percent of impervious area (as a percent of the total impervious area) that would be considered directly connected was estimated for each land use type. That percent was then subtracted from 1 and multiplied by the total impervious area, leaving portion of impervious area that is routed through the pervious. This estimate was then area weighted by land use to determine the percent routed within the overall catchment.

The imperviousness and proportion that is considered directly connected used for each land use type in the initial model development is provided in Table 5. Any modifications to the impervious or direct connect impervious area values were address during calibration (Section 3.2).

TABLE 5 Imperviousness and Percent Routed by Land Use Type

Land Use Type	Proportion of Watershed (%)	Imperviousness (%)	Directly Connect Impervious Area (%)
Agricultural	3.4	0	0
Beach/Bluff	<0.1	0	0
Cemetery	0.2	35	0
Commercial	5.5	84	95
Forest	9.5	0	0
Golf Course	0.3	0	0
High Density Residential	1.7	80	75
Industrial	12.6	84	95
Institutional	1.5	80	80
Lacustrine	0.6	100	0
Meadow	7.7	0	0
Medium Density Residential	40.5	64	60
Railway	0.9	60	25
Recreational/Open Space	4.6	20	0
Riverine	0.1	100	0
Roads	4.7	90	100
Rural Residential	0.6	25	25
Successional Forest	3.5	0	0
Vacant Land	0.2	0	50
Wetland	1.6	100	0

3.4.2 Catchment Slope

Catchment slope is used in PCSWMM as part of Manning's equation for overland routing. The greater the catchment slope, the higher the proportion and faster the runoff is from the catchment. Although slope does have some impact on the volume of runoff from the catchment, it is more influential on peaks and shape of the hydrograph. Catchment slope in the hydrology model was defined by overlying each catchment with the provided DEM. PCSWMM has a built-in tool to determine average catchment slope. Computational Hydraulics International (CHI) recommends resampling a detailed DEM (1 to 2 m resolution) to a 5 or 10 m resolution before the catchment slope tool is run, to remove any abrupt changes in the topography. The 1 m DEM for the Frenchman's Bay watershed was resampled to both 5 and 10 m, but minimal differences were found in the resulting slopes. The 5 m resampled DEM was ultimately used to define the initial catchment slopes in the model.

3.4.3 Flow Length

The approach to defining catchment flow length in a PCSWMM model is a debated topic that largely depends on why and how a hydrologic model is developed. Many discussions on SWMM forums allude to flow length being a true calibration parameter, one that is initially estimated but has unlimited boundaries to how high or low the parameter can range. Similar to slope, flow length is built into the reservoir routing equation and affects the timing of runoff but, depending on the imperviousness, can also affect the volume. Generally, the lower the imperviousness, the greater the effect flow length has on the volume of runoff, as only one flow length is given to represent both pervious and impervious portions of the catchment.

Typically, a SWMM model is developed to represent an urban area where various components of infrastructure are explicitly defined (e.g., catch basins, pipes, storage facilities). In a large-scale watershed model, this level of detail is not suitable and flow length becomes a representation of many processes that are occurring within the catchment including:

- overland sheet flow, such as runoff from driveways and backyards, before it enters the street or catch basin
- conveyance through pipe networks, once water enters into the minor stormwater system
- major overland flow routes, typically through roadways, ditches, and right of ways

Without explicit representation of these routing elements (e.g., roads and pipes), flow length becomes a lumped parameter representing all routing processes through the catchment.

Initial flow lengths were estimated for each catchment using a United States Department of Agriculture relationship to total catchment area (USDA 2010):

$$l = 209A^{0.6}$$

Where:

l = flow length (ft)
A = drainage area (acres)

The United States Department of Agriculture (USDA) approach to deriving flow lengths generally matched the longest drainage pathways for each catchment that were defined during the catchment delineation process (Figure 8). These flow lengths represented the flow path within each catchment that would translate to the time of concentration.

The catchment length was then adjusted to convert the natural watershed shape into an equivalent rectangular cascading plane (kinematic wave (KW) approach) (Guo and Urbonas 2009). Equivalent KW planes are estimated for natural watershed shapes using area, slope, Z factor (area skewness coefficient) and K factors (typically 4 to 6). Several options to further modify and refine the flow lengths were reviewed during the calibration process.

FIGURE 8 Overland Drainage Pathways in Urban area Example

3.4.4 Additional Parameters

Initial parameterization of other storage and routing parameters were initially defined with widely accepted default values. These values were assessed and modified during the sensitivity analysis and calibration process but initially defined as:

- n impervious: 0.013
- n pervious: 0.25
- depression storage impervious (mm): 2 mm
- depression storage pervious (mm): 5 mm
- impervious area with no depression storage: 25%
- subarea routing was set to pervious, which defines that a portion of the impervious area will be routed through the pervious area before reaching the outlet

3.4.5 Infiltration

Infiltration in the PCSWMM model was defined using the Modified Green and Ampt method. Green and Ampt is a physically based method of estimating infiltration assuming a homogenous soil profile with a wetting front (Kipkie 1998). Green and Ampt requires the input of three parameters to PCSWMM:

- hydraulic conductivity (mm/hour)
- suction head/wetting front
- initial moisture deficit (IMD)

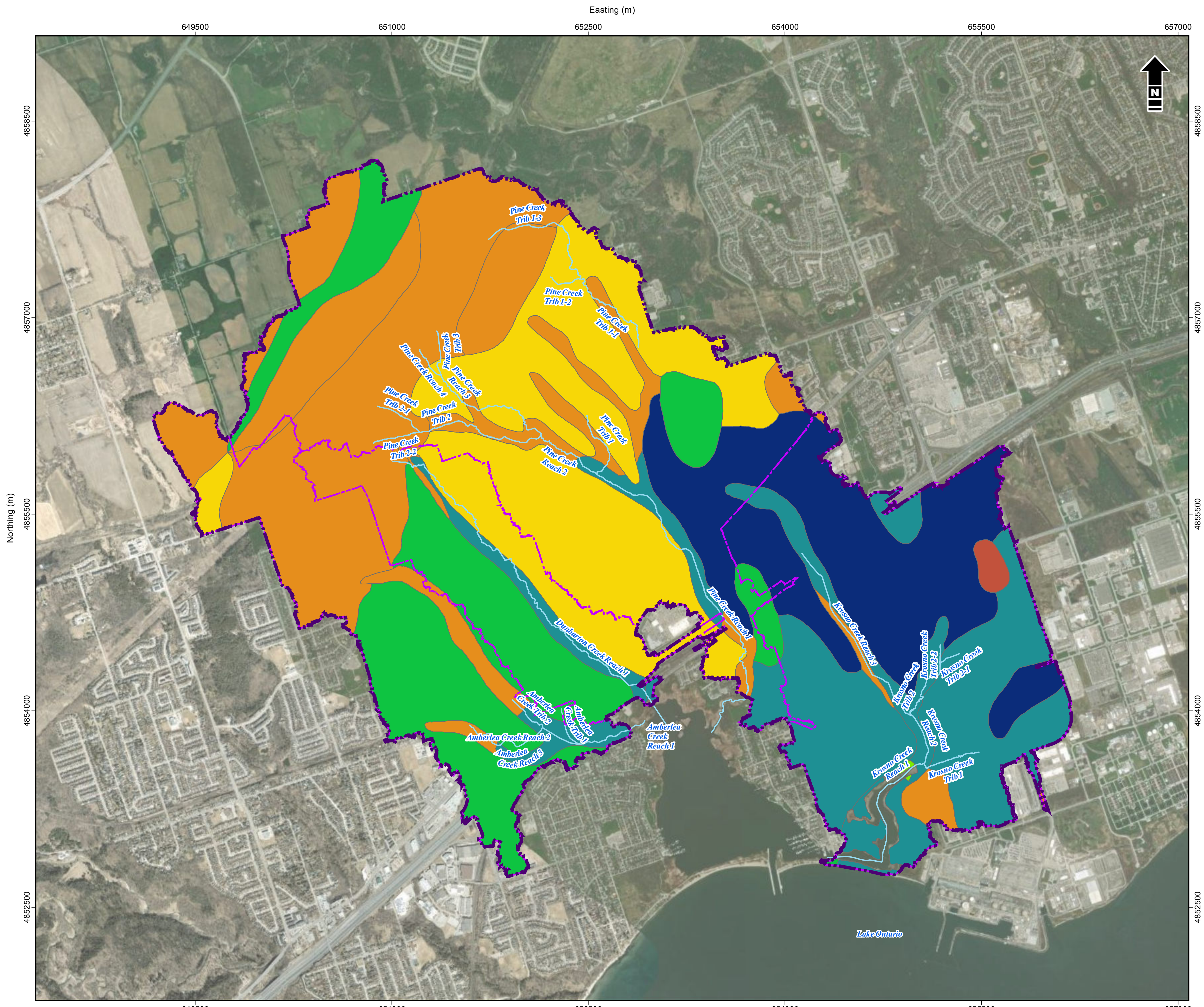
The soils and surficial geology mapping were used to define the infiltration parameters for each catchment (Figure 2). The resulting soils layer was overlaid with the catchments and parameters were area weighted. Each soil type (ranging from sand to clay) was assigned a value for each of the three Green and Ampt parameters listed above. Most soils in the watershed have been disturbed through urbanization, leading to some uncertainty associated with the soils to infiltrate as they could be compacted. A range of soil parameters were reviewed during calibration.

Table 6 shows the mapped soils within Frenchman's Bay, the portion of the watershed the soil represents, and the Green and Ampt parameters based on the value provided in the PCSWMM soil characteristic guidance document (Rawls et al. 1983). The most prominent soils in in the watershed were defined as loam (29%), loamy sand (20%), silty clay (18%), silt clay loam (17%) and sandy loam (16%). Sand and clay make up less than 2%. Figure 9 shows the Assigned Green and Ampt soil type throughout the modelled watersheds.

TABLE 6 Mapped Soils within Frenchman's Bay

Soils[1, 2]	Percent of Highland Watershed	Assigned Green and Ampt Soil Types	Hydraulic Conductivity (mm/hour)	Suction Head (mm)	Initial Moisture Deficit
Brighton	20%	Loamy Sand	30.0	61	0.390
clay, silt	5%	Silty Clay	0.51	290	0.228
Darlington	2%	Loam	3.3	89	0.347
diamicton	4%	Loam	3.3	89	0.347
Marsh	1%	Silty Clay	0.51	290	0.228
Milliken	22%	Loam	3.3	89	0.347
Muck	1%	Clay	0.25	320	0.210
sand, gravel	1%	Sand	120.3	49	0.413
Schomberg	11%	Silty Clay	0.51	290	0.228
Smithfield	17%	Silty Clay Loam	1.02	270	0.261
Woburn	16%	Sandy Loam	10.9	110	0.368

1. Surficial geology was used to define infiltration parameters in areas where soil mapping was "unclassified."
2. Soils making up less than 0.5% of the watershed were not included in the summary table.



Frenchman's Bay Watershed
Subwatershed
Watercourse

Soil Type

- Clay
- Loam
- Loamy Sand
- Sand
- Sandy Loam
- Silty Clay
- Silty Clay Loam

1:30,000 metres
250 0 250 500
NAD 1983 UTM Zone 17N

Reference: Contains information licensed under the Open Government Licence – Ontario. Contains information made available under the Toronto and Region Conservation Authority (TRCA)'s Open Data Licence v 1.0. Imagery Source: Esri, Maxar, Earthstar Geographics, and the GIS User Community

Matrix Solutions Inc.
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Toronto and Region Conservation Authority
Frenchman's Bay Floodplain Mapping Update

Assigned Green and Ampt Soil Types

Date:	Project:	Submitter:	Reviewer:
February 2024	35765	K. Molnar	A. McKay

Figure 9

3.5 Channel Routing

Channel routing is the representation of watercourses in the hydrology model and affects how water from each catchment is conveyed downstream to the outlet of the model. Channel routing is important as it affects the timing of peak flows that will ultimately be used as input into the hydraulic model. In previous hydrology models, channel routing was represented using route hydrographs where a single cross-section geometry, length, and slope defined the conveyance. In PCSWMM, there is the capability to directly import HEC-RAS geometry, including bridges and culverts, to represent channel routing elements more discretely in the model.

Cross-sections used for channel routing in the PCSWMM model were derived from the HEC-RAS channel dimensions based on the LiDAR data and used characteristic cross-sections to represent a larger reach area. This process results in a more accurate model representation of the valley corridors within Frenchman's Bay while maintaining reasonable reach lengths to limit routing instabilities.

3.5.1 Road Crossings and Structures

The Frenchman's Bay hydrology model took advantage of the HEC-RAS geometry import tool in PCSWMM by importing the concurrently developed HEC-RAS model geometry to represent channel conveyance. After importing, each hydraulic structure in the watershed was reviewed to determine if the structure was "hydrologically significant," meaning that it would modify the peak flows enough that it should be represented within the hydrology model. Hydrologic significant structures were defined by running the 10-year design storm event and comparing the change in water level upstream and downstream of the structure. If the difference was more than a 0.25 m during the, then the structure was considered hydrologically significant. The analysis resulted in 50 structures that were defined as hydrologically significant and included in the model.

3.5.2 Cross-sections

During the HEC-RAS import, cross-sections were autogenerated as irregular conduits with assigned bank stations connected by junctions. Initially, over 400 reaches were imported into the hydrology model representing each cross-section in the hydraulic model. During the validation runs, it was found that having too many short, steep conduits resulted in model instabilities, and the watercourse network required simplification. A watercourse simplification process built in to the PCSWMM model was used to remove small conduits and merge with the most similar conduit (i.e., similar slope and cross-sectional area) up or downstream. All conduits less than 50 m were selected in the model and, where appropriate, merged with the adjacent conduits. The model was then run during the 100-year and Regional storm events, and hydrographs from each conduit were reviewed to assess whether an instability occurred. Areas with instabilities were further refined until the instabilities were addressed.

Cross-sections represented in each conduit from the HEC-RAS model were reviewed and trimmed (low portions outside the channel were removed) to prevent flow from splitting over a bank (see Figure 10). As ineffective flow areas and obstructions cannot be represented PCSWMM model, trimming of cross-sections was required to reduce artificial conveyance capacity. How flow splits in a cross-section will be different during each storm event, but the 100-year event wase used to assess where modification to the cross-sections would be required. There were also some cross-sections where the water level exceeded the left or right extents (Figure 10). As PCSWMM creates vertical walls at the edge of each cross-section, no water was lost from the system and these cross-sections were not modified. As the purpose of the hydrology model is to determine the expected peak flow at a specific instance (and not how that flow interacts with the floodplain and channel geometry) this representation was considered acceptable.

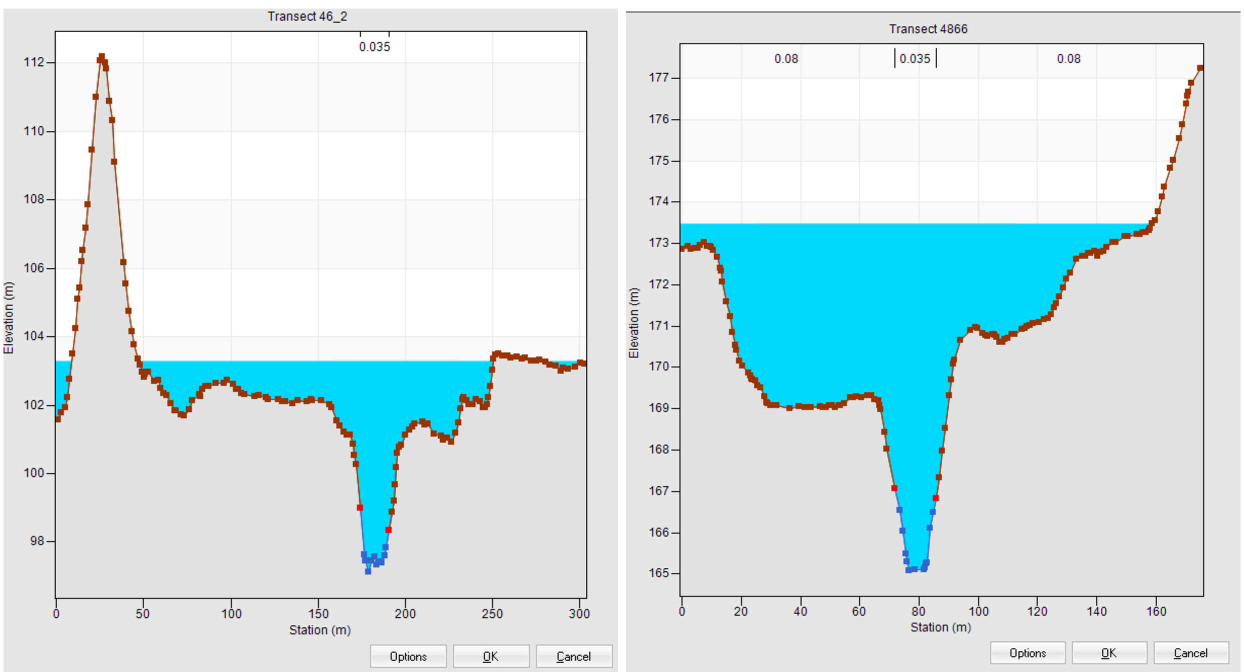

FIGURE 10 PCSWMM Cross-section (left shows flow splitting, right shows flow exceedance)

The horizontally varied Manning's n values used in HEC-RAS cross-sections could not be represented in the PCSWMM model because PCSWMM only allows three Manning's n values within a cross-section. Mannings n values for each cross-section were set to TRCA's standard values: 0.035 for the channel and 0.08 or 0.05 for the overbanks.

3.6 Stormwater Management Facilities

TRCA provided a spatial file showing 6 SWM facilities within the Frenchman's Bay watershed. The lack of SWM facilities is due to the timing of when most of the watershed was developed in the 1970s. SWM facilities will affect the timing and peak flows within the watercourse by attenuating runoff from the catchments. While it is important to represent SWM facilities to accurately reflect the attenuation that would occur during the calibration and validation events, it is estimate that the SWM facilities only serve approximately 4% of the watershed area (MMM 2009). Locations of the SWM facilities are shown on Figure 2.

3.6.1 Stormwater Management Facility Review

TRCA provided location and information for the SWM facilities. The information was reviewed and used to determined if and how each SWM facility would be represented within the hydrologic model. Recommendations for how each SWM facility should be represented within the hydrologic model was provided to TRCA for approval. Of the 6 reviewed SWM facilities, 3 were included in the hydrologic model. A summary of the SWM facility review is provided in Table 7. Parameters related to the SWM facility drainage area, outlet structure, maximum release rate, pond control level, and pond type (wet/dry, online/offline) were summarized and are provided in Appendix A.

TABLE 7 Stormwater Management Facility Summary

Facility Name	Pond Type	Pond ID	Subwatershed	Off/Online	Reported Total Contributing DA (ha)	Included in Model (Y/N)
Pickering Harbour Pond	Wet Pond	182	Outlet Frenchman’s Bay	Offline	4.7	N - drains directly to Frenchman's Bay
Amberlea Commercial Site Pond	Dry Pond	252	Amberlea	Offline	138	Y
K.S.W Development Pond (Temporary)	Dry Pond	262	Dunbarton	Offline	9.6	Y
Amberlea Detention Pond	Dry Pond	265	Not in Frenchman's Bay Watershed	Offline	64	N - was included in Petticoat Creek model
Dixie Estates – Pond 1	Dry Pond	160	Pine Creek	Offline	4.6	Y
Dixie Estates – Pond 2	Dry Pond	160.1	Pine Creek	Online	157.4	N – represented with structure and cross-sections

SWM facilities were represented in the hydrologic model using storage nodes with stage/storage curves and outlets with stage/discharge curves. Where available, storage and outflow curves were taken from the design reports. Only a small number of SWM facilities had detailed stage/storage and stage/outflow information available. When only maximum storage or maximum outflow was provided, the storage or outflow curve was assumed to be linear. Similarly, when only a maximum outflow rate was provided, the stage discharge curve was also assumed to be linear. A summary of the stage/storage and stage/discharge curves are provided in Appendix B.

3.7 Major/Minor Flow Splits

Frenchman's Bay is highly urbanized and in some catchment areas the minor system (catch basins and pipes) catchment contributed flow to one subwatershed and the major system (road and ditches) convey flow into another subwatershed. As the subwatersheds are small, the impact of the minor system on flows can be significant during smaller storms such as those simulated in the model calibration. In this scale of study, the minor pipe system is not explicitly represented, which poses a unique challenge within the hydrologic model.

Theoretically, the overland or major flow paths would only be used when the sewer system was at capacity. Representing this in the hydrologic model means that the runoff from the catchment should be conveyed to the sewershed outlet up to a certain flow/level but then trigger the overland flow route above a specific threshold. To represent this function in the hydrologic model, the following approach was taken:

1. Runoff from the catchment was directed to a junction.

2. From the junction, two conduits were added: one conduit was offset from the junction at a higher elevation (generally 1 m) to convey major flows; another conduit was added (not offset) to direct minor flows to the associated watercourse. This allows flows to be conveyed through the minor system first (until the capacity/flow limit is reached) and then overflow into the major system conduit.

3. The 5-year, 1-hour AES storm was run and the peak runoff (m^3/s) for the catchment was set as the flow limit on the minor system conduit to the associated watercourse. The 5-year, 1-hour AES storm was selected as it was used as the City of Pickering standard (City of Pickering 2019).

4. Elevations for the junctions were taken from the surface topography. Major system conduits were offset by 1 to 2 m from the downstream junction to eliminate any backwater potential storage capacity from the watercourse.

Figure 11 shows an example of a major/minor flow split between two subwatersheds in Frenchman's Bay.

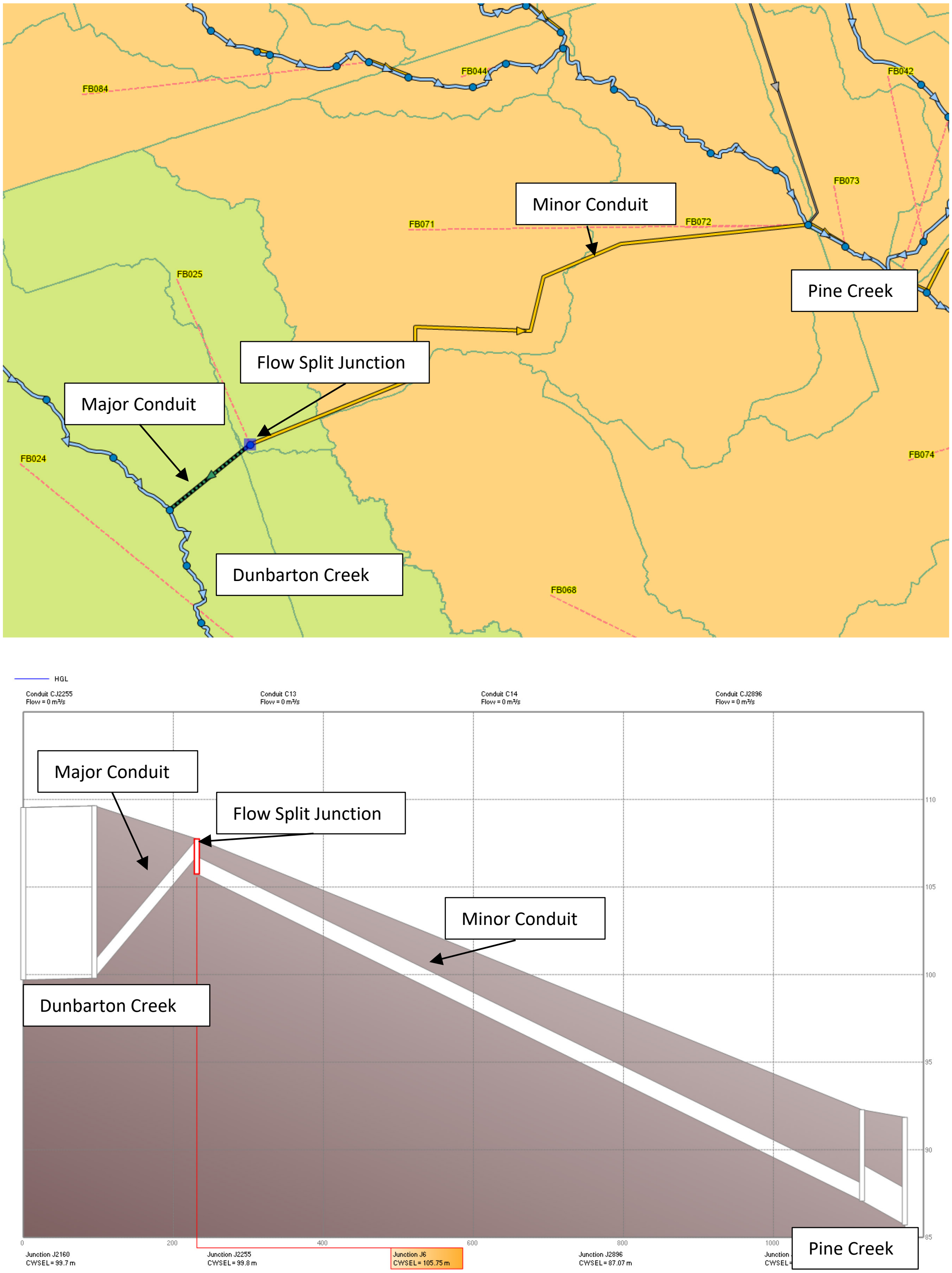

FIGURE 11 Major/Minor System Flow Spit Schematic

4 MODEL CALIBRATION AND VALIDATION

Model calibration is the process in which the modeller adjusts model parameters to minimize differences between simulated output (typically flows for hydrologic models) and observed conditions. By being able to reasonably replicate historical flow conditions, the confidence in the model to predict a watershed's response to differing climatic conditions (or modified land use) is increased. Following model calibration, the model is further tested (or validated) by evaluating the predicted response from an independent set of rainfall events. This validation exercise ensures that the calibrated model parameters are appropriate for events beyond those considered during the calibration exercise.

In the case of the Frenchman's Bay hydrologic update, the model will be ultimately used to estimate peak flows in all watercourses for the 2- through 100-year, 350 year, and Regional flood events. Thus, the focus of the calibration/validation exercise is placed on higher flows associated with specific flood events, rather than low flows or the average seasonal variation.

The following approach was taken to calibrate and validate the Frenchman's Bay hydrologic model:

- Event selection: Rainfall and flow data from the monitoring stations within and surrounding Frenchman's Bay were reviewed for events to complete the model calibration and validation exercise.

- Sensitivity analysis: Sensitivity analysis of the various model parameters was completed during the model calibration to understand the magnitude and effect of parameter adjustments on the model output.

- Model calibration: Parameters were adjusted during model calibration to achieve the TRCA requirements to match 3 out of 5 events for peak flows (-15% to +25% of observed), volumes (-10% to +20% of observed), and hydrograph timing (time to peak).

- Model validation: Once the model was calibrated, five validation events were simulated using the hydraulic model to ensure that the current model calibration was adequate.

TRCA was consulted throughout the model calibration and validation process to ensure the approach and objectives of the hydrologic model calibration were being met.

4.1 Rainfall and Flow Data Processing

Rainfall and flow data were provided by TRCA and reviewed for completeness. Rainfall data was compiled from the available monitoring stations surrounding Frenchman's Bay. The recording interval of rainfall was available in 5-minute increments, and was adjusted to account for daylight savings by TRCA.

During the review of streamflow data, some inconsistencies in the translation of water levels to derived flow values for both monitoring stations were identified. Through consultation with TRCA's hydrometric monitoring staff, it was discovered that observed flow values post-2012 were not always reported, and pre-2012 high flow values were suspect. As a result, no reliable high flow values were available to calibrate the model.

To address this critical data gap, TRCA requested that Matrix investigate methods of extending existing rating curves using desktop methods for the two gauging stations on Pine Creek (HY052) and Krosno Creek (HY040). Matrix completed the rating curve analysis and extensions, which is documented in Appendix C. This analysis allowed the existing rating curves to be extended to encompass the full range of flows, including high flow values post-2012. The extended rating curve also modified previous flow values that had been reported by the third party prior to 2013.

4.2 Event Selection

Events selected for calibration/validation correspond with times where multiple rain gauges and flow monitoring gauges were recording. Multiple rain gauges are important to properly represent the spatial distribution of a rainfall event over the watershed. As a first step to identify appropriate calibration events, rainfall and flow monitoring data were reviewed to determine when overlapping recording intervals occurred.

Events were selected for rainfall periods only (April to October). No snowmelt events were considered in the assessment, as the model was not set up to simulate temperature or snow-pack conditions. Data was available between 2001 and 2023 at most flow and rainfall monitoring gauges (see Tables 1 and 2). Before 2013, flow data was only available in hourly intervals, which is insufficient to accurately represent the rapid respond time of the watercourses in Frenchman's Bay (15-minute data between 2008 and 2012 for flow monitoring station HY040 was further provided by TRCA after the completion of model calibration procedure). As such, priority was placed on events post-2012 as 5-minute rainfall and 15-min flow data were available.

Calibration and validation events were initially selected by reviewing the highest flows from both the HY040 and HY052 monitoring stations. Corresponding rainfall depths from TRCA climate monitoring stations was also included in the comparison. As summary table of the analyzed events is provided in Table 8.

TABLE 8 Calibration and Validation Event Analysis

Event Date	Rainfall HY102 (mm)	Rainfall HY009 (mm)	Rainfall HY004/HY001[1] (mm)	HY040 Peak Flow (m^3/s)	HY052 Peak Flow (m^3/s)	Notes
2001-07-04	-	-	-	12.2	6.0	no rainfall data available
2002-07-22	-	-	-	7.9	5.1	no rainfall data available
2002-11-10	-	-	-	7.3	4.4	no rainfall data available
2004-08-29	18.6	-	9.0	8.5	6.1	HY009 not installed yet
2005-08-19	77.4	-	92.2	19.3	10.7	largest event, HY009 not installed yet
2009-07-02	36.8	40.4	26.2	12.8	4.7	multi-peak event
2009-07-25	55.4	60.6	24.0	17.9	12.9	high intensity event, second largest flow
2009-08-10	34.2	37.2	37.0	7.8	3.3	series of small events over 2 days
2010-07-09	38.6	45.2	34.8	6.6	4.7	single peak event
2010-07-23	43.8	51.0	55.8	10.7	5.4	multi-peak event
2011-08-09	29.4	19.6	53.2	7.8	2.6	variable rainfall over the gauges
2011-08-21	32.0	24.4	33.0	12.8	4.8	single peak event
2011-09-30	31.0	36.4	20.0	10.7	6.4	low intensity event
2012-09-04	53.8	59.4	55.8	9.4	4.4	multi-peak event
2014-07-27	35.8	-	-	10.1	4.7	missing rainfall at HY009 and HY004
2014-10-16	27.6	29.6	21.8	11.9	6.1	variable rainfall over the gauges
2015-06-22	52.6	46.9	-	7.4	2.7	missing rainfall at HY004
2017-06-23	46.4	51.9	61.8	13.0	7.6	long duration event
2022-07-24	28.5	46.4	38.4	17.3	11.2	second largest flow event
2023-06-26	30.2	30.2	31.6	8.6	5.8	multi-peak event at HY040
2023-08-03	16.8	18.7	21.4	8.5	3.7	multi-peak event
2023-09-12	12.4	9.6	7.2	11.8	3.3	potential beaver impacts at HY052
2023-09-18	12.8	2.0	22.4	13.7	1.8	variable rainfall over gauges

1. Rainfall data from HY001 was used between 2003 and 2010, and rainfall data from HY004 was used from 2011 - 2023

During event selection, emphasis was placed on events that resulted in the greatest peak flows, which occurred at both HY040 and HY052 flow gauges. If rainfall was not available at least two of the three monitoring stations for an event, the event was not selected for the calibration or validation process. Matrix worked with TRCA to select the calibration and validation events which are summarized in Table 9.

TABLE 9 Calibration and Validation Event Selection

Event ID[1]	Simulation Date	Observed Timestep	HY040 Peak Flow (m^3/s)	HY052 Peak Flow (m^3/s)
C1	2023-06-26	15 min	8.6	5.8
C2	2022-07-24	15 min	17.3	11.2
C3	2017-06-23	15 min	13.0	7.6
C4	2015-06-22	15 min	8.0	6.3
C5	2014-10-16	15 min	11.9	6.1
V1	2011-08-09	15 min/1 hr[2]	7.8	2.6
V2	2010-07-23	15 min/1 hr[2]	10.7	5.4
V3	2009-07-25	15 min/1 hr[2]	17.9	12.9
V4	2009-07-02	15 min/1 hr[2]	12.8	4.7
V5	2023-08-03	15 min	8.5	3.7
August 19, 2005	2005-08-19	1 hr	19.3	10.7

1. IDs with the prefix "C" denote calibration events; IDs with the prefix "V" denote validation events.
2. 15-min data from HY040 (2008 to 2012) was provided after model calibration and was included in the calibration and validation results (Section 4.3). The table shows HY040 peak flows from the 15-min data.

The August 19, 2005, event was also simulated in the hydrologic model for additional consideration. The observed flows were only recorded hourly and rainfall monitoring station HY009 had not yet been established.

4.2.1 Rainfall Application

Following rainfall data processing and QA/QC checks, the rainfall time series was applied to the catchments within the model representation. Ideally, sufficient rain gauges are available to properly characterize the spatial distribution of the rainfall event throughout the watershed. Properly representing the spatial distribution of rainfall is a key component to accurately simulating the watershed's response to an event. Without a proper representation of the watershed receiving rainfall, it is likely that simulated flow conditions will not match observed conditions.

For urban systems, higher densities of rain gauges are recommended to capture convective systems and the rapid runoff that occurs from impervious areas (Vieux 2005). The World Meteorological Organization's *Guide to Hydrological Practices* (WMO 2008) recommends a rainfall network density range of 10 to 20 km^2/gauge for urban areas to capture convective events. As there are no rainfall gauges directly within the Frenchman's Bay watershed, care was taken to review and use as many rain gauges adjacent to the watershed as possible to simulate each calibration and validation event.

4.2.2 Rainfall and Flow Data Adjustments

During calibration it was found that flow events recorded prior to 2013 appeared to have a 1-hour offset. Through coordination with the TRCA hydrometric team it was determined that a 1-hour offset was introduced by assuming the data was recorded at the end of the hour as opposed to the beginning of the hour. The flow monitoring data pre-2013 was subsequently adjusted to occur 1 hour earlier. This aligned with the observed rainfall/runoff response time.

As there are no rain gauges directly within the Frenchman's Bay watershed, and most events that generated peak flows were localized, short-duration, convective events, there is a strong likelihood that rainfall recorded at a monitoring station did not occur throughout the watershed. Through review of radar data, comparison of rainfall and observed flow along with consultation with TRCA, the use of rainfall from station HY004 was removed from some simulated events due to it being unrepresentative of watershed-wide rainfall patterns and volumes. This is documented in the calibration methods and results.

4.2.3 Antecedent Moisture Conditions

Antecedent moisture conditions represent the level of saturation in the soil prior to the rainfall event. Antecedent moisture conditions can be determined by reviewing the climate conditions anywhere from 5 to 30 days prior to an event; however, the National Engineering Handbook (US SCS 1964) suggests 5 days of prior rainfall is suitable. The total daily rainfall 5 days and 3 days before each calibration and validation event were summed (Table 10). Seven of the selected calibration/validation events showed "wet" conditions (>6 mm of rainfall) prior to the event.

TABLE 10 Antecedent Moisture Conditions Prior to Calibration and Validation Events

Event ID(1)	Event Date	Average Event Rainfall (mm)	Pre-event 5-day Rainfall(1) (mm)	Pre-Event 3-day Rainfall(1) (mm)	Condition
C1	2023-06-26	22.0	29.2	29.2	Wet
C2	2022-07-24	38.1	0.5	0.4	Dry
C3	2017-06-23	53.4	15.6	11.8	Wet
C4	2015-06-22	49.8	0.0	0.0	Dry
C5	2014-10-16	27.8	9.3	9.3	Wet
V1	2011-08-09	34.1	6.8	6.7	Wet
V2	2010-07-23	50.3	4.7	0.0	Dry
V3	2009-07-25	46.7	28.3	27.0	Wet
V4	2009-07-02	34.5	17.5	8.8	Wet
V5	2023-08-03	11.8	7.7	7.4	Wet
19-Aug-05	2005-08-19	90.6	6.2	6.2	Wet

1. Average of the total rainfall depth measured at the surrounding rain gauges prior to the event.

There is no set standard to varying IMD in the Green and Ampt equation to represent different soil moistures. Simulations were completed which include both the 5-day and 3-day pre-event rainfall. The flow data during the four wet condition events were compared against the observed flow data and it was shown that the 3-day pre-event rainfall best simulated wet conditions prior to the calibration/validation events. As such, the pre-event 3-day rainfall was simulated prior to each calibration and validation event.

4.2.4 Peak Flow Analysis

Observed flow data from TRCA's monitoring stations HY040 and HY052, required manual review and processing to ensure that the observed dataset contained no major errors or questionable data that may negatively affect the calibration process. Frenchman's Bay is a highly-responsive system, and often the rise and fall of the hydrographs can occur over a period less than 1 hour. The peakiness of the flows presents issues with the collection for manual flow data as well as recording intervals in the level loggers. To collect a manual high flow measurement, field teams need to respond within hours of a rainfall event and capture the flow in the creek before the hydrograph recedes. In the case of Frenchman's Bay, in the time to capture a manual measurement (typically 1 hour), flows can vary between 30% and 40%, leading to a high variability in the manual measurement, and consequently a high degree of uncertainty with the developed rating curve.

Peak flows were available for 23 years. For years prior to 2013, peak flows were taken from hourly intervals, while for post-2012 the data is available in 15 minutes intervals. The Log Pearson Type III distribution was used to estimate return period peak flows for the 2- through 100-year events. Annual peak flow data is provided in Table 11.

TABLE 11 Annual Peak Flow Data for HY040 and HY052

Year	HY040 Peak Flow(1) (m^3/s)	HY052 Peak Flow(2) (m^3/s)	Notes
2001	12.2	6.0	Hourly timestep(2)
2002	7.9	5.1	
2003	7.8	3.7	
2004	8.5	6.1	
2005	19.3	10.7	
2006	6.3	6.0	
2007	3.6	3.1	
2008	6.3	6.6	
2009	13.5	12.9	
2010	7.6	5.4	
2011	8.8	6.4	
2012	7.5	4.4	
2013	4.9	2.6	15-min timestep
2014	11.9	6.1	
2015	8.0	6.3	
2016	11.0	3.9	
2017	13.0	7.6	
2018	6.1	2.7	
2019	6.2	3.5	
2020	7.8	2.9	
2021	7.9	3.4	
2022	17.3	11.2	
2023	13.7	5.8	

1. Peak flows were derived based on TRCA water level data and Matrix derived rating curve (Appendix C).
2. 15-min data for HY040 from 2008 to 2012 was provided after the peak flow analysis had been completed.

Estimates of the return period flows are provided in Table 12 and were used to support the design storm selection. The August 19, 2005, storm event is considered one of the largest recent rainfall events to have occurred in Frenchman's Bay. However, data was only recorded hourly during this event, and based on a review of the hydrograph, likely did not capture the instantaneous peak flow. The lack of instantaneous flow measurements may result in the return period flows presented in Table 12 to be underestimated. Plots of the computed return period peak flow fits are provided on Figures 12 and 13.

TABLE 12 Estimated Return Period Flows

Return Period	Estimated Flows (m^3/s)	
	HY040	HY052
100	22.1	15.5
50	19.8	13.5
25	17.5	11.6
10	14.5	9.2
5	12.1	7.5
2	8.7	5.1
Years of Used in the Analysis	23	23
Actual Years of Record	23	23

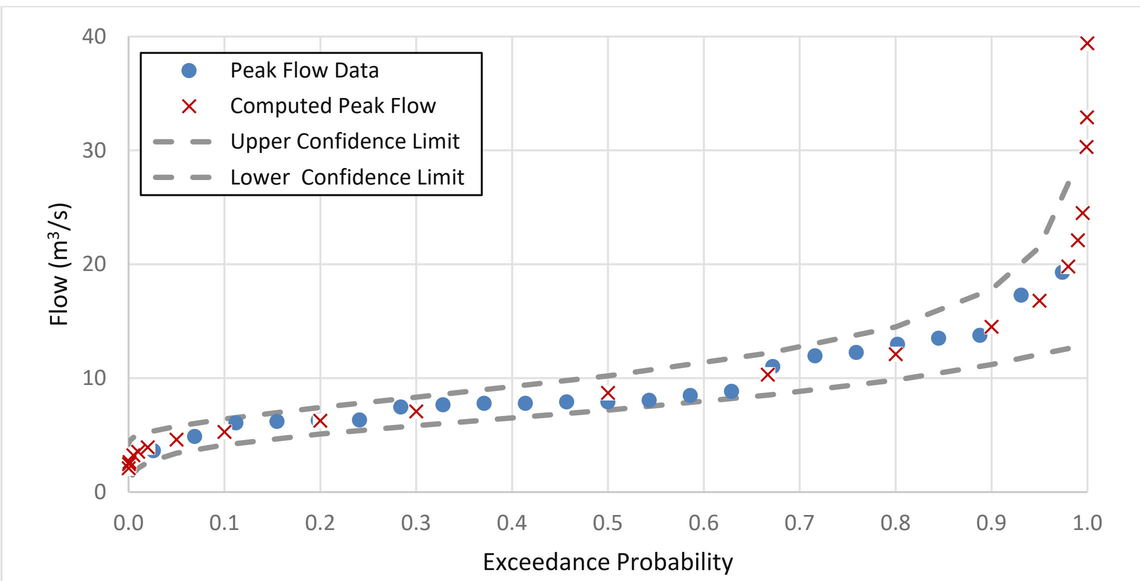

FIGURE 12 Computed Peak Flow Plot for HY040 (Log Pearson Type III Distribution)

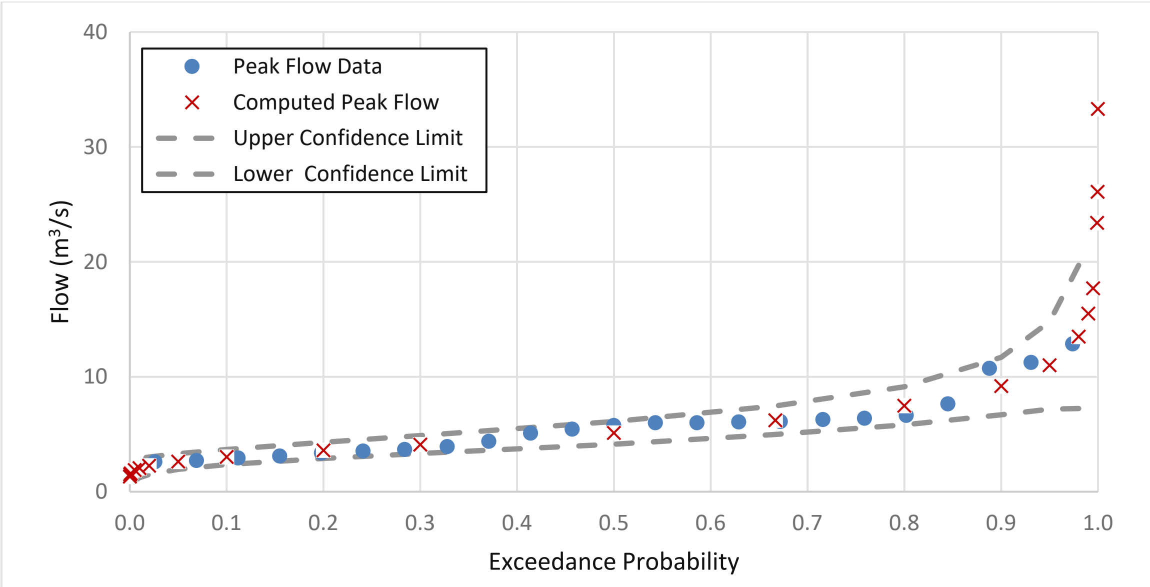

FIGURE 13 Computed Peak Flow Plot for HY052 (Log Pearson Type III Distribution)

4.2.4.1 Event Analysis

The total observed rainfall and runoff from each event selected for calibration/validation was summarized and compared at each monitoring station to help inform the model calibration process. Table 13 outlines the rainfall depth and runoff proportion for each event at monitoring stations HY040 and HY052. At monitoring station HY040, runoff as a proportion of rainfall ranges from 44% to 85% and averages 67%. At monitoring station HY052, runoff ranges from 13% to 30%, averaging 20% of total rainfall volumes. The total imperviousness of the catchments upstream of HY040 and HY052 are 67.8% and 42.5% respectively. A graph showing the corresponding rainfall/runoff portion for each event is shown on Figure 14.

TABLE 13 Observed Event Rainfall/Runoff Proportions

Event ID	Event Date	HY040 Event Rainfall (mm)	HY052 Event Rainfall (mm)	HY040 Runoff (as % of Rainfall)	HY052 Runoff (as % of Rainfall)
C1	2023-06-26	21.7	25.0	44%	14%
C2	2022-07-24	42.8	46.9	84%	17%
C3	2017-06-23	56.9	51.9	85%	24%
C4	2015-06-22	46.9	46.9	63%	21%
C5	2014-10-16	33.9	33.9	57%	20%
V1	2011-08-09	19.6	19.6	56%	16%
V2	2010-07-23	51.2	51.2	55%	26%
V3	2009-07-25	42.3	60.6	74%	30%
V4	2009-07-02	33.3	40.4	83%	20%
V5	2023-08-03	13.0	12.1	69%	13%
19-Aug-05	2005-08-19	92.2	84.8	62%	16%

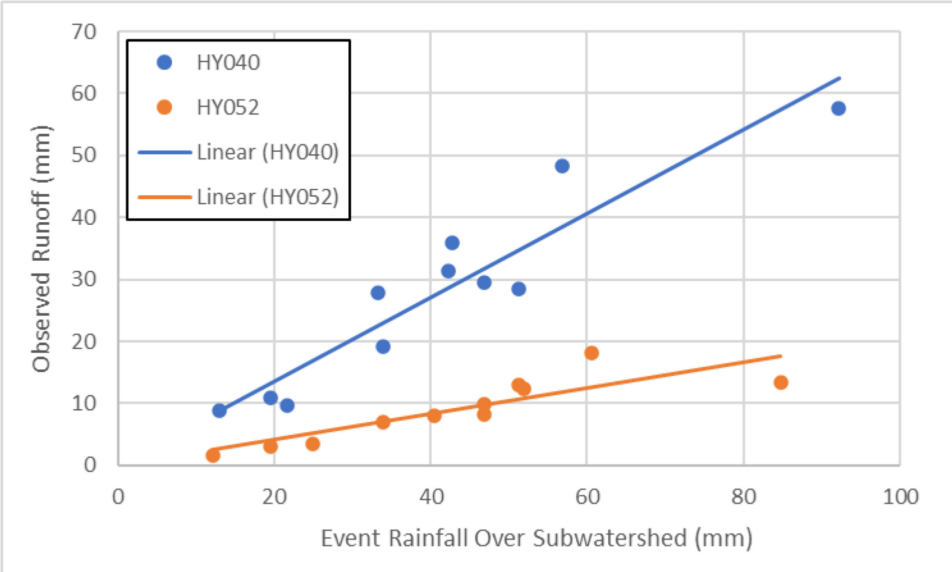

FIGURE 14 Rainfall/Runoff Analysis for Krosno and Pine Creek Gauging Locations

Although rainfall is fairly consistent between the monitoring stations during the selected events, runoff is on average 47% higher at monitoring station HY040 (Krosno Creek) when compared to HY052 (Pine Creek). The differences make sense given the relative difference in imperviousness and drainage areas between the two gauges (Krosno Creek is highly impervious (68% imperviousness) with a drainage area of approximately 2.8 km^2 at the gauge, where Pine Creek is less impervious (43% imperviousness) with a drainage area of approximately 8.1 km^2 at the gauge.

4.3 Calibration Methods and Results

Local calibration of the hydrologic model considered five different rainfall events where model parameters were adjusted to match runoff volume, runoff peaks, and peak timing to observed events at the HY040 and HY052 monitoring stations.

4.3.1 Calibrated Parameters and Approach

Before calibration began, each hydrologic model parameter was reviewed to assess the following:

- its sensitivity to adjustment
- what effects adjustment would have on the simulated hydrograph
- whether the parameter was suitable for adjustment during calibration

A summary of the hydrologic model parameters and approach to calibration is outlined in Table 14. The approach was discussed with TRCA prior to model calibration and TRCA was consulted on any deviations from the original calibration approach during the process. The final calibrated hydrologic model values and model schematics are provided in Appendix D.

TABLE 14 Calibration Parameters and Approach

Parameter	Sensitivity	Hydrograph Effects	Initial Parameterization	Calibration Approach
Area (ha)	High	Volume	GIS delineated	not modified
Width (m) or Flow Length (m)	High	Volume, Peak, Shape	longest flow path length	modified by factors ranging from 0.5 to 1.5
Slope (%)	Low	Peak, Shape	averaged over the catchment	not modified
Imperviousness (%)	High	Volume, Peak	impervious analysis exercise	see Section 3.2.1.2
Manning's N Impervious	Low	Peak, Shape	single textbook values for impervious surfaces - 0.013	tested a range of values from 0.011 to 0.014
Manning's N Pervious	Low	Peak, Shape	single textbook values for pervious surfaces, 0.25	Varied textbook values for pervious surfaces, weighted by land use type (e.g., forest 0.6, residential 0.25)
Depression Storage Impervious (mm)	Low	Volume	single textbook value for impervious surfaces, 2 mm	tested a range of values from 1 to 3 mm
Depression Storage Pervious (mm)	Moderate	Volume	single textbook values for pervious surfaces, 5 mm	varied textbook values for pervious surfaces, weighted by land use type (e.g., forest 10 mm, residential 3.5 mm)
Zero Impervious (%)	Low	Volume	set a default 25%	not modified
Subarea Routing	High	Volume, Peak	pervious routing	not modified
Percent Routed (%)	High	Volume, Peak	estimated values based on land use type	modified values based on land use type
Suction Head (mm)	Moderate	Volume	based on assigned soil type	not modified
Conductivity (mm/hour)	High	Volume	based on assigned soil type	modified for different soils types in the urban vs. rural areas to account for compaction in disturbed/urban areas
Initial Deficit (frac.)	Moderate	Volume	based on assigned soil type	not modified

Discussion on the calibration approach for each of the hydrologic parameters is provided in the following sections.

4.3.1.1 Flow Length

Overland flow length is a sensitive parameter that affects how rapidly runoff is conveyed to the catchment outlet. Several alternatives were used to estimate flow length within each catchment to achieve the desired model calibration. As discussed in Section 2.4.3, using short flow lengths such as those used in a traditional urban model approach (i.e., whereby the flow length represents overland sheet flow before it is channelized typically 100 to 150 m), lacks the necessary representation of watershed scale catchment routing. Simulating such short flow lengths within each catchment created a response to runoff that was too rapid in comparison to observed events.

Various alternatives to estimate flow length were tested within a subset of catchments to determine what other hydrologic parameters could be adjusted to replicate the routing impact of minor and major conveyance systems, while maintaining the event volumes. Manning's roughness n, catchment slope, and flow length all affect the runoff peak, with less effect on runoff volumes. While Manning's n and catchment slope can be adjusted within certain ranges, the resultant impact on peak flows was not sufficient. Larger adjustments to the catchment flow length were needed to meet the runoff response for the watershed.

The approach to estimate flow length was based on a drainage area relationship that has been developed by the USDA (USDA 2010). This method matched well to the measured longest flow path lengths in GIS and showed a response more reflective of the observed flow conditions. The catchment length was then adjusted to convert the natural watershed shape into an equivalent rectangular cascading plane KW approach (Guo and Urbonas 2009). Flow lengths were then further modified by applying scaling factors, with higher factors (e.g., 1.3) being applied to rural catchments and lower factors (e.g., 0.7) being applied to urban catchments.

4.3.1.2 Land-use- and Soil-type-based Calibration Parameters

To maintain a defensible and repeatable approach to model calibration, adjustments to model parameters were not made to individual catchments or subwatersheds, but through the area weighted breakdown of land use and soil types, as well as a division of rural verses urban catchment. As there was little evidence to suggest that a soil type responds differently in one subwatershed of Frenchman's Bay than another subwatershed, modifications to model parameters tied to specific soil or land use types were made a watershed scale.

Parameters in the hydrologic model that were adjusted based on land use/soils type included:

- Manning's n
- depression storage
- soil parameters (suction head, hydraulic conductivity and initial deficient)
- percent routed
- imperviousness

An overview of the urban vs. rural, soil and land use types within each of the four major subwatersheds is outlined in Tables 15, 16 and 17. Catchments were considered urban if the total imperviousness was greater than 30% and rural if less than 30%. Most rural catchments are located in Pine Creek.

TABLE 15 Urban Vs Rural Catchment Types by Subwatershed

Subwatershed	Subwatershed Area (km^2)	% Rural	% Urban
Amberlea Creek	3.2	20%	80%
Dunbarton Creek	2.3	2%	98%
Krosno Creek	5.6	3%	97%
Pine Creek	8.9	34%	66%

TABLE 16 Land Use Types by Subwatershed

Land Use	Amberlea Creek	Dunbarton Creek	Krosno Creek	Pine Creek
Agricultural	7%	0%	4%	1%
Beach/Bluff	0%	0%	0%	0%
Cemetery	0%	0%	1%	0%
Commercial	6%	4%	3%	10%
Forest	8%	9%	16%	1%
Golf Course	0%	0%	0%	1%
High Density Residential	1%	0%	1%	4%
Industrial	0%	0%	6%	36%
Institutional	4%	1%	1%	1%
Lacustrine	0%	0%	0%	2%
Meadow	5%	2%	10%	9%
Medium Density Residential	53%	68%	42%	19%
Railway	1%	1%	1%	1%
Recreational/Open Space	3%	2%	4%	7%
Riverine	0%	0%	0%	0%
Roads	8%	8%	3%	4%
Rural Residential	1%	0%	1%	0%
Successional Forest	4%	3%	5%	1%
Vacant Land	0%	0%	0%	0%
Wetland	0%	1%	2%	3%

TABLE 17 Soils/Surficial Geology Types by Subwatershed

Urban/Rural	Soil Type	Amberlea Creek	Dunbarton Creek	Krosno Creek	Pine Creek
Rural	Loamy Sand	3%	0%	0%	3%
	Sandy Loam	0%	0%	0%	6%
	Loam	16%	2%	0%	26%
	Silty Clay Loam	0%	0%	1%	0%
	Silty Clay	0%	0%	2%	0%
Urban	Sand	0%	0%	3%	0%
	Loamy Sand	0%	28%	0%	34%
	Sandy Loam	44%	43%	2%	4%
	Loam	30%	16%	3%	15%
	Silty Clay Loam	0%	0%	41%	9%
	Silty Clay	6%	12%	48%	4%
	Clay	0%	0%	1%	0%

Manning's n

In PCSWMM, the Manning's n values applied to catchments were considered for both impervious and pervious areas. During calibration, Manning's n values were adjusted based on land use using the City of Pickering's SWM guidelines. Land use considered in the hydrology model was more granular than the SWM guidelines, therefore professional judgement was used to apply the most reasonable Manning's n value. The impervious Manning's n value was set ay 0.011 and pervious Manning's n values by land use are summarized in Table 18. The Manning's n values were not considered a sensitive parameter (Table 14) and no additional adjustments were carried out during model calibration.

TABLE 18 Manning's n Values Based on Land Use

Land Use	Manning's n
Commercial, High Density Residential, Industrial, Institutional, Lacustrine, Medium Density Residential, Roads, Vacant Land, Beach/Bluff	0.15
Agricultural	0.17
Golf Course, Railway, Recreational, Rural Residential	0.24
Cemetery, Meadow, Riverine, Successional Forest	0.40
Forest, Wetland	0.60

Depression Storage

Similar to Manning's n, depression storage in PCSWMM is considered for impervious and pervious areas within each catchment. The City of Pickering SWM Guidelines were used as a reference to develop initial depression storage values for each land use at the beginning of model calibration. The depression storage values for pervious area land use are provided in Table 19. Depression storage for pervious areas is considered a moderately sensitive parameter; during calibration adjustments were made to the forest and successional forest land use areas to better represent observed hydrologic conditions in the watersheds.

TABLE 19 Pervious Area Depression Storage Values based on Land Use

Land Use	Pervious Depression Storage
Agricultural, Beach/Bluff, Meadow, Riverine, Vacant Land, Wetland	7 – 8 mm
Commercial, Cemetery, Golf Course, High Density Residential, Industrial, Institutional, Lacustrine, Medium Density Residential, Roads, Railway, Recreational, Rural Residential	5 mm
Forest, Successional Forest	12 mm

Notes:
1. Impervious areas were calibrated to a value of 1 mm

Soils Parameters (suction head, hydraulic conductivity, and initial deficient)

PCSWMM provides guidance for suction head, hydraulic conductivity and initial deficit soil parameters based on the underlying soil type (Rawls et al. 1983). Soil types were assumed based on the soils mapping described in Section 3.1.3. The soil parameters were aerial weighted based on the soil type within each catchment. During calibration, soils were considered separately for urban and rural areas, as urban areas can have more compacted soils when compared to the same soils in a rural setting. To represent this difference, the hydraulic conductivity for select urban soils, generally located in the Krosno watershed, were scaled by 0.5. The resulting soil parameters are provided in Table 20.

TABLE 20 Soil Parameters by Soil Type

Urban/Rural	Soil Type	% of Watershed	Hydraulic Conductivity (mm/hr)	Suction Head (mm)	Initial Deficit
Rural	Loamy Sand	14.3%	29.9	61	0.390
	Sandy Loam	2.0%	10.9	110	0.368
	Loam	2.5%	3.3	89	0.347
	Silty Clay Loam	0.6%	1.0	270	0.261
	Silty Clay	0.2%	0.51	290	0.228
Urban	Sand	0.4%	120.0	49	0.413
	Loamy Sand	14.2%	29.9	61	0.390
	Sandy Loam	18.3%	5.5	110	0.368
	Loam	0.7%	3.3	89	0.347
	Silty Clay Loam	14.2%	0.51	270	0.261
	Silty Clay	17.4%	0.25	290	0.228
	Clay	15.2%	0.25	320	0.210

Percent Routed

In PCSWMM, the percent routed parameter is estimated based on a relationship between the total imperviousness and Directly Connected Impervious Area (DCIA) within a catchment (Section 3.4.1.1). The percent routed parameter was weighted for each catchment based on land use. Initial DCIA values were based on both TRCA and the City of Pickering SWM guidelines. During calibration, the DCIA values for medium density land use was adjusted to 45% from the City of Pickering and TRCA guideline values (60% and 50% respectively) to improve the hydrologic representation of the watershed.

Imperviousness

Imperviousness for each catchment was estimated using land use provided by the TRCA and revised based on the aerial analysis described in Section 3.4.1. Although the final values appeared to be low for commercial and industrial land uses relative to guidance estimates of imperviousness, calibration of the hydrologic model was carried out with the intention that the calculated imperviousness would not be adjusted during calibration. During calibration, minor adjustments were made to select land use impervious values to better represent hydrologic conditions observed in the watershed; high density residential imperviousness was increased from 80% to 85% (85% is the City of Pickering standard); and medium density residential was decreased from 64% to 60%. This was deemed appropriate as the impervious assessment (Table 4) showed that imperviousness can range from 59% to 71% for medium density residentials areas.

Minor System Considerations

During model development, efforts were made to best represent major and minor flow splits (Section 3.7). As a result, runoff from a catchment is conveyed to a sewer shed and, when flows exceed the 5-year, 1-hour AES peak flow (assumed minor system capacity), are routed to an overland flow route (the major system). These flow splits generally fall within the same subwatershed (e.g., drainage remains in Pine Creek), however, in some instances, particularly in the headwater catchments, flow splits occur that direct either minor or major flows to an adjacent subwatershed. Table 21 summarizes the major and minor flows splits represented in the existing conditions model.

As per Ministry of Natural Resources and Forestry's (MNRF; formerly Ministry of Natural Resources) Technical Guidelines (MNR 2002), and for the purpose of Regulatory flood hazard assessment, storage is not accounted for, and minor system (i.e., sewer pipes) would be overwhelmed during the Regulatory storm. Given this, the future conditions (Regulatory) model was developed with no hydrologic controls considered, i.e., SWM infrastructure and crossings were removed. Minor flow splits are also not considered, and do not contribute flow, resulting in the potential to both overestimate and under-estimate Regulatory flows in these locations. For example, in catchment FB027, the minor system is assumed to convey up to 1.3 m^3/s to Trib 2 in Amberlea Creek before generating overland runoff which drains to Dunbarton Creek. Not accounting for the minor system in the Regulatory model results in 1.3 m^3/s not being accounted for in Amberlea Creek Trib 2 (potentially underestimating flows); all generated runoff during the event is assumed to reach Dunbarton Creek (potentially overestimating flows).

TABLE 21 Major/Minor Flow Split Locations

Catchment	Drainage Area (ha)	Minor System Subwatershed	Major System Subwatershed	5-Year, 1-hour AES Peak Flow (m^3/s)
FB001	7.7	Amberlea	Petticoat Creek	0.6
FB008	8.1	Amberlea	Frenchman's Bay	0.8
FB010	14.2	Dunbarton	Amberlea	0.5
FB012	3.2	Amberlea (Reach 3)	Amberlea (Trib 2)	0.2
FB014	33.8	Amberlea (Reach 3)	Amberlea (Trib 2)	2.2
FB020	3.7	Dunbarton	Amberlea	0.3
FB023	2.6	Pine	Frenchman's Bay	0.2
FB025	7.4	Pine	Dunbarton	0.6
FB027	20.7	Amberlea (Trib 2)	Dunbarton	1.3
FB030	24.2	Amberlea (Trib 1)	Dunbarton	1.6
FB035	11.7	Pine (Trib 2)	Pine (Reach 3)	<0.1
FB036	13.3	Pine (Trib 2)	Pine (Reach 3)	0.3
FB037	2.6	Pine (Trib 2)	Pine (Reach 3)	0.1
FB038	2	Pine (Trib 2)	Pine (Reach 3)	0.2
FB045	12.6	Pine	Frenchman's Bay	0.9
FB046	3.9	Pine	Frenchman's Bay	0.5
FB049	73	Krosno	Pine	3.4
FB066	15.1	Pine	Pine	1.5
FB076	6.3	Dunbarton	Pine	0.8
FB108	3.1	Krosno (Reach 1)	Krosno (Reach 3)	0.3
FB115	41.5	Krosno (Trib 2-2)	Krosno (Trib 2)	10.2
FB001	7.7	Amberlea	Petticoat Creek	0.6

4.3.2 Calibration and Validation Results

Calibrating the hydrologic model first focused on matching the runoff event volumes and peak flows for more recent events (e.g., periods with 15-minute flow data), as there was a higher confidence in the rating curve, as discussed in 4.1. Calibration to events pre-2012 were completed as a secondary priority as there is more uncertainty with the observed flows.

TRCA provided criteria for matching calibration and validation events and require that at least three of the five selected events fall within the acceptable criteria ranges for:

- runoff volume, -10% to +20% of observed
- peak flow, -15% to +25% of observed
- time to peak, comparison of peaks
- goodness of fit parameters:
  - **Nash-Sutcliffe Efficiency (NSE):** measures the predictive power of hydrologic models by comparing whether the observed mean is a better predictor than the modelled data. A value of 1

is consider a perfect model match. A satisfactory result is typically considered to be 0.65 or above (Moriasi et al. 2007).

- **Coefficient of Determination (R^2)**: output of a regression analysis measuring the proportion of variance between dependent and independent variables, with 1 being a perfect regression. A satisfactory result is typically considered to be 0.75 or above (Moriasi et al. 2007).

- **Integral Square Error (ISE) and Integral Square Error Rating:** integrates the square of the difference between the observed and simulated data over the event period (Sarma et al. 1973). Ratings are shown in Table 22.

TABLE 22 Integral Square Error Values and Integral Square Error Ratings

Rating	Integral Square Error Value
Excellent	<3.0
Very good	3.0-6.0
Good	6.0-10.0
Fair	10.0-25.0
Poor	>25.0

Calibration of the hydrologic model initially focused on matching event volumes. Parameters were then refined to meet peak flows and peak timing in the observed data. The final calibrated parameters for each catchment in the watershed are provided in Appendix D.

The results for each calibration and validation event are summarized in Tables 23 and 24 for monitoring stations HY040 and HY052, respectively. Following completion of the calibration exercise, 15-minute data for HY040 was provided by the TRCA and the results were updated with the 15-minute data comparison for all events. Figures showing the observed and simulated hydrographs are provided in Appendix E.

At the HY040 monitoring station, three of the five simulated calibration events met the goodness of for requirements for peak flow and event volumes (C3, C4, and C5). The June 2023 (C1) event simulated higher peak flows and peak volumes than the observed, where the July 2022 (C2) event simulated less runoff than what was found in the observed data. There is some suspect data in the streamflow observations for the C1 event as it produces very low runoff as a percent of rainfall when compared to other, similar events in the watershed (Table 13, 44% runoff as a percent of rainfall in comparison to an average of 67% for all other events). For the validation events, four of five events are within the range of acceptable peak flows; with two events within the acceptable volume event range. In general, the hydrologic model is better at simulating larger events (C2, C3, V3), than the smaller events. This is expected as at smaller event volumes, more localized processes that are not typically represented in hydrologic models can have a larger relative impact than during large events. Additionally, this provides higher confidence that the model is better suited to replicate the streamflow response during flood conditions, which is the objective of the exercise.

Calibrating flows at HY052 was more difficult, as the model tended to overestimate the observed peak flows and volumes. Three of the five simulated calibration events met the goodness of fit for peak flow and event volumes (C3, C4, and C5). Similar to HY040, the June 2023 (C1) event simulated higher peak flows and peak volumes than the observed. The C5 event simulated a higher peak flow than the observed (although the discrete different was less than 2.5 m^3/s). For the validation events, one of the five events was within the range of acceptable peak flows; most of the other validation events overestimate the peaks flows and volumes. As discussed in Section 4.1 the data for Pine Creek is only available in hourly format before 2013 which limits the confidence in the observed flow data. The validation event that was simulated within acceptable ranges was the only validation event with 15-minute data.

Calibration to observed flows was discussed with TRCA during technical meetings and it was decided to prioritize the calibration of the more recently collected data, as there was more confidence in the observed data. In this way, the calibration is more conservative, as over-estimating flows would result in more conservative (higher) design storm and Regional flow estimates.

TABLE 23 HY040 Event Calibration and Validation Results

Event ID	Date of Simulation	Rain Gauges Applied	Observed Peak Flow (m^3/s)	Observed Volume (ML^3)	Modelled Peak Flow (m^3/s)	Modelled Volume (ML^3)	Peak Flow Difference (%)	Volume Difference (%)	NSE	R^2	ISE	ISE Rating
C1	2023-06-26	HY102, HY004, HY009	8.6	25,736	11.3	41,709	31.5%	62.1%	0.73	0.94	22.1	Fair
C2	2022-07-24	HY102, HY004, HY009	17.3	97,322	15.0	76,586	-13.2%	-23.1%	0.87	0.90	10.6	Fair
C3	2017-06-23	HY102, HY004, HY009	13.0	114,940	11.3	108,640	-12.8%	-5.5%	0.94	0.94	3.9	Very good
C4	2015-06-22	HY102, HY009	8.0	78,316	10.0	85,701	24.6%	9.4%	0.79	0.84	9.17	Good
C5	2014-10-16	HY102, HY009	11.9	51,781	10.7	61,260	-10.2%	18.3%	-0.18	0.15	36.5	Poor
V1	2011-08-09	HY102, HY009	6.0	29,875	8.7	38,488	11.7%	28.8%	0.94	0.97	8.53	Good
V2	2010-07-23	HY102, HY009	7.6	73,548	9.1	86,542	-14.4%	17.7%	0.88	0.90	7.74	Good
V3	2009-07-25	HY102, HY004, HY009	13.5	86,776	17.9	90,145	0.2%	3.9%	0.97	0.97	5.92	Very good
V4	2009-07-02	HY102, HY004, HY009	9.1	77,661	8.1	62,234	-36.4%	-19.9%	0.74	0.82	13.5	Fair
V5	2023-08-03	HY102, HY004, HY009	8.5	24,837	7.3	19,961	-14.3%	-19.6%	0.84	0.91	17.9	Fair
						AVERAGE	**-3.3%**	**7.4%**				

within acceptable range
lower than acceptable range
above acceptable range

NSE - Nash Sutcliffe Efficiency
R^2 - Coefficient of Determination
ISE - Integral Square Error

TABLE 24 HY052 Event Calibration and Validation Results

Event ID	Date of Simulation	Rain Gauges Applied	Observed Peak Flow (m³/s)	Observed Volume (ML³)	Modelled Peak Flow (m³/s)	Modelled Volume (ML³)	Peak Flow Difference (%)	Volume Difference (%)	NSE	R^2	ISE	ISE Rating
C1	2023-06-26	HY102, HY004, HY009	5.8	27,800	9.7	49,914	67.9%	79.5%	0.20	0.96	24.1	Fair
C2	2022-07-24	HY102, HY004, HY009	11.2	70,754	12.6	82,788	12.0%	17.0%	0.86	0.90	10.2	Fair
C3	2017-06-23	HY102, HY004, HY009	7.6	94,053	8.2	90,297	7.9%	-4.0%	0.86	0.88	4.76	Very good
C4	2015-06-22	HY102, HY009	6.3	79,083	7.8	79,884	24.8%	1.0%	0.00	0.43	13.7	Fair
C5	2014-10-16	HY102, HY009	6.1	58,475	8.5	60,836	40.0%	4.0%	0.89	0.96	6.16	Good
V1	2011-08-09	HY102, HY009	2.6	24,084	4.9	34,469	88.9%	43.1%	0.14	0.63	36.8	Poor
V2	2010-07-23	HY102, HY009	5.4	96,979	6.6	83,981	21.4%	-13.4%	0.87	0.92	9.02	Good
V3	2009-07-25	HY102, HY004, HY009	12.9	150,299	21.4	188,284	66.2%	25.3%	0.25	0.57	29.5	Poor
V4	2009-07-02	HY102, HY004, HY009	4.7	65,606	7.4	69,561	56.0%	6.0%	0.52	0.62	20.1	Fair
V5	2023-08-03	HY102, HY004, HY009	3.7	15,867	3.4	19,116	-9.6%	20.5%	0.90	0.90	10.3	Fair
						AVERAGE	**37.5%**	**17.9%**				

within acceptable range
lower than acceptable range
above acceptable range

NSE - Nash Sutcliffe Efficiency
R^2 - Coefficient of Determination
ISE - Integral Square Error

5 DESIGN STORM AND REGIONAL SIMULATIONS

Having achieved TRCA agreement that the Frenchman's Bay model was considered satisfactorily calibrated, the Regional storm (Hurricane Hazel), 2 through 100-year and 350-year return period design storm events were simulated to estimate peak flows for input to the hydraulic model. The calibrated model was developed based on the existing conditions land use mapping, and subsequently applied to simulate the 2 through 100-year design storm flows. The Regional, 100-year, and 350-year design storms were simulated using future conditions land use based upon the municipal Official Plan, with all hydrologic controls removed.

5.1 Future Conditions Model

The future conditions model reviewed the City of Pickering Official Plan land use categories and compared them to the existing land use mapping, and cross-referenced with aerial imagery. TRCA supported the cross-referencing of the two spatial datasets and a final layer identifying the potential land use changes was overlaid with the catchment boundaries and updated in the hydrologic model. The total area identified to transition to higher-impervious commercial, industrial and medium density residential land uses in the future is 48 ha.

Table 25 shows the difference between the existing conditions and future conditions imperviousness for each subwatershed. The largest increase in imperviousness occurs in Krosno Creek where existing pervious areas are designated as industrial and commercial uses in the official plan land use. The overall change within the Frenchman's Bay watershed is an increase in imperviousness of 1.5%.

TABLE 25 Future and Existing Land Use Comparison

Subwatershed	Subwatershed Area (km^2)	Existing Imperviousness	Future Imperviousness	Difference
Amberlea Creek	3.2	51.2%	52.6%	1.4%
Dunbarton Creek	2.3	56.9%	57.5%	0.6%
Krosno Creek	5.6	65.3%	67.7%	2.4%
Pine Creek	8.9	42.8%	44.2%	1.4%
Overall	**20.0**	**52.1%**	**53.6%**	**1.5%**

The modified land use was represented by adjusting the associated parameters including imperviousness, percent routed, depression storage, and pervious roughness (Manning's n) values. Soils, slope, flow length were left the same as the existing conditions model for each subcatchment.

5.2 Design Storm Simulations

Design storm event depths were obtained from Environment Canada's City of Toronto IDF curves (Station ID: 6158355 – formerly known as the Bloor Street Station). The IDF curve was developed based on 73 years of data collected between 1940 and 2021. To select the most appropriate precipitation distribution, six different design storm distributions were simulated in the hydrologic model to compare to the return period flows calculated from the gauge record. The simulated storm distributions included:

- AES: 1-hour, 30% 12-hour, 70% 12-hour
- Chicago: 3-hour, 4-hour, and 12-hour

Previous hydrologic models typically used an AES rainfall distribution.

The rainfall depths for each return period, for each of the design storm distributions is shown in Table 26. Longer-duration, lower-intensity distributions such as the AES 12-hour, 30% and 70% are more applicable to larger and/or rural watersheds (less then 30% imperviousness) with slower response times, whereas the shorter duration, higher intensity 1-hour AES and Chicago storms distributions are typically applied to urbanized watersheds, such as is the case in the Frenchman's Bay watershed.

TABLE 26 Design Storm Distribution Depths for 2- through 100-year Return Periods

Return Period	Design Storm Depths (mm)					
	AES			Chicago		
	AES 1-hour	AES 30% 12-hour	AES 70% 12-hour	Chi_3hr	Chi_4hr	Chi_12hr
2	23.8	42.8	42.8	29.0	31.4	42.8
5	32.6	56.6	56.6	38.7	41.9	56.6
10	38.4	65.7	65.7	45.2	48.9	65.7
25	45.7	77.3	77.3	53.4	57.6	77.3
50	51.2	86.0	86.0	59.5	64.2	86.0
100	56.6	94.4	94.4	65.5	70.7	94.4

Output from the hydrologic model was extracted at the HY040 (Krosno Creek) and HY052 (Pine Creek) monitoring station locations for comparison (Figure 15 and Figure 16). The flood frequency analysis results summarized in Section 4.2.4 were included for comparison.

The 30% and 70% 12-hour AES storm produced the lowest return period flows at each location. All remaining distributions produced similar peak flow estimates with the highest being the 1-hour AES.

The design storm return period flows were compared to estimates from the flood frequency analysis at monitoring stations HY040 and HY052. In both Krosno Creek (HY040) and Pine Creek (HY052), the flood frequency distribution trended lower than most of the estimates from the design storms (Figures 15 and 16; Tables 27 and 28). Comparing the frequency flows to the design storms results may not be an appropiate comparision as some instantaneous flow data was missing from the records (e.g., August 19, 2005, events prior to 2012 etc.) and the records were limited to 23 years of peak flow data, which would effect the flood frequency results.

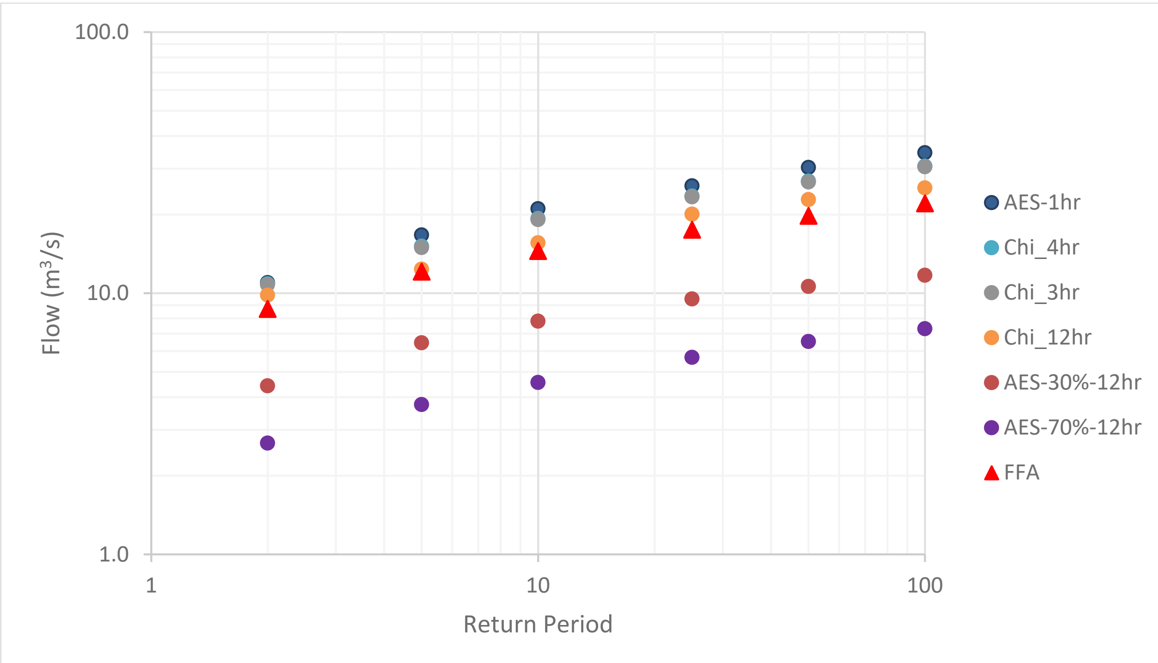

FIGURE 15 Hydrological Model Output at HY040 (Krosno Creek)

TABLE 27 Design Storm Distribution Flows for 2- through 100-year Return Periods (HY040)

Return Period	Design Storm Flows (m^3/s)						Flood Frequency Analysis (m^3/s)
	AES			Chicago			
	AES 1-hour	AES 30% 12-hour	AES 70% 12-hour	Chi_3hr	Chi_4hr	Chi_12hr	
2	11.0	4.4	2.7	10.8	10.9	9.8	8.7
5	16.7	6.5	3.7	14.9	15.1	12.4	12.1
10	21.0	7.8	4.5	19.1	19.3	15.6	14.5
25	25.8	9.5	5.7	23.4	23.5	20.1	17.5
50	30.3	10.6	6.5	26.7	26.9	22.8	19.8
100	34.5	11.7	7.3	30.5	30.7	25.3	22.1

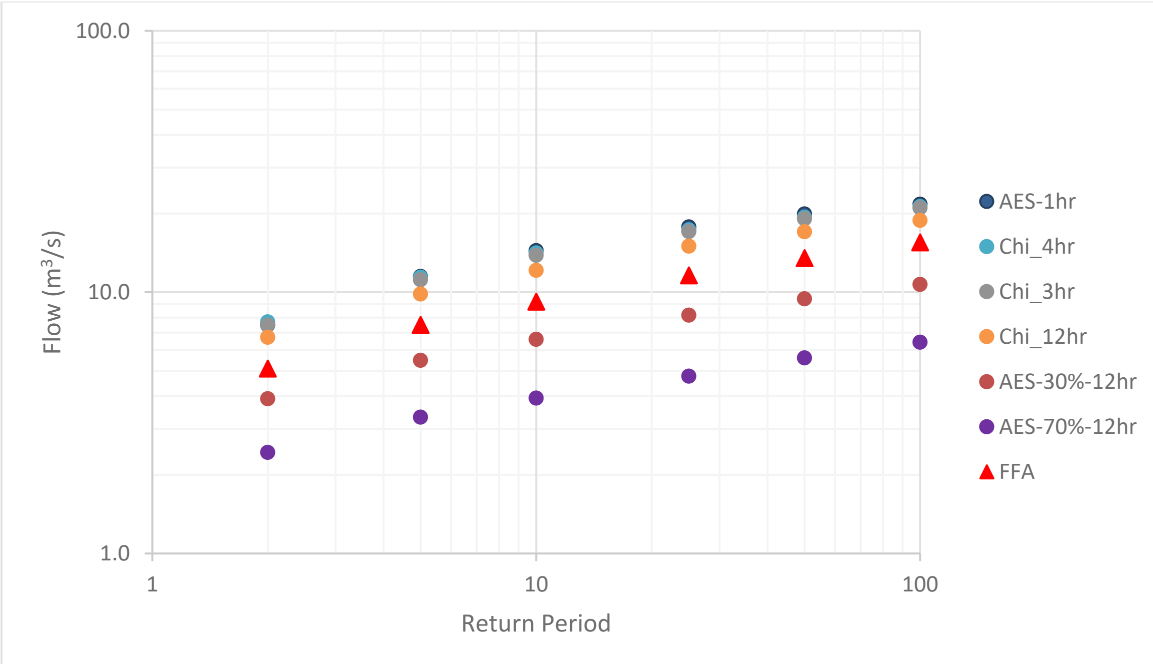

FIGURE 16 Hydrological Model Output at HY052 (Pine Creek)

TABLE 28 Design Storm Distribution Flows for 2- through 100-year Return Periods (HY052)

Return Period	Design Storm Flows (m^3/s)						Flood Frequency Analysis (m^3/s)
	AES			Chicago			
	AES 1-hour	AES 30% 12-hour	AES 70% 12-hour	Chi_3hr	Chi_4hr	Chi_12hr	
2	7.5	3.9	2.4	7.5	7.7	6.7	5.1
5	11.5	5.5	3.3	11.2	11.4	9.8	7.5
10	14.4	6.6	3.9	13.8	14.1	12.1	9.2
25	17.8	8.2	4.8	17.0	17.3	15.0	11.6
50	19.9	9.4	5.6	19.1	19.3	17.0	13.5
100	21.7	10.7	6.4	21.0	21.2	18.8	15.5

Following a detailed review and consultation amonst the study team, the 1-hour AES distribution was selected to represent the design storm flows for use in the Frenchman's Bay hydraulic modelling based on the following:

- The 1-hour AES distribution is applicable to urbanized watersheds, such as is the case in the Frenchman's Bay watershed.
- The high-intensity, short-duration, 1-hour AES storm distibution is similar to the historical events that have occurred over the watershed in the past few decades (e.g., August 19, 2005) and yielded the highest flow responses.

- Given the relatively small size of the watershed (20 km^2), a 1-hour AES storm distibution could occur simultaneously throughout the watershed.

- The flood frequency analysis potentially underestimates maximum peak flows as instaneous measurements were not recorded, with gauge information limited to either hourly to 15-minutes data intervals (i.e., peak flows may well have been missed).

Areal reduction factors are commonly used to convert point rainfalls to averages over a larger area, to represent the spatial variability of rainfall that occurs over a watershed. No reduction in point rainfall is typically applied to drainage areas less than 25 km^2 and adjustment curves are applied to drainage areas greater than 25 km^2. Due to the relatively small size of the Frenchman's Bay watershed, areal reduction factors were not required for the design storm simulations.

Results of the 1-hour AES designs storm distributions are provided in Appendix F.

5.3 Regional Storm Simulations

The Regional storm event (Hurricane Hazel) was simulated in the calibrated hydrologic model with land use adjust to future conditions. To account for saturated conditions, the full 48-hour Hazel hyetograph was used to simulate the Regional event. As per the MNRF Technical Guidelines (MNR 2002), all potential storage elements such as culvert and bridge crossings and SWM facilities were removed from the future conditions model as they may not be used to provide a reduction in peak flows for flood hazard assessments.

A summary of the Regional flows from the future conditions model for the Frenchman's Bay watershed is provided in Appendix G. A comparison to the previous hydrology model results is provided in Table 29. Similar to the design storms comparison, differences in peak flow from the previous hydrology study are largely due to refinements with the catchment delineation (from updated LiDAR), model software used, land use conditions (i.e., existing versus future), increased resolution of channel routing elements, incorporation of additional hydraulic structures, the refined model parameterization (recent and long-term rainfall and flow data), as well as the revised storm distribution. In general, the updated Regional flows are generally lower (8 m^3/s, on average) than previous model estimates.

TABLE 29 Comparison of Regional Flow Estimates – Previous Model to 2024 Update

Subwatershed	Flow Node/Location	Previous TRCA Regional Flow[1] (m^3/s)	2024 Update Regional Flows (m^3/s)	% Difference
Amberlea	Reach 3 at Sheppard Ave.	9.7	4.3	-56%
	Trib 2 at Sheppard Ave.	25.3	23.6	-7%
	Trib 2 upstream of Reach 3 confluence	26.4	24.5	-7%
	Reach 2 at Hwy. 401	34.8	28.5	-18%
	Reach 2 upstream of Trib 1 confluence	38.2	29.6	-22%
	Trib 1 at CNR	4.6	0.6	-87%
	Amberlea Creek at Bayly St.	45.2	32.0	-29%
	Amberlea Creek at Outlet	47.7	32.8	-31%
Dunbarton	Whites Rd.	4.9	1.7	-66%
	Finch Ave.	6.2	3.2	-49%
	Appleview Rd.	14.3	16.0	12%
	Hwy. 401	18.5	20.6	11%
	Bayly St./Outlet	22.3	23.6	6%
Krosno	Hwy. 401	21.7	10.7	-51%
	Bayly St.	30.5	19.3	-37%
	Morden Lane	-	21.5	-
	Reytan Blvd.	-	25.3	-
	Alyssum St.	39.1	28.1	-28%
	Confluence with East Trib	60.0	48.5	-19%
	South Sandy Beach Rd	74.1	59.3	-20%
	Outlet to Bay	86.5	55.6	-36%
Pine	Reach 4 at Fairport Rd.	11.3	6.4	-43%
	Reach 3 at Finch Ave.	16.9	9.6	-44%
	Erin Gate Blvd.	7.6	5.0	-34%
	Trib 1 at Finch Ave.	10.5	7.1	-33%
	Reach 2 at Finch Ave.	27.4	16.8	-39%
	Kitley Ave.	39.8	28.5	-28%
	Glenanna Rd.	55.5	45.5	-18%
	Kingston Rd.	67.0	52.6	-22%
	Upstream of Hwy. 401	73.8	63.2	-14%
	Downstream of Hwy. 401	76.1	63.7	-16%
	Outlet to Bay	80.8	65.8	-19%

Notes:
1. Amberlea Creek Regional Flows (Aquafor Beech, 2005)
2. Pine and Dunbarton Creek Regional Flows (Greenland Consulting, 2007)
3. Krosno Creek Regional Flows (TRCA, 2002)

In additional to the general list of causes for variability in Regional flow estimates outlined above, some subwatershed specific notes include:

Amberlea Creek

- The largest Regional flow differences occur in the Reach 3 and Trib 1 which receive most of their flows from the minor (sewer system) that is not represented in the Regulatory model.
- Updated subwatershed delineation resulted in a 16% smaller watershed area than the 2005 assessment (3.2 km^2 vs. 3.8 km^2).
- More detailed catchment representation, routing, and parameterization.
- Differing model platforms and infiltration routines (CN parameterization vs. Green and Ampt).

Dunbarton Creek

- Updated subwatershed delineation resulted in a 35% larger watershed area than the 2002 assessment (2.3 km^2 vs. 1.7 km^2), attributable to changes in the headwater areas, as well as a portion of previously delineated Amberlea Creek catchment now routed overland to Dunbarton Creek.
- More detailed catchment representation, routing, and parameterization.
- Differing model platforms and infiltration routines (CN parameterization vs. Green and Ampt).

Pine Creek

- Updated delineated resulted in a 6% larger watershed area than the 2002 assessment (8.9 km^2 vs. 8.4 km^2), attributable to changes in the headwater areas.
- 22 more years of available calibration and validation data, available in 15-minute intervals in recent years.
- Updated rating curve relationship based on a 1D-hydraulic model.
- More detailed catchment representation, routing, and parameterization.
- Differing model platforms and infiltration routines (CN parameterization vs. Green and Ampt).

Krosno Creek

A comparison of the current 2024 Regional flows to those of the Flood Reduction Study (2013) as well as the 2002 TRCA floodplain mapping study area, is provided in Table 30. As shown, both the 2013 study and current 2024 hydrology update show a reduction in Regional flows, as compared to the 2002 TRCA study. The 2002 study was conducted in a different modelling platform (Visual OTTHYMO) than the more recent

2013 and 2024 studies, both of which allow for more detailed representation of the urbanized catchments. Further, the 2002 study estimated a drainage area of 6.5 km^2, where the 2024 study delineated a total subwatershed area of 5.6 km^2 (14% smaller). Flows generated within the 2013 and 2024 studies are more comparable, but some differences remain. While these two models were set up with similar parameterization, some differences are noted including:

- Structures and storages were not removed from the Regional simulation in the 2013 study.
- The 2013 used actual pipe sizes and slope to calculate the capacity of the minor system. The 2024 study assume the capacity of the minor system was equivalent to the 5-year, 1-hour AES peak flow.
- There was a different assumption of how major flows above of Hwy. 401 drain to Krosno Creek or Pine Creek. The 2013 study assumed more major flows were conveyed across Kingston Road to Krosno Creek.
- Catchment delineation in 2013 study was mainly based on sewersheds (minor system); catchment delineation in current 2024 study considered both the major/minor flows with a higher focus on ensuring the major system boundaries were accurate.

TABLE 30 Comparison of City of Pickering 2013 Regional Flow Estimates for Krosno Creek

Subwatershed	Flow Node/Location	TRCA 2002(1) Flow (m^3/s)	City of Pickering 2013(2) Flow (m^3/s)	Matrix 2024 Flow (m^3/s)
Krosno	Hwy. 401	21.7	17.7	10.7
	Bayly St.	30.5	24.9	19.3
	Morden Lane	-	28.2	21.5
	Reytan Blvd.	-	28.5	25.3
	Alyssum St.	39.1	33.0	28.1
	Confluence with East Trib	60.0	48.5	48.5
	South Sandy Beach Rd.	74.1	53.4	59.3
	Outlet to Bay	86.5	61.5	55.6

Notes:
1. (TRCA, 2002)
2. (TMIG, 2013)

5.4 Hydraulic Model Flow Inputs

The Regulatory peak flows used to inform the hydraulic model are based on the higher of the Regional and 100-year peak flows for future development conditions (Section 5). Within the hydraulic modelling, the selection of flow input locations was based on guidelines specified in the *Technical Guidelines for Flood Hazard Mapping* (EWRG 2017), as summarized in Table 31. The approach allows for a practical and effective hydrologic model to be developed in terms of the number of subcatchments required, while at the same time ensuring sufficient flow details can be translated to the hydraulic model.

A summary of the flow junction locations from the hydrologic model and the associated reach from the hydraulic model was reviewed and confirmed by the TRCA. Overall, the flow inputs align with the guidelines specified in the EWRG guidelines, however there are instances where the accumulated flow change is greater than 10%. These locations were reviewed and agreed upon by the study team. The flow values for all flow change locations and all scenarios are included in Appendices F and G and the unitary discharge flows are included in Appendix H.

TABLE 31 Derivation of Flows for Hydraulic Model

Case	Flow Change Location Reference Name	Hydraulic Model Flow Value Derivation
1	First flow change location (headwater cross-section)	Flow value derived from outlet of headwater catchment (assigned to most upstream cross-section in hydraulic model)
2	Standard flow change location	Flow value derived from outlet of catchment (assigned to most upstream cross-section in catchment)

6 UNCERTAINTIES AND LIMITATIONS

Models are simply tools to help analyze, estimate, and predict values based on a set of inputs. A high level of care and professional judgement was used to calibrate and validate the hydrologic model to ensure the physical processes of infiltration, runoff, and routing within the Frenchman's Bay watershed are properly represented. Nevertheless, within any model, there are sources of inherit uncertainty in inputs, calibration parameters, or process representation within the model itself. This section is intended to highlight the largest sources of uncertainty encountered in this study, as well as provide guidance on the limitations of use associated with the PCSWMM model for Frenchman's Bay.

6.1 Uncertainties

Recognizing the uncertainty associated with the analysis reported herein, appropriate measures were taken to reduce the uncertainty associated with the peak flow estimates and increase confidence in the model's ability to predict peak flows. Measures to improve model uncertainty included calibration and validation of flow estimates to two TRCA flow monitoring gauges HY040 (Krosno Creek) and HY052 (Pine Creek) for a range of high flow events. In areas where observed flow data was not available for comparison, unit peak flows (peak flow divided by drainage area) was reviewed against soils conditions and imperviousness to confirm reasonable peak flows were being simulated from these areas (Appendix H). Although these measures help to increase confidence in the model predictions, areas of residual uncertainty associated with the hydrologic modelling include:

- Limited flow data was available for calibration/validation in Krosno Creek (HY040) and Pine Creek (HY052). No flow observations were available for comparison in Amberlea and Dunbarton Creeks. Therefore, the representation of hydrologic parameters in Krosno and Pine Creek are assumed to represent the conditions in Amberlea and Dunbarton Creeks.

- Lack of high-quality observed data for large flow events. Comparing Table 28 to Tables 23 and 24, shows that most of the events used for calibration/validation are within the 2-year to 10-year return period range. There are no observed discharge events greater than 25-year return period with 15-minute data available at both gauge locations.

- Lack of detailed soils mapping for the watershed. Soils mapping available for the Frenchman's Bay watershed is highly influence by the urbanized setting. It is unclear how much the urbanized setting will influence the soils ability to infiltrate and storage water. Given the range of mapped soils in the watershed and the highly impervious nature of Frenchman's Bay, it is felt this is an uncertainty of minor significance.

- Lack of rainfall monitoring within the local subwatersheds. None of the rainfall monitoring stations used for the calibration/validation analysis are located within the Frenchman's Bay subwatershed. As discovered through the analysis, the rainfall depths and distribution of the event can vary significantly between stations, and it is difficult to determine the rainfall the best represents the observed flow conditions.

- No discrete representation of the minor system. In urbanized watersheds, the majority of runoff is conveyed to the watercourse through the sewer network, which was not explicitly represented in the Frenchman's Bay hydrology model. Catchments were parameterized to balance routing that would occur through minor system as well as overland to achieve model calibration, while adequately representing the Regulatory storm hydrology. While this uncertainty is typically minor when considering high return period flows (e.g., 50 to 100 years) or Regulatory flows, the sewer may be capable in some areas of conveying much larger events than the typical 2-year or 5-year design capacity.

6.2 Limitations

The PCSWMM model was calibrated to match runoff volumes and peak flows for single events. The PCSWMM model was not developed for, and should not be relied on for, continuous modelling analysis (i.e., multi-event simulation), water balance modelling, or generating low flow estimates. Furthermore, the model does not include a discrete representation of the minor system network which would convey the majority of runoff during more frequent storm events. Given the model's purpose to determine Regulatory flows, SWM facilities and watercourse crossings were ignored for the Regulatory event (i.e., higher of the Regional or 100-year event) and no credit was given to attenuation around structures in the channel. Care should be taken when using the model to predict flow estimates for purposes other than floodline generation.

7 RECOMMENDATIONS

Recommendations to improve the hydrologic model parameterization and calibration to reduce uncertainty associated with the peak flow estimates include the following:

- Additional data to confirm stage-discharge relationships. Increasing high flow measurements and data collection frequency (5-minute intervals). Installing long-term continuous flow monitoring gauges in Amberlea Creek and Dunbarton will allow for calibration in all subwatersheds.

- Enhanced representation of the minor system. Minor system representation within Frenchman's Bay was simplified and could be refined with additional analysis or data review. Confirming the service level of the storm sewer system strengthen the underlying runoff assumptions around major/minor flow splits. Alternatively, if the TRCA wish to more accurately estimate design storms and assess existing and future build conditions, a dual drainage model may be more appropriate to develop.

- Survey and site reconnaissance of the culverts, ditch connections, and storm sewer outfalls will improve the knowledge of major and minor flow system delineation. This is particularly in the area within Whites Road, the highway 401 and rail corridors.

- Install one or more rain gauges within the Frenchman's Bay watershed. Having rain gauges directly into the watershed will help support the understanding of rainfall/runoff conditions and ensure that the timing of peak flows at the gauging locations is accurately represented.

8 SUMMARY

An updated hydrologic model was developed in PCSWMM for the Frenchman's Bay watershed. Key aspects of the hydrologic model development and calibration include:

- Catchments in the hydrologic model were delineated from 1 m LiDAR, resulting in 118 individual catchments to represent the watershed. Catchments were parameterized based on land use, orthoimagery, soils, and surficial geology mapping.

- Four SWM facilities were incorporated in the hydrologic model to provide representative detention storage. Hydrologically significant culvert and bridge crossings were also included in the channel routing to reflect potential attenuation.

- The hydrologic model was calibrated to five recorded rainfall events and validated to five recorded rainfall events between 2005 and 2023.

    - At the HY040 and HY052 monitoring stations, the model was able to predict peak runoff rates and runoff volumes within the acceptable criteria for three of the five calibration events. The model was not able to replicate the three of the five validation events in HY052, likely due to the lack of 15-minute observed data.

- The 1-hour AES design storm distributions was selected to represent return period in the hydrologic model. The 1-hour AES storm was seen as most suitable based on the scale and condition of the Frenchman's Bay watershed.

- The Regulatory events (100-year and Hazel) were simulated in the hydrologic model with the SWM facilities and watercourse structures removed. No areal reduction factors were applied to the Regulatory event analysis was per the technical guidelines (EWRG 2017, MNR 2002).

- The model provides flow estimates for all mapped watercourses in the Frenchman's Bay watershed for the Regional and 2- through 350-year return period events.

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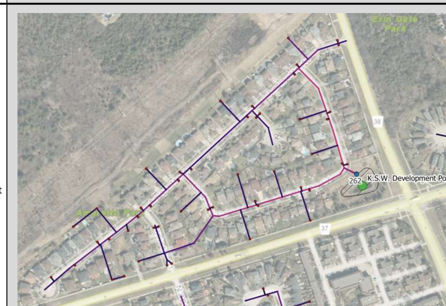
APPENDIX A
Stormwater Management Facility Summary

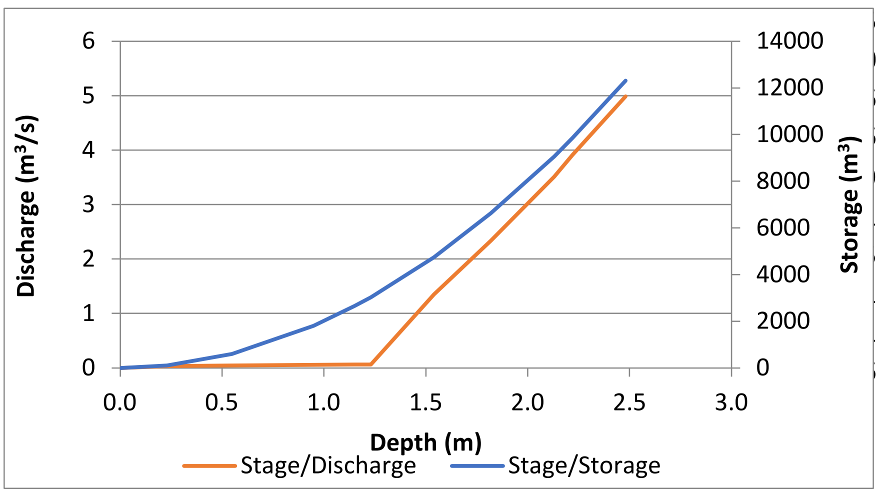
Appendix A: Stormwater Management Facility Summary

FacilityNa	Pond Type	Pond ID	Subwatershed	Off/Online	Reported Total Contributing DA (ha)	Other Reported DA (ha)	Outlet Structure	Flood Control	Quality Control	Erosion Control	Maximum Release Rate (m3/s)	Flood Control Level	Storage Volume (m3)	Stage/Storage Info Provided (Y/N)	Additional SWMF Notes	Image
Pickering Habour Pond	Wet Pond	182	Outlet Bay	Offline	4.7	-	-	N	N	N	-	-	-	N	Pickering# AB SWMP 01 (Begley St Pond). Built, Edited by Thomas Dole on February 6, 2006 to reflect the fact that the pond has been built	
Amberlea Commercial Site Pond	Dry Pond	252	Amberlea	Offline	138	Controlled Area: 75 Upstream Area: 138	See tab	Y	N	N	-	-	QNTY CTL = 5,800 m3	N	Quantity Control Depth = 2.9 m Pickering# AC SWMP 01 (Amberlea Commercial Site). Private, Built, Major system pond - all major system flows outlet to pond except for Whites Road. Major system flows for Whites Road are uncontrolled Discharge to storm sewer system and overflow to Whites Rd. Also known as "Whites Road Detention Pond" from the Pickering	
K.S.W Development Pond (Temporary)	Dry Pond	262	Dunbarton	Offline	9.6	-	-	N	Y	Y	4.99	-	ED = 2,306 m3	Y	ED Depth = 1.72 m Included in MMM report and modelled in Greenland Report	

FacilityNa	Pond Type	Pond ID	Subwatershed	Off/Online	Reported Total Contributing DA (ha)	Other Reported DA (ha)	Outlet Structure	Flood Control	Quality Control	Erosion Control	Maximum Release Rate (m3/s)	Flood Control Level	Storage Volume (m3)	Stage/Storage Info Provided (Y/N)	Additional SWMF Notes	Image
Amberlea Detention Pond	Dry Pond	265	Not in Frenchman's Bay Watershred	Offline	64	-	-	-	-	-	-	-	-	-	Quantity Control Depth = 1.85 m Quantity Control Vol = 7130 m3 Pickering# PT SWMP 02 (Braeburn Pond). Built, Although this pond is located within the Frenchman's Bay Watershed, flows from the pond are released to a tributary of Petticoat Creek -Facility is located in a park -Major system overland flows are directed to this facility, all minor system flows by pas	
Dixie Estates – Pond 1	Dry Pond	160	Pine Creek	Offline	4.6	-	-	N	Y	Y	-	-	ED = 424 m3	N	Erosion Control Depth = 1.5 m Identified in the MMM Report	
Dixie Estates – Pond 2	Dry Pond	160.1	Pine Creek	Online	157.4	Controlled Area: 4.6 Upstream Area: 151.4 (From EA)	Fre_85 Structure	Y	N	N	-	-	QNTY CTL = 6,500 m3	N	Quantity Flood Control Depth = 2.7 m Identified in MMM Report, Modelled in Greenland Hydrology Update*	

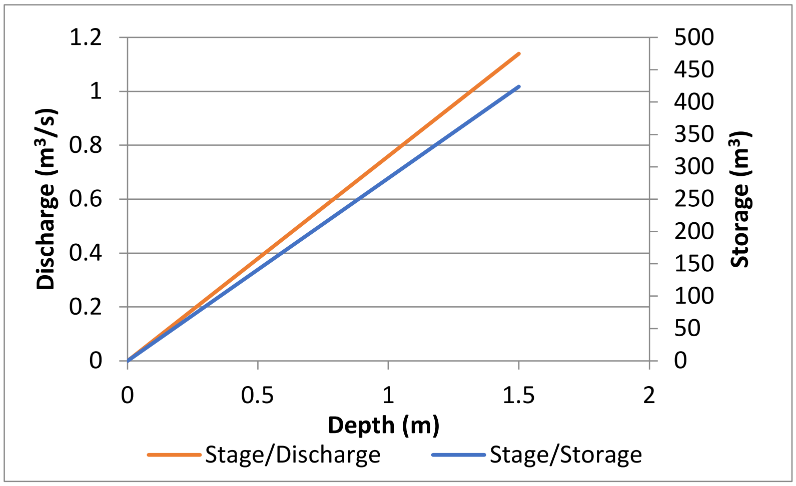
APPENDIX B
Stormwater Management Facility
Stage/Storage/Discharge Curves

Facility Name:	K.S.W Development Pond		
Pond ID:	262		
Type:	Dry Pond - Offline		
Storage/Discharge Curve			
Depth (m)	Area (m^2)	Discharge (m^3/s)	Volume (m^3)
0.0	0	0	0
0.2	465	0.031	107
0.6	1100	0.045	605
1.0	1896	0.056	1,801
1.2	2306	0.06	2,652
1.2	2459	0.06	3,025
1.5	3081	1.35	4,745
1.8	3645	2.34	6,634
2.1	4251	3.51	9,055
2.2	4441	3.91	9,859
2.5	4966	4.99	12,316



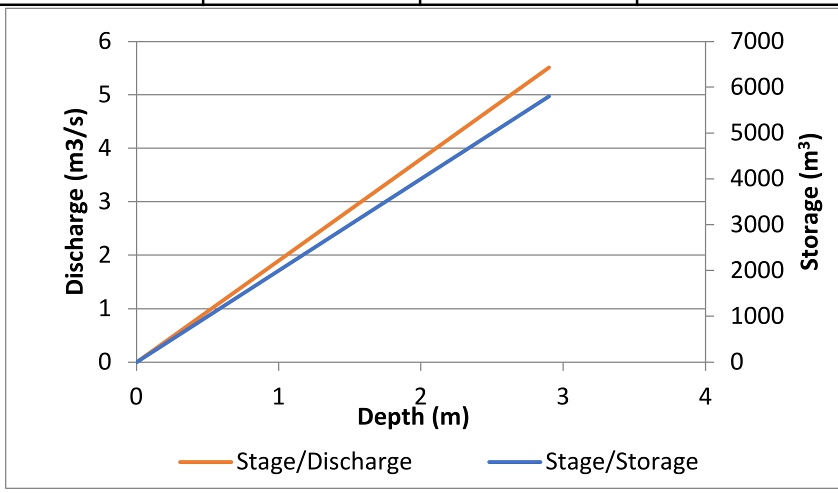
Taken from provided reports

Facility Name:	Dixie Estates Pond 1		
Pond ID:	160		
Type:	Dry Pond - Offline		
Storage/Discharge Curve			
Depth (m)	Area (m^2)	Discharge (m^3/s)	Volume (m^3)
0	283	0	0
1.50	283	1.140	424



Assumed from provided reports

Facility Name:	Inglewood Park Pond		
Pond ID:	252		
Type:	Offline/Overflow		
Storage/Discharge Curve			
Depth (m)	Area (m^2)	Discharge (m^3/s)	Volume (m^3)
0	-	0	0
2.90	2,000	5.510	5,800



Assumed from sewer data and topography

APPENDIX C
Rating Curve Extension – Technical Memo

Version 1.0
February 26, 2024 Matrix 35765-531

Qiao Ying
TORONTO AND REGION CONSERVATION AUTHORITY
101 Exchange Avenue
Vaughan, ON, L4K 5R6

Subject: Rating Curve Extension for Pine Creek and Krosno Creek in Frenchman's Bay

Dear Qiao Ying:

1 INTRODUCTION

Toronto and Region Conservation Authority (TRCA) retained Matrix Solutions Inc., a Montrose Environmental company, to complete a comprehensive update to hydrologic and hydraulic modelling in the Frenchman's Bay watershed, which consists of four major watercourses and their drainage areas: Pine Creek (8.9 km^2), Krosno Creek (5.6 km^2), Amberlea Creek (3.2 km^2), and Dunbarton Creek (2.3 km^2). The objective of this study is to complete watershed-wide delineation of Regulatory floodplain limits using recent topographic and hydrologic data. To complete this objective, an up-to-date hydrologic model is being developed to calculate peak flows throughout the watershed.

During the review of available rainfall and flow data for the Frenchman's Bay hydrologic model calibration efforts, some inconsistencies with the translation of water levels to derived flow values were identified. Through consultation with TRCA's hydrometric monitoring staff, it was discovered that although observed water level values were reported during operational period, observed flood values were not always reported; particularly high flow values greater than two times the highest measured flow values were not extrapolated in the dataset after 2012 (per industry-standard guidance). As a result, no reliable high flow values have been estimated during recent (post-2012) runoff events. Note that prior to 2012, the data was collected, reviewed, and derived into flows by a third party, which did estimate peak flows greater than two times the highest measured flow values.

In terms of manual flow measurements, TRCA hydrometric staff has been consulted about when the flow measurement were conducted, i.e., during rising limb or falling limb of the hydrograph. The response is the staff try to obtain the measurement on the rising limb but it is not always possible due to the rapid response of the urbanized watershed; therefore manual flow measurements are mix of rising and falling limb. High flow manual measurements are also difficult to obtain due to safety concerns.

The Frenchman's Bay hydrologic model development includes calibration to recently collected (e.g., last 10 years) high flow events. In the absence of observed flow data for these events, the model can only be assumed reasonable based on professional judgement, which does not meet typically defined standards for Regulatory floodplain modelling or mapping. As such, TRCA requested that Matrix investigate methods of extending existing rating curves for the two gauging stations on Pine Creek (HY052) and Krosno Creek (HY040) (Figure 1), both of which have water level data for approximately 20 years.

This letter report documents the approach used by Matrix to extend the rating curves, a comparison of the extended rating curves to observed data and the existing rating curve and recommends a rating curve extension approach.

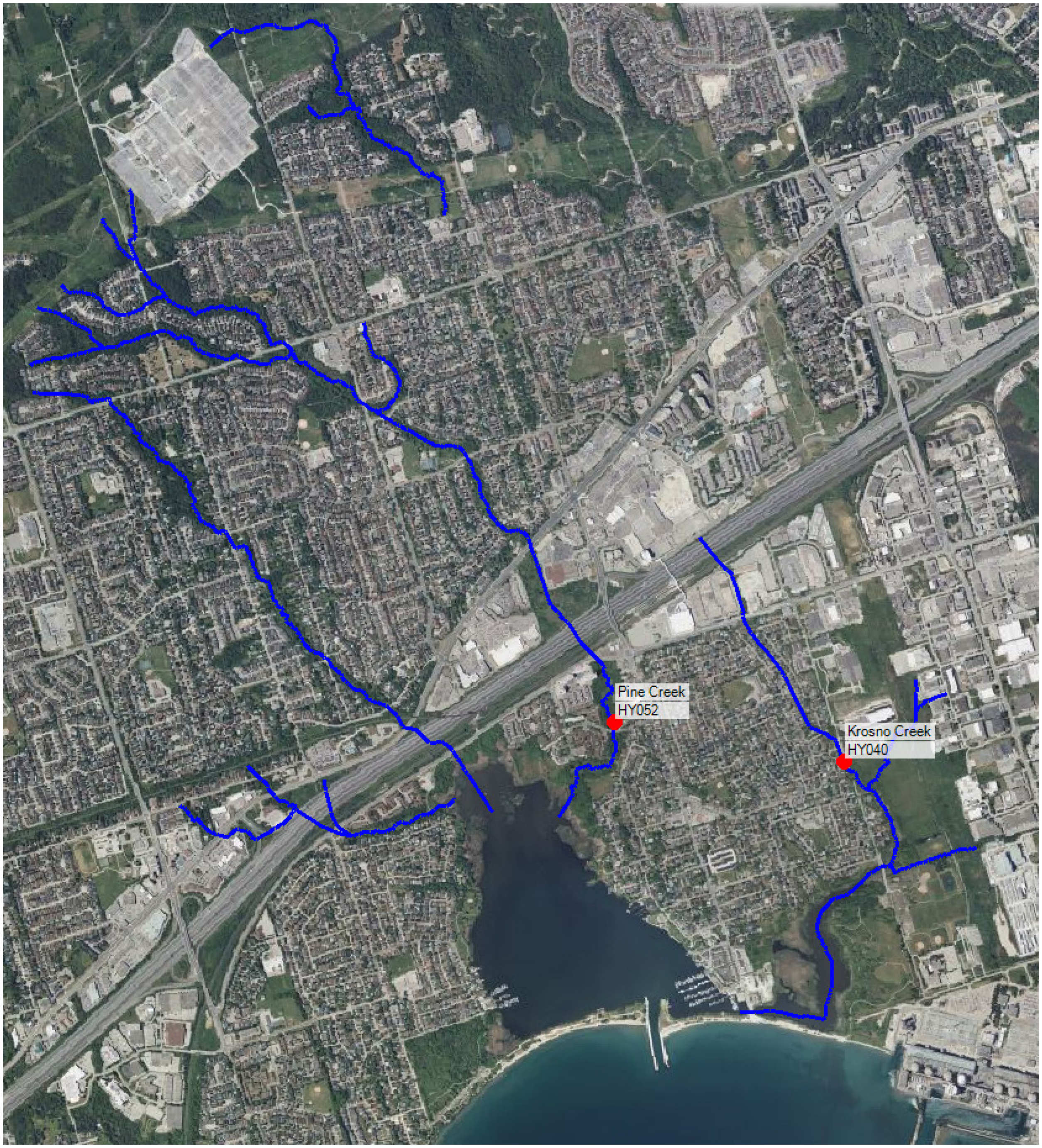


Figure 1 Frenchman's Bay Gauge Locations

2 METHODS

2.1 Approach

Pine Creek and Krosno Creek gauging stations are both located in urbanized areas, where structures and road embankments influence the flood stage and flow paths during high-flow events. Matrix reviewed the *Extension of Rating Curves at Gauging Stations Best Practice Guidance Manual* (Ramsbottom and Whitlow 2003) as well as other literature to determine which methods are most appropriate to extend the rating curves based on the site conditions. Based on the guidance provided, the following approaches were used to develop and compare rating curves for the gauging station:

- divided channel method (DCM)
- one-dimensional (1D) model
- two-dimensional (2D) model

The DCM is a variation on the slope-area method for sites with overbank flow, separating the channel into three sections (left floodplain, channel, and right floodplain). This method uses the Manning's equation and assumes the friction slope equates to water surface slope, making it most appropriate for high-flow extension when there are minimal backwater affects. One-dimensional (1D) models are most appropriate for high-flow extension in non-uniform cross-sections and/or backwater effects, or where floodplain is embanked. Two-dimensional (2D) models are most appropriate for high-flow extension in complex floodplains where flow paths may not be predictable.

For the DCM method, Matrix used Flow Master to determine a rating curve for each of the three channel segments (left floodplain, channel, and right floodplain), assuming a channel slope and Manning's n. The three curves were then combined into a single rating curve by summing the total flow at each elevation.

1D hydraulic models (HEC-RAS v 5.0.7) were already in development as part of the larger project and were updated and refined by Matrix appropriately to capture the gauge location and available survey data.

2D modelling was used for Krosno Creek gauge given the complex overland flow path (high flows are known to spill over Sandy Beach Road and do not follow a single flow path). TRCA completed this work in MIKE FLOOD using a 1D-2D approach (Appendix A).

More details on the application of these methods are provided in the following sections for Pine Creek and Krosno Creek, respectively.

2.2 Assumptions

The following assumptions were made with respect to the rating curve extension work:

- The provided water level data and flow measurements was reviewed in detail for quality or accuracy. It is assumed that the TRCA-provided data was subjected to internal quality assurance (QA)/quality control (QC) review and that any data quality issues or consideration for its use have been noted.

- The derived high flow rating curves do not take seasonal conditions into account (e.g., varying downstream water levels and vegetation growth).

- The conditions at each site affecting high flow water levels, such as topography or structural controls, have not changed over the monitoring period. Only one rating curve per method has been derived for each site.

- No additional field work, structure, or floodplain surveys have taken place. Input data relies on LiDAR, survey data provided by TRCA, and the existing information collected by Matrix during the structure inventory work completed in the spring 2023.

3 PINE CREEK (HY052)

3.1 Gauge Location

The Pine Creek watershed upstream of the gauging location is approximately 8.1 km^2. The gauge is located approximately 500 m upstream of Frenchman's Bay (Figure 1), and 35 m upstream of Radom Street (Figure 1). Photographs of the gauge location and downstream Radom Street crossing are shown in Figure 2.

Figure 2 Pine Creek Gauge Location

<table>
<tr>
<td>
Figure 3A Pine Creek Gauge Looking Downstream to Structure FRE-09 Radom Street (Matrix 2023)</td>
<td>
Figure 3B Structure FRE-09 Radom Street Looking Upstream to Pine Creek Gauge Location (Matrix 2023)</td>
</tr>
<tr>
<td>
Figure 3C Pine Creek Gauge Looking Downstream to Structure FRE-09 Radom Street (provided by TRCA)</td>
<td>
Figure 3D Pine Creek Gauge Looking Upstream (provided by TRCA)</td>
</tr>
</table>

Figure 3 Pine Creek Gauge Location and Radom Street Crossing Photographs

TRCA completed a survey of the gauge on April 13, 2021. The survey was taken as an assumed hydraulic control point downstream of the gauge closer to the culvert crossing and not at the actual gauge location. The approximate location of the survey, as well as the gauge cross-section is shown in Figure 4. A comparison to the LiDAR shows the surveyed invert (76.477 m) is approximately 30 cm below the LiDAR invert (76.714 m), indicating either the presence of a low flow channel or a scour pool not captured by the LiDAR.

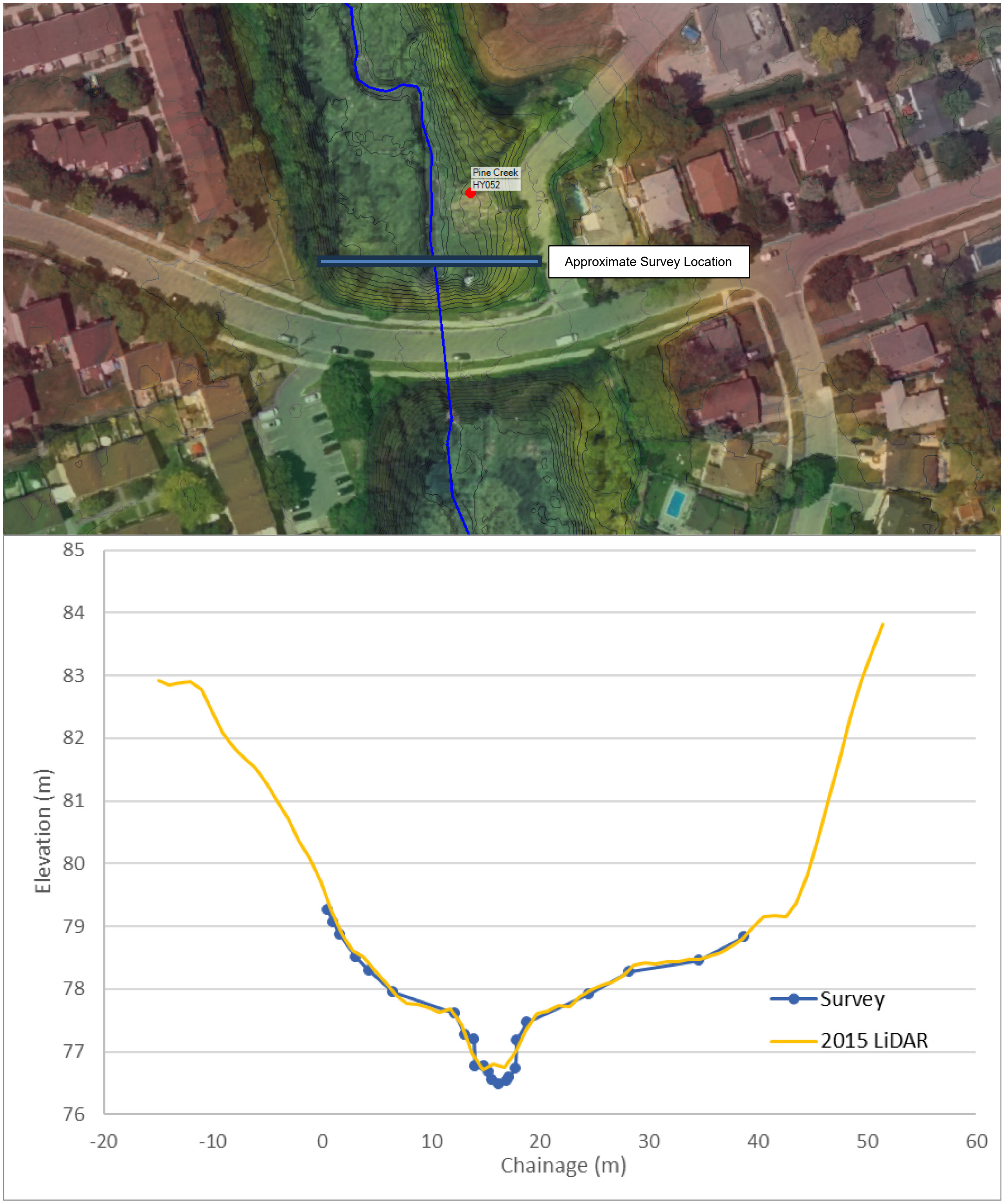


Figure 4 **Pine Creek Gauge Cross-Section and Approximate Survey Location**

3.2 Existing Rating Curve

TRCA has developed a rating curve based on measured water levels and flows at the gauge location. While 72 observations are available for rating curve development, they are all in the relatively low range of flows, ranging from 0.0084 to 2.66 m^3/s (water surface of 77.318 m). For reference, the highest recorded water surface elevation in the data is 78.68 m.

The most recent rating curve from TRCA was updated in 2020 to refine flows. The curve was developed for stages between 76.670 to 77.713 m and used the following equation $Q = 6.087 \times (Y-76.610)^{2.345}$. As shown in Figure 5, the curve was extended approximately 2 times the highest observation (inline with industry standards). However, given the complexity of the downstream hydraulics, caution should be used for flows above the highest observed data point.

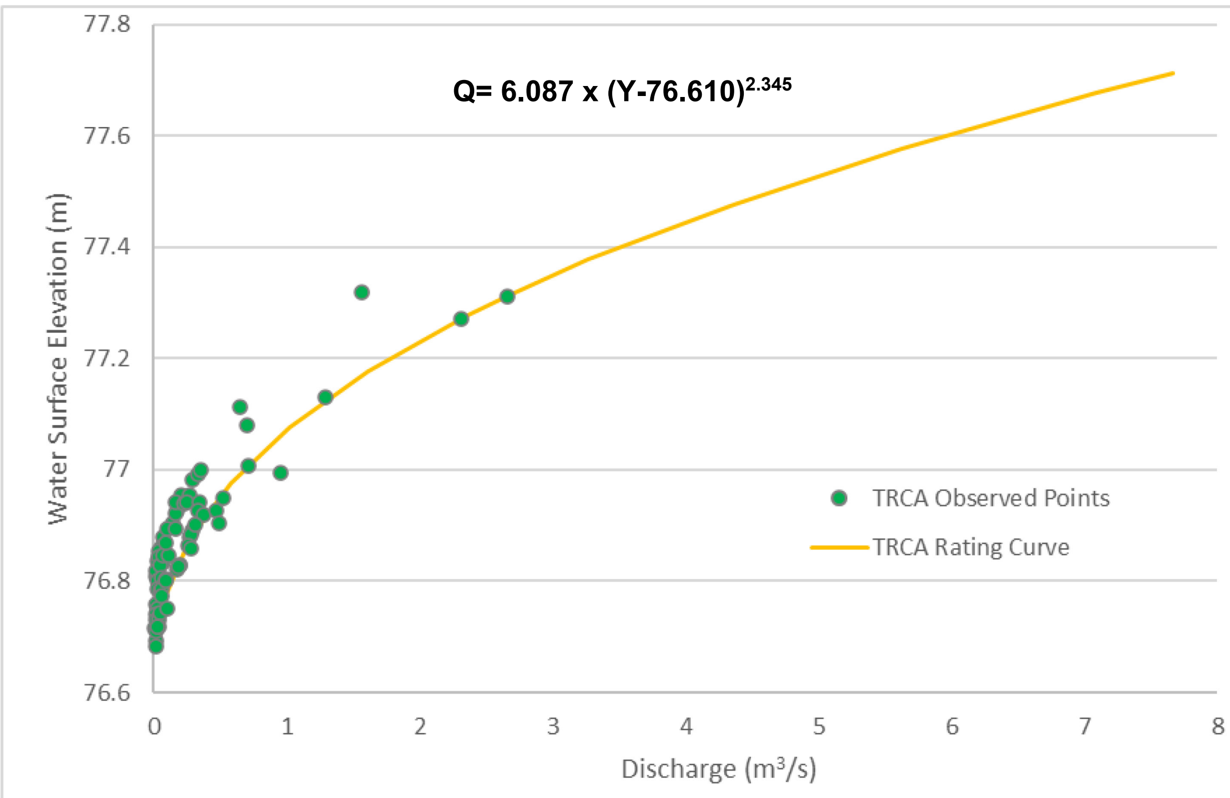


Figure 5 Pine Creek Existing Rating Curve and Observed Data

3.3 Rating Curve Extension

The current TRCA rating curve is only suitable for low flows (i.e., flows less than 8 m^3/s) as there are no high flow observations to fit the curve to. Thus, rating curve extension methods are required. Pine Creek is in an open channel but flows at the gauging station are influence by a hydraulic constriction less than 50 m downstream at the Radom Street crossing. Due to the localized conditions, two methods for rating extension were identified: the DCM method, and the 1D hydraulic model. The application of these methods is detailed in the following sub sections, as well as a comparison to the existing TRCA rating curve.

3.3.1 Divided Channel Method

To apply the DCM, Matrix extended the survey section by combining with the LiDAR in the floodplain. The cross-section was then split into three sections, left floodplain, channel, and right floodplain. A single Manning's n was assumed for each segment, 0.035 for the channel, and 0.05 for the floodplain based on TRCA's standard Manning's for watercourses and urban pervious areas. The 1D model and LiDAR indicated a fairly flat slope (0.07%) in the area of the gauge, while the area upstream showed a steeper slope of 0.4%. Considering the invert at the gauge survey location, the reach slope was assumed to be more in line with 0.4%. As there is some uncertainty with the slope and extent of the low flow channel, a sensitivity was completed with varying channel slopes.

Matrix used FlowMaster to determine a rating curve for a range of slopes. The resulting DCM rating curves are shown in Figure 6. Comparing with the existing TRCA rating curve, the steeper slopes (0.3% to 0.4%) overestimate the flows for the lowest observed measurements, while the flatter slope (0.07%) underestimates the flow for the higher observed flow measurements.

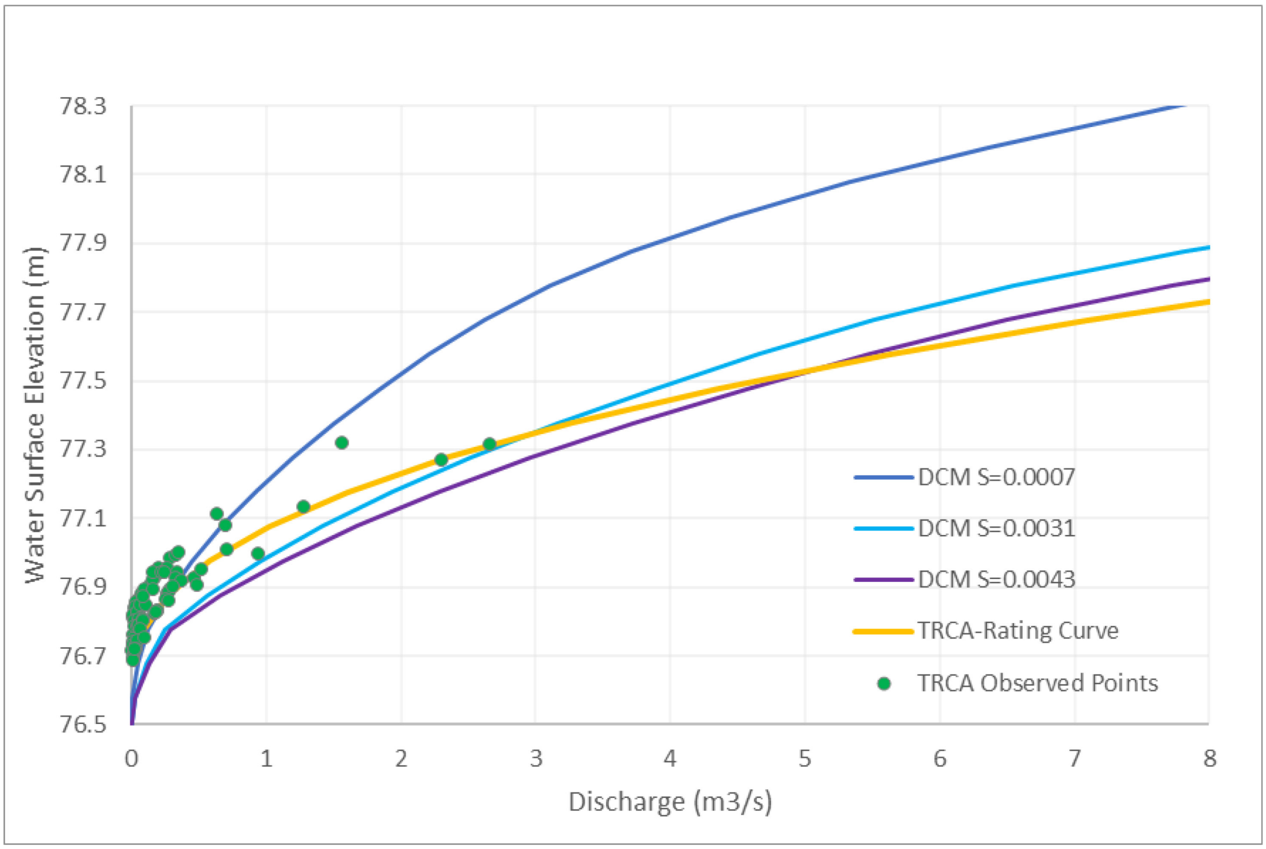


Figure 6 Pine Creek Gauge Divided Channel Method Rating Curve

3.3.2 1D Hydraulic Model

The draft 1D hydraulic model for Pine Creek (refer to Matrix hydraulics report [Matrix 2024]) was used to develop a rating curve at the gauge location. The model was updated to add an additional cross-section at the gauge location and refine the channel profile. A schematic of the 1D hydraulic model and gauge location is shown in Figure 7.

Figure 7 1D Hydraulic Model Cross Sections at Gauge Location

TRCA provided a surface to recut the low flow channel for sections in the 50 m immediately downstream of Radom Street crossing by up to 0.5 m. The cross-section immediately upstream of the culvert crossing (XS 548) was assumed to match the location of the provided survey and was updated to reflect the surveyed low flow channel. No changes were made the upstream cross-section (XS 631). The invert of two cross-section upstream of the crossing (XS 546 and XS 570.20 [gauge location]) were lowered to match/continue the assumed 0.4% slope observed upstream in the LiDAR.

The 1D hydraulic model assumed a lake level of 74.8 m. A sensitivity analysis confirmed that a higher lake level (up to 75.7 m) does not impact the water levels at the gauge location.

The resulting rating curve from the 1D hydraulic model at the gauge location is shown below on Figure 8. The rating curve matches well to the observed flow data but diverges from the TRCA existing rating curve. The 1D hydraulic model rating curve derives lower flows than the existing rating curve. The rating curve is impacted by the crossing embankment as observed through the change in shape at the higher elevations. Figure 9 illustrates the impact of backwater from both the Radom Street crossing and downstream pedestrian bridge structure.

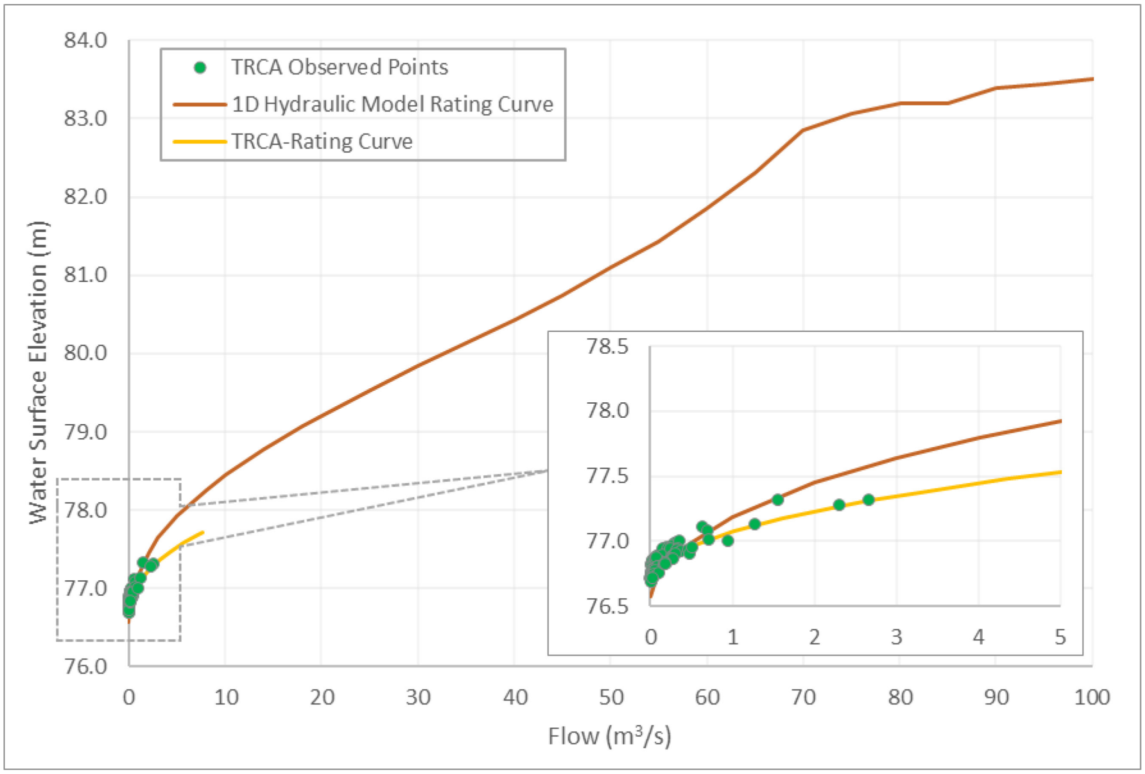


Figure 8 Pine Creek Gauge 1D Hydraulic Model Rating Curve

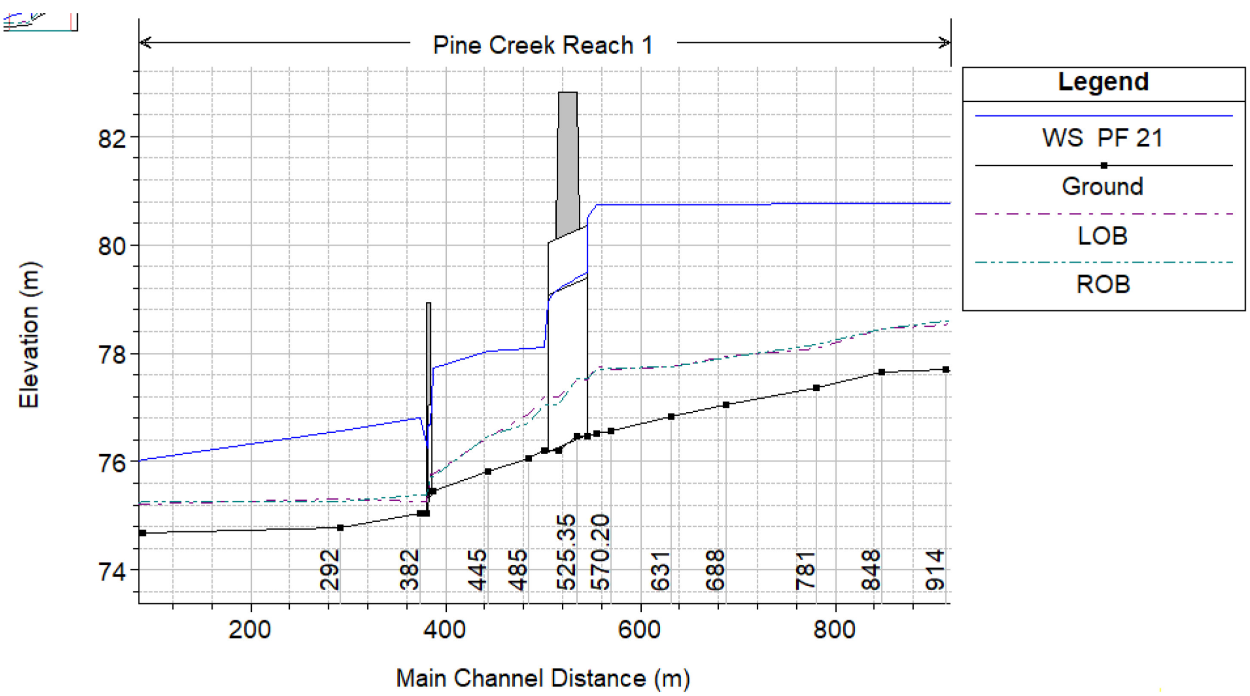


Figure 9 1D Hydraulic HEC-RAS Model Profile Showing Culvert Backwater Impact (570.20 - gauge location)

3.4 Recommended Rating Curve for Pine Creek

A comparison of both the DCM and 1D hydraulic model rating curve extensions are shown in Figure 10. The 1D hydraulic model was found to produce a more reliable rating curve extension as it represents the backwater impacts from downstream structures, and clarifies the uncertainty in the channel slope

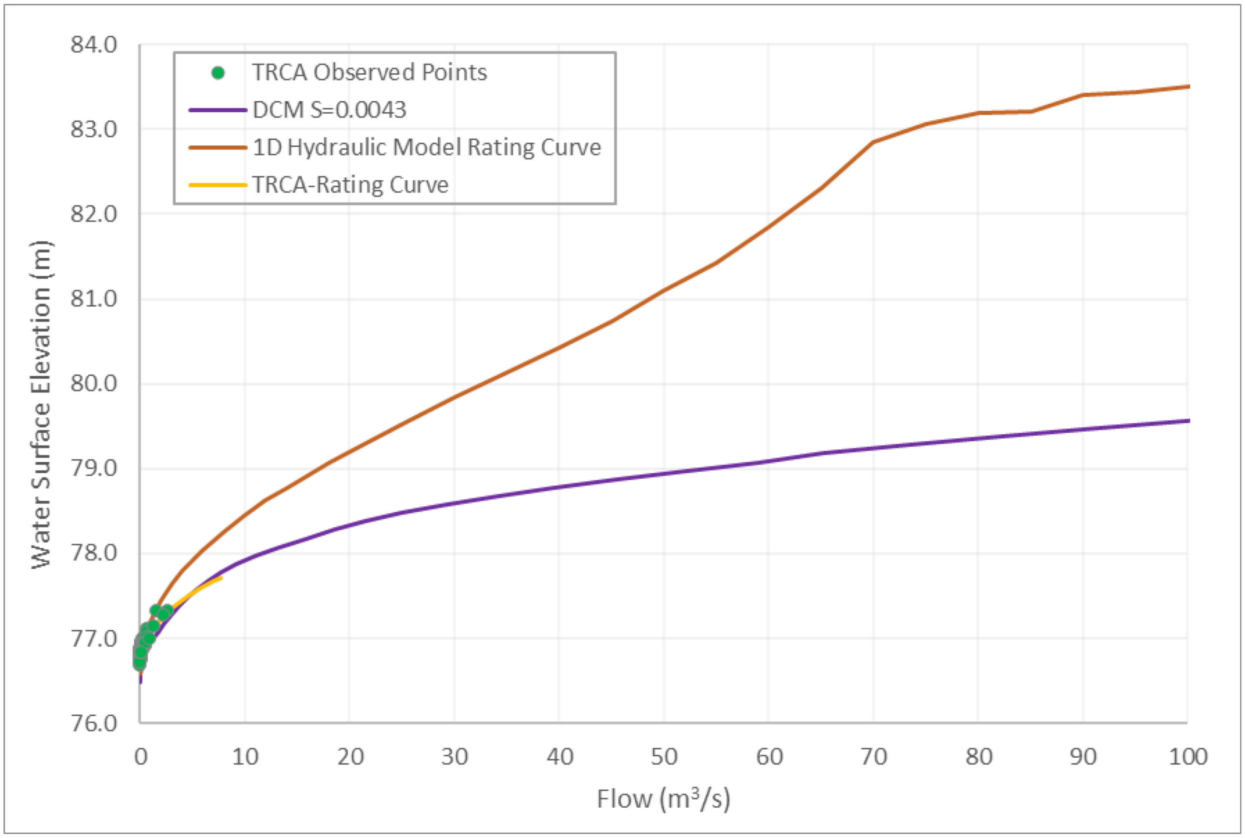


Figure 10 Pine Creek Comparison of Rating Curve Extensions Methods

Matrix split the rating curve based on inflection points shown in the curve, and fit equations to each segment. The resulting rating curve is shown on Figure 11 with Table 1 listing the equations and water surface elevations for which the equations are valid.

Table 1 Proposed Rating Curve Equations for Pine Creek

Stage Range		Equation	Notes
76.577	76.60	Q=0.157x - 12.022	linear extension to assumed invert
76.60	76.94	$Q=6.34947x^2$ - 974.32507x + 37,377.51861	TRCA Observed data
76.94	78.45	$Q=3.05921x^2$ - 468.99789x + 17975.214	Matrix 1D hydraulic model
78.45	79.23	Q=13.188x - 1024.8	Matrix 1D hydraulic model
79.23	82.95	$Q=-1.0139x^2$ + 178.57x - 7763.3	Matrix 1D hydraulic model
82.95	83.73	$Q=56.881659x^2$ - 9,416.545514x + 389,788.870564	Matrix 1D hydraulic model

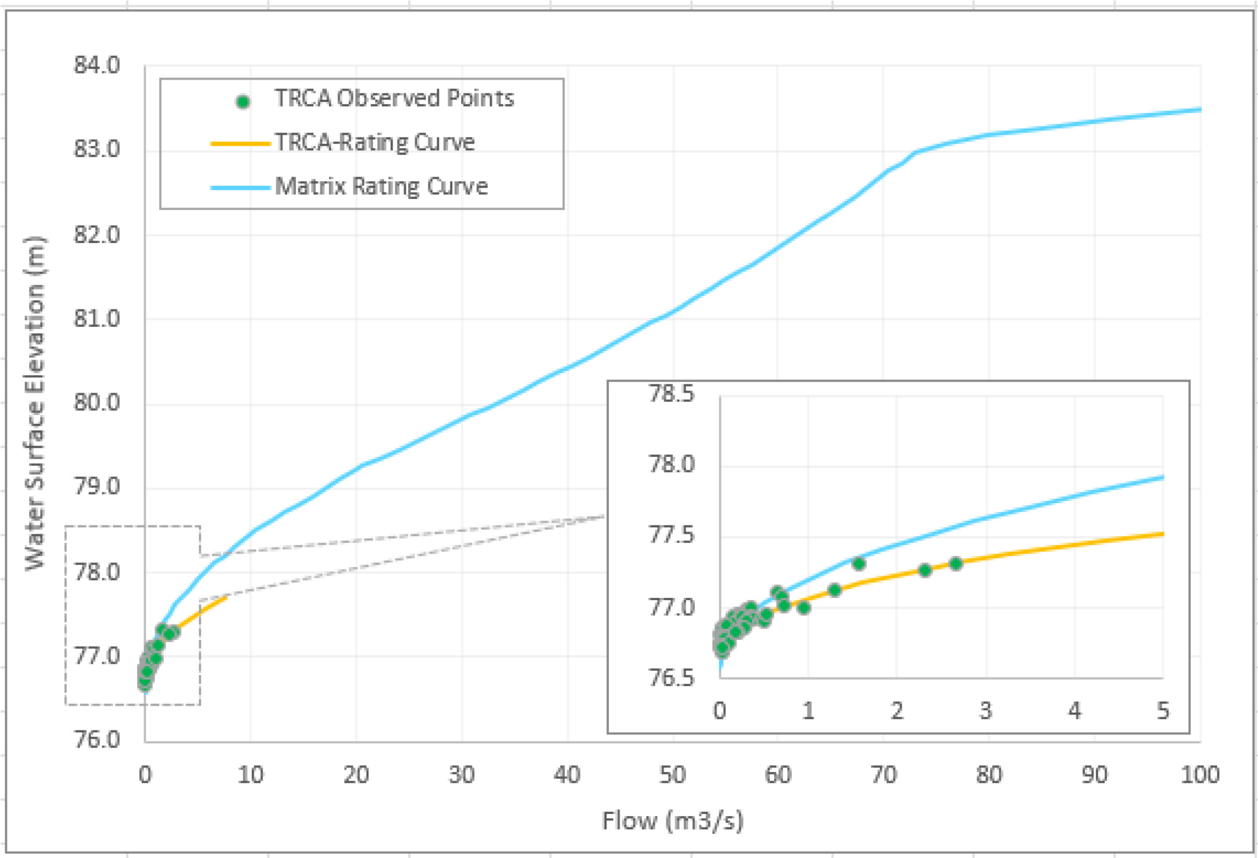


Figure 11 Proposed Pine Creek Rating Curve Extension

3.5 Derived Flows

Water level data was provided by TRCA for the Pine Creek gauge between January 7, 2001, and September 30, 2023. Prior to 2012, the data was provided in 1-hour increments; post-2012, the data was provided in 15-minute increments. Maximum daily derived flows for the existing TRCA rating curve and the proposed rating curve are provided on Figure 12. Applying the Matrix derived rating curve generally shows a reduction in the derived flow estimates (e.g., July 25, 2009, previous estimated peak flow was 16.83 m^3/s and new estimated peak flow is 12.85 m^3/s).

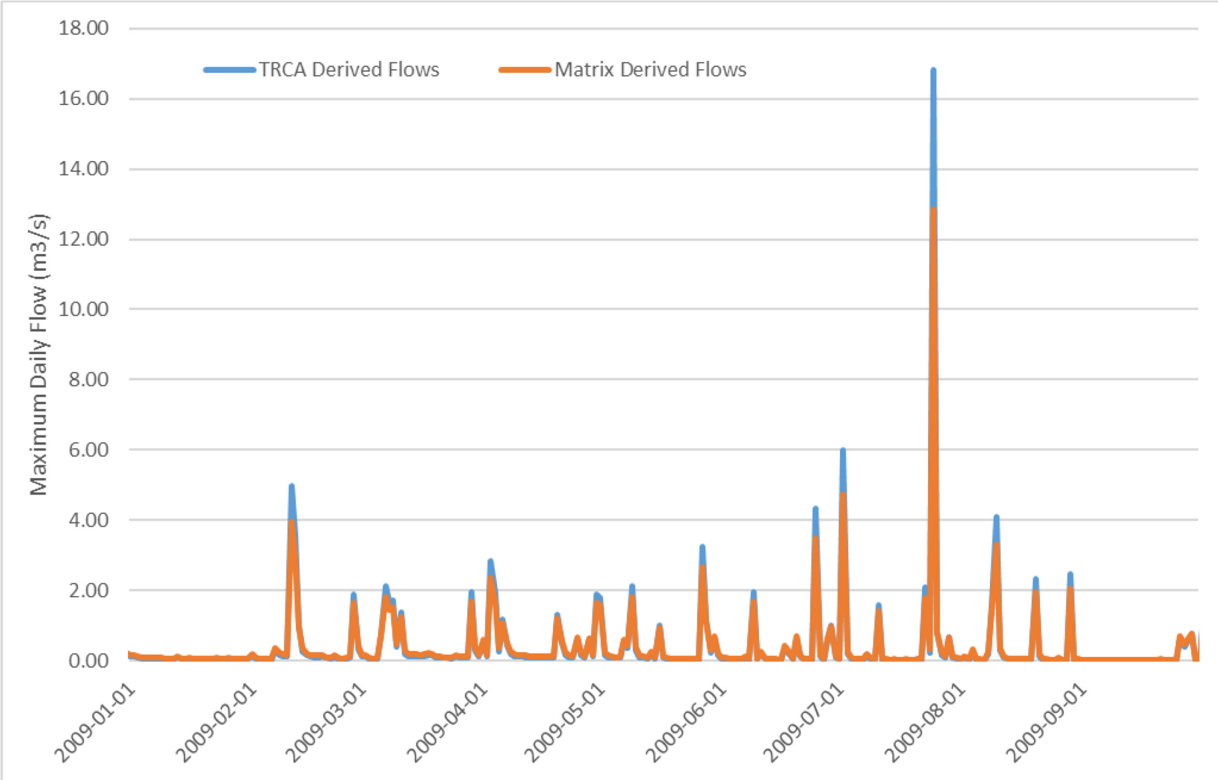


Figure 12 Daily Maximum Derived Flow Comparison for Pine Creek (2009)

Table 2 shows a comparison of rainfall/runoff volumes for several events pre-2012. The analysis was completed to determine the reasonableness of the derived flows. For context the total impervious area of the Pine Creek watershed upstream of the gauging location is 42.5%. The results show that both rating curve estimates appear to be similar with the new rating curve producing runoff estimates between 1% and 10% lower than the previous rating curve. It is expected the runoff would be higher given the imperviousness of the watershed; however, the hourly data interval may have missed the peak in some instances.

Table 2 Rainfall/Runoff Analysis Comparison – Pine Creek

Event Date	Matrix Rating Curve (Event Volume – m^3)	TRCA Rating Curve (Event Volume – m^3)	Rainfall (m^3)	Runoff as a % of Matrix Rating Curve	Runoff as a % of TRCA Rating Curve
2012-09-04	114,900	126,900	434,653	26	29
2011-08-21	37,720	43,700	212,925	18	21
2011-08-09	25,250	27,450	152,336	17	18
2010-07-23	108,100	126,100	372,834	29	34
2010-07-09	90,430	95,750	328,956	27	29
2009-07-25	174,700	215,800	443,980	39	49
2009-07-02	71,700	80,520	295,936	24	27
2005-08-19	125,700	136,100	618,108	20	22

4 KROSNO CREEK (HY040)

4.1 Gauge Location

The Krosno Creek watershed is approximately 2.8 km^2 upstream of the gauging location. The gauge is located 2.2 km upstream of Frenchman's Bay (Figure 1), and 40 m upstream of Sandy Beach Road (Figure 13). Photos of the gauge location and downstream Sandy Beach Road crossing and shown in Figure 14.

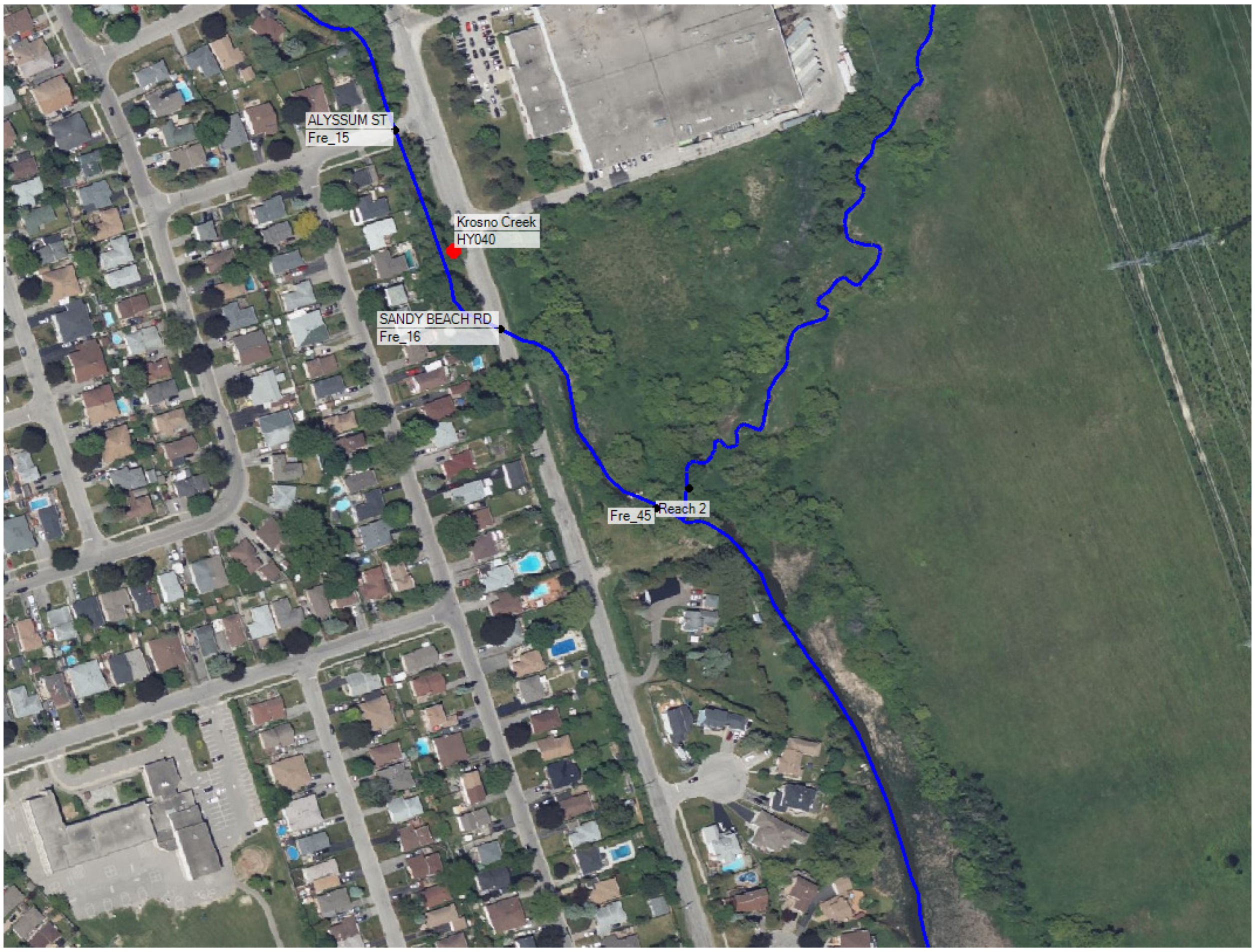


Figure 13 Krosno Creek Gauge Location

Figure 14A Looking Downstream to Structure FRE-16 Sandy Beach Road (Matrix 2023)

Figure 14B Structure FRE-16 Looking Upstream to Krosno Creek Gauge Location (Matrix 2023)

Figure 14C Krosno Creek Gauge Looking Downstream to Structure FRE-16 Sandy Beach Road (TRCA 2021)

Figure 14D Krosno Creek Gauge Looking Upstream to Structure FRE-15 Alyssum Street (TRCA 2021)

Figure 14 Krosno Creek Gauge Location and Sandy Beach Road Crossing Photographs

TRCA completed a survey of the gauge on April 13, 2021. The survey was taken as an assumed hydraulic control point downstream of the gauge closer to the Sandy Road Beach culvert crossing. The approximate location of the survey, as well as the gauge cross-section is shown on Figure 15. A comparison to the LiDAR shows the surveyed invert (75.377 m) is approximately 10 cm above the LiDAR invert, indicating there is no low flow channel not captured by LiDAR at this location.

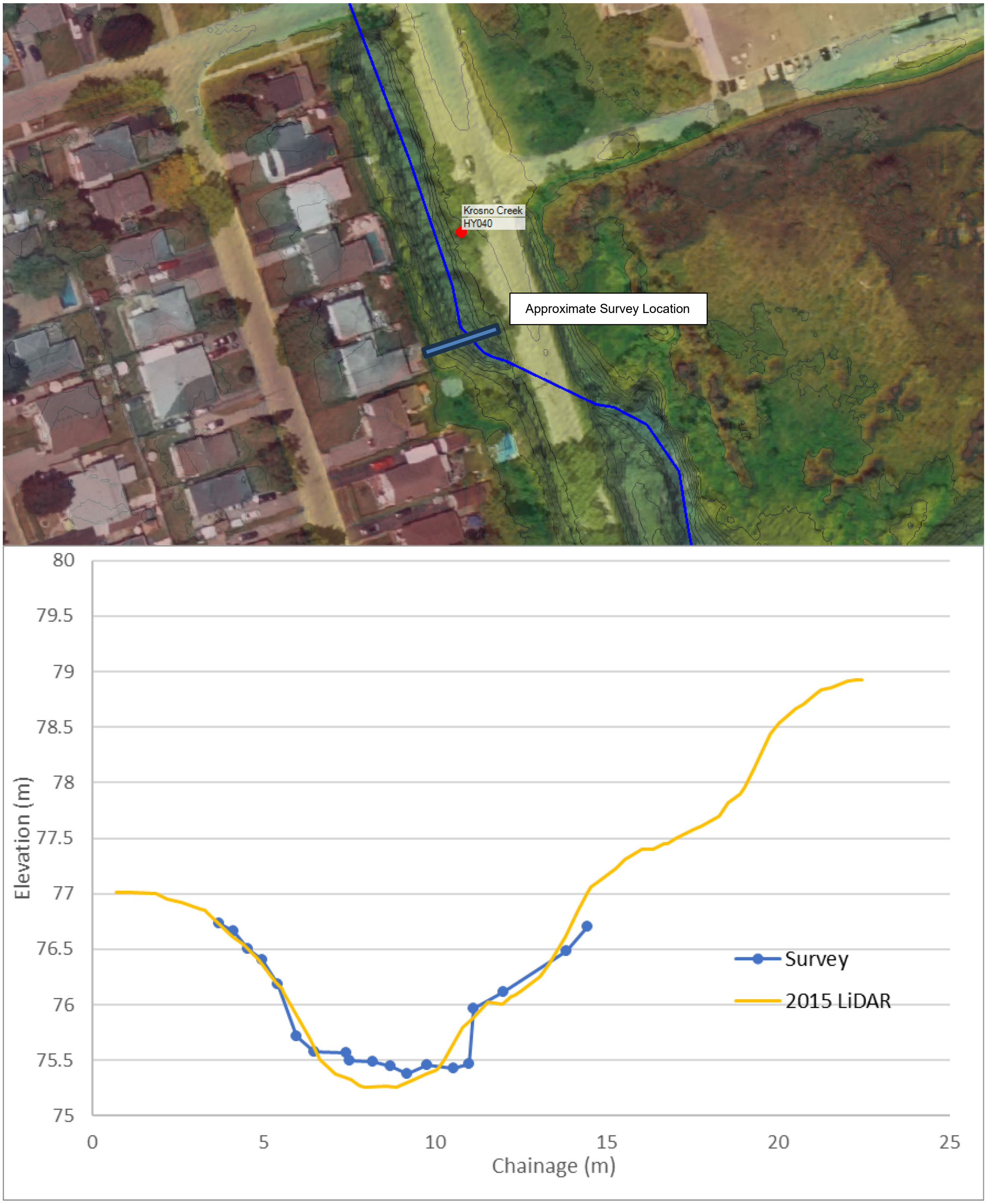


Figure 15 Krosno Creek Gauge Cross-Section and Approximate Survey Location

4.2 Existing Rating Curve

TRCA has developed a rating curve based on measured water levels and flows at the gauge location. The 14 observations available for rating curve development capture a relatively low range of flows, ranging from 0.004 to 0.88 m^3/s (water level elevation of 75.77 m). For reference, the highest recorded water surface elevation in the observed data is 77.66 m).

The most recent rating curve from TRCA was updated in 2021 to refine flows. The curve was developed for stages between 75.48 to 76.18 m, and used the equations shown below in Table 3. As shown in Figure 16, TRCA's curve was extended above the typical two times the highest measured observation, and caution should be used for flows above the highest observed data point.

Table 3 Existing Rating Curve Equations for Krosno Creek

Stage Range		Equation
75.480	75.556	$142.143 \times (Y-75.410)^{4.249}$
75.556	75.580	$1133.472 \times (Y-75.410)^{5.328}$
75.580	75.780	$16.652 \times (Y-75.410)^{2.946}$
75.780	76.180	$16.651 \times (Y-75.410)^{2.946}$

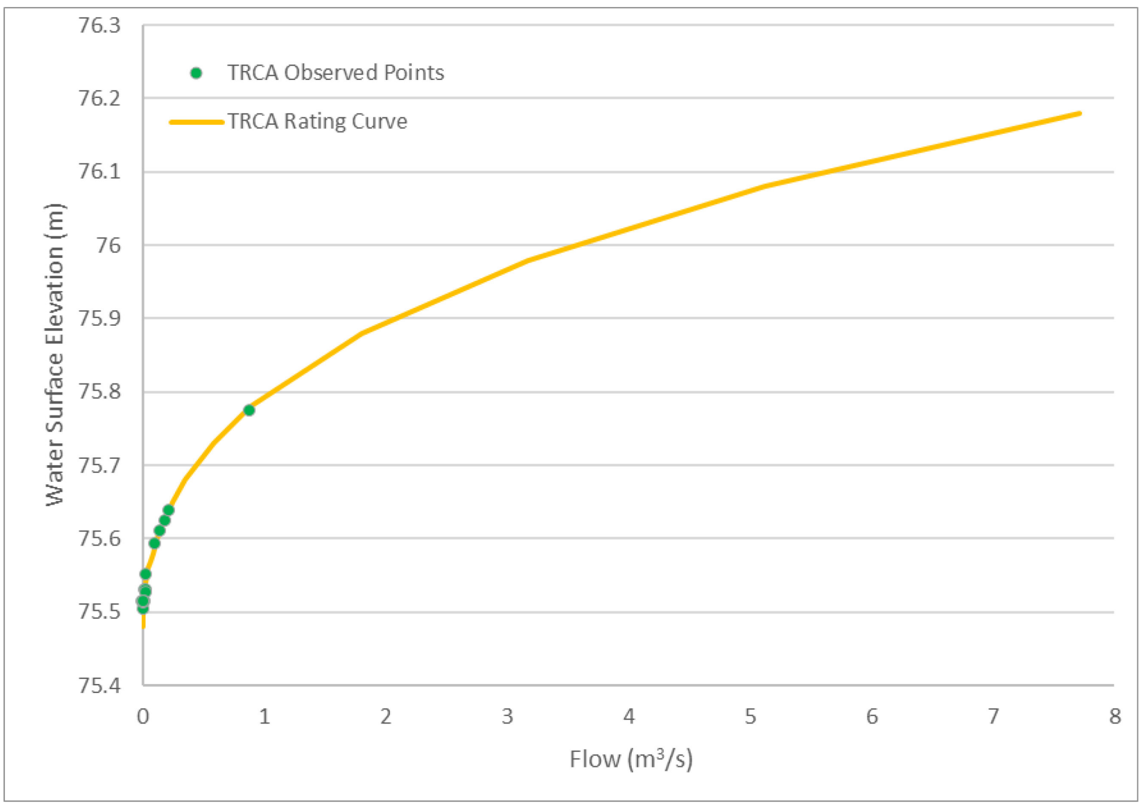


Figure 16 Krosno Creek Existing Rating Curve and Observed Data

4.3 Rating Curve Extension

4.3.1 Divided Channel Method

To apply the DCM, Matrix extended the gauge survey section by combining with the LiDAR in the floodplain. The cross-section was then split into three sections, left floodplain, channel and right floodplain. A single Manning's n was assumed for each segment, 0.035 for the channel, and 0.05 for the floodplain based on TRCA's standard Manning's for watercourses and urban pervious areas. The 1D hydraulic model and LiDAR indicated a slope of 0.7% between Alyssum Street and Sandy Beach Road. At the gauge location the LiDAR is flatter (approximately 0.2% in the area of the gauge). Given the uncertainty with the slope and presence of a low flow channel, a sensitivity was completed with varying channel slopes. Figure 17 shows the result of sensitivity analysis using a range of slopes between 0.1% and 1%.

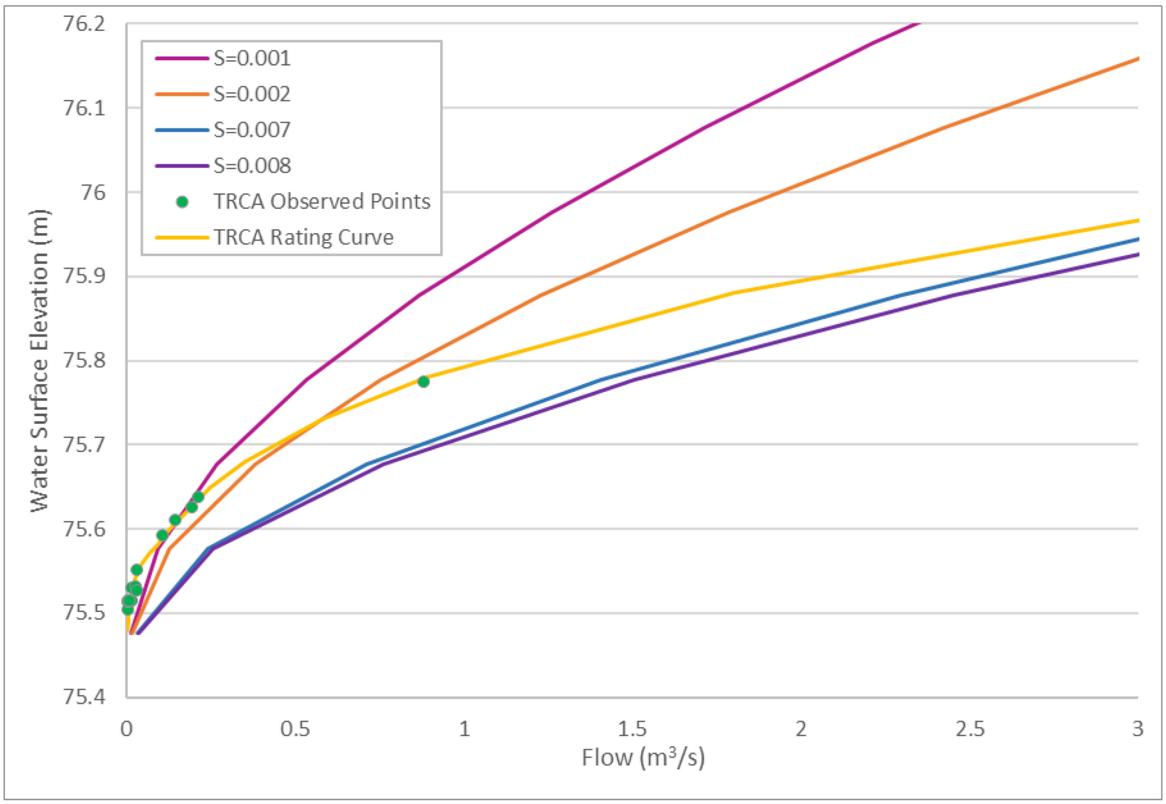


Figure 17 Krosno Creek Divided Channel Method Rating Curve

4.3.2 1D Hydraulic Model

TRCA updated Matrix's 1D hydraulic model with the survey data and provided a rating curve. The derived rating curve results were pulled from a cross-section upstream of the existing gauge (XS 2202). The resulting rating curve compared against the TRCA curve and observed points is shown on Figure 18.

The hydraulic assessment was evaluated using a lake level of 74.8 m. A sensitivity analysis confirmed that a higher lake level of 75.7 m has minor impacts in low flow water levels at the gauge location. A lake level of 76.2 m does impact the rating curve, specifically the low flow and moderate flows.

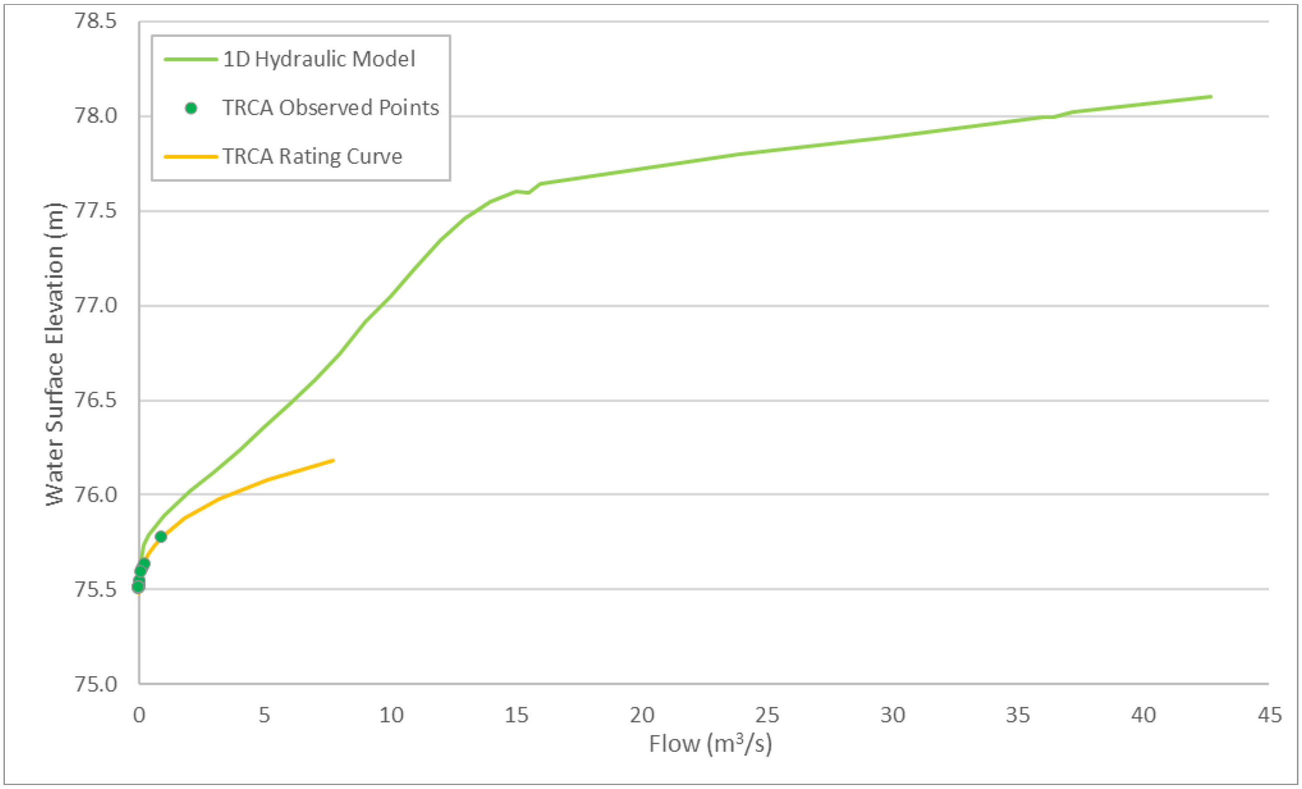


Figure 18 Krosno Creek 1D Hydraulic Model Rating Curve Comparison

4.3.3 2D Model

As high flows are known to spill over Sandy Beach Road and do not follow a single flow path, a 2D model was considered appropriate for high flow rating curve extension at this location. TRCA developed a 1D-2D MIKE FLOOD model of Krosno Creek to represent the gauge location and upstream and downstream structures that may affect flows. Details of the model development are provided in Appendix A. The resulting rating curve from the 1D-2D model are shown below in Figure 19.

The 2D rating curve is looped as the input requires a hydrograph as opposed to steady state flows. Higher water levels are found on the falling limb of the hydrograph for a given flow. The differences in the looped curves are minimal above 15 m^3/s. From discussion with the TRCA, it was decided to consider the lower curve (rising limb) of the hydrograph resulting in the higher flow. The rising limb agrees best with both the observed water levels and the 1D model (see next section), as well as provides a more conservative flow estimate.

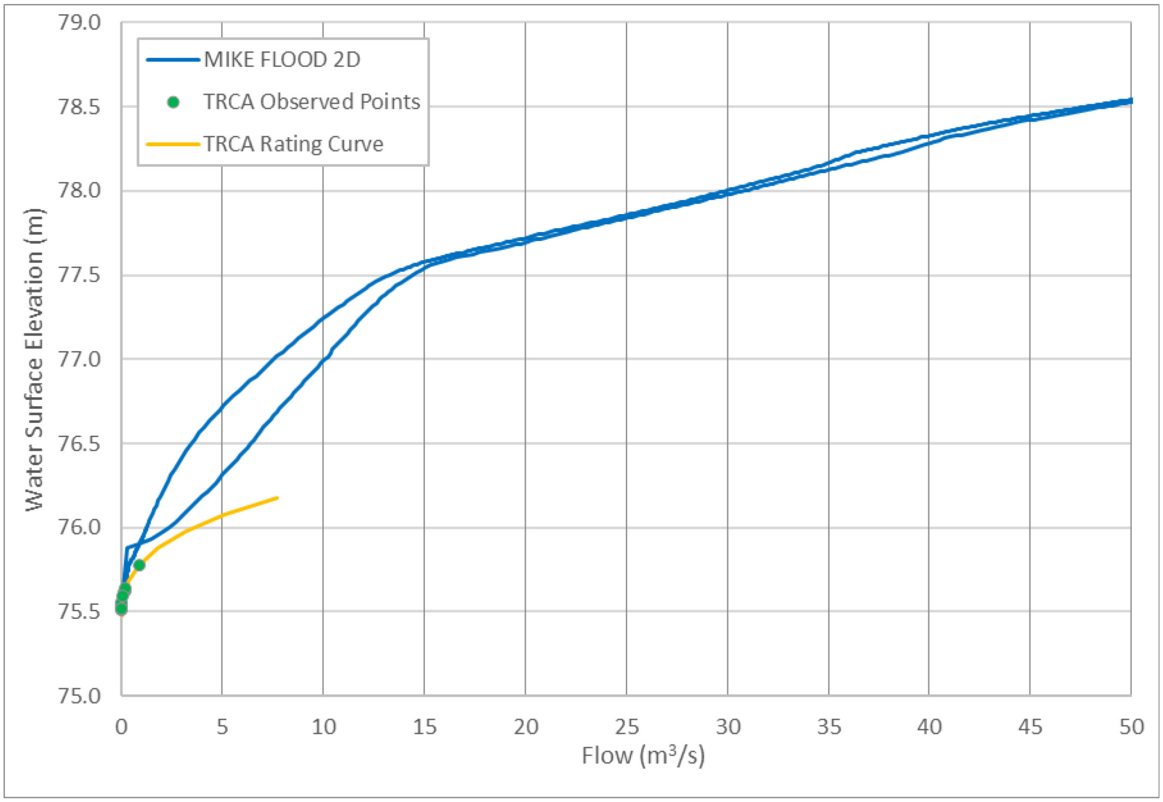


Figure 19 Krosno Creek 2D MIKE FLOOD Model Rating Curve

4.4 Recommended Rating Curve

A comparison both the DCM, 1D and 2D rating curve extensions are shown in Figure 20. The 1D and DCM curves produce similar curves up to an elevation of 76.7 m, which aligns to elevation of when the downstream culvert is almost full. The 1D model and the rising limb of the 2D model are similar until 75.75 m, where they start to diverge under overtopping conditions. The 2D model will more accurately represent overtopping conditions as the flow paths are complex. Note that the 2D model has a looped rating curve.

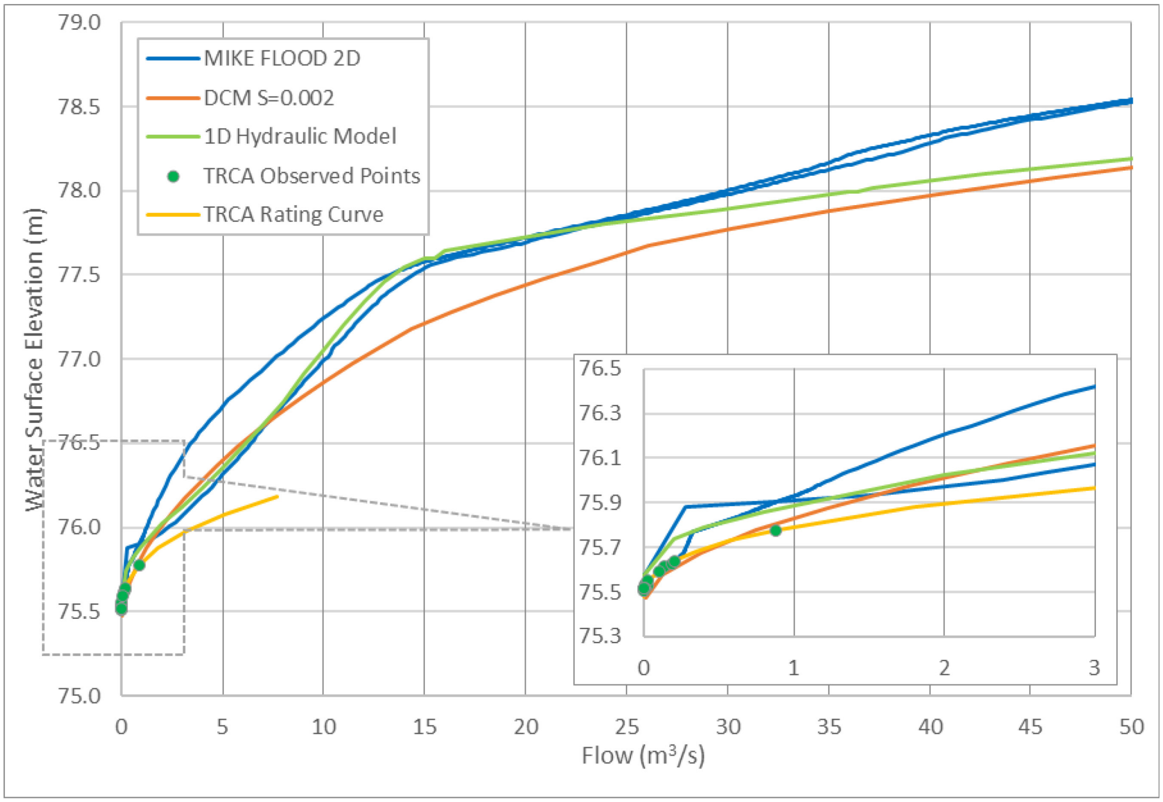


Figure 20 Krosno Creek Rating Curve Extension Comparison

The 2D model is believed to represent the hydraulic conditions of the creek most accurately, particularly the overtopping conditions once water levels exceed 75.75 m. Therefore, it was determined that the results from the 2D model should be used for the rating curve extension. The resulting rating curve, based on equations, is shown below in Figure 21. Table 4 lists the equations and water surface elevations for which the equations are valid.

Table 4 Proposed Rating Curve Equations for Krosno Creek

Stage Range		Equation	Notes
75.48	75.556	$142.143 \times (Y-75.410)^{4.249}$	TRCA Existing
75.556	75.58	$1133.472 \times (Y-75.410)^{5.328}$	TRCA Existing
75.58	75.64	$16.652 \times (Y-75.410)^{2.946}$	TRCA Existing
75.64	75.88	$11.58795x^2 - 1{,}753.42377x + 66{,}329.78549$	TRCA MIKE 1D-2D
75.88	77.56	$3.851600x^3 - 886.167140x^2 + 67{,}968.706577x - 1{,}737{,}877.921725$	TRCA MIKE 1D-2D
77.56	78.56	$3.4091x^2 - 497.2781x + 18{,}077.2609$	TRCA MIKE 1D-2D

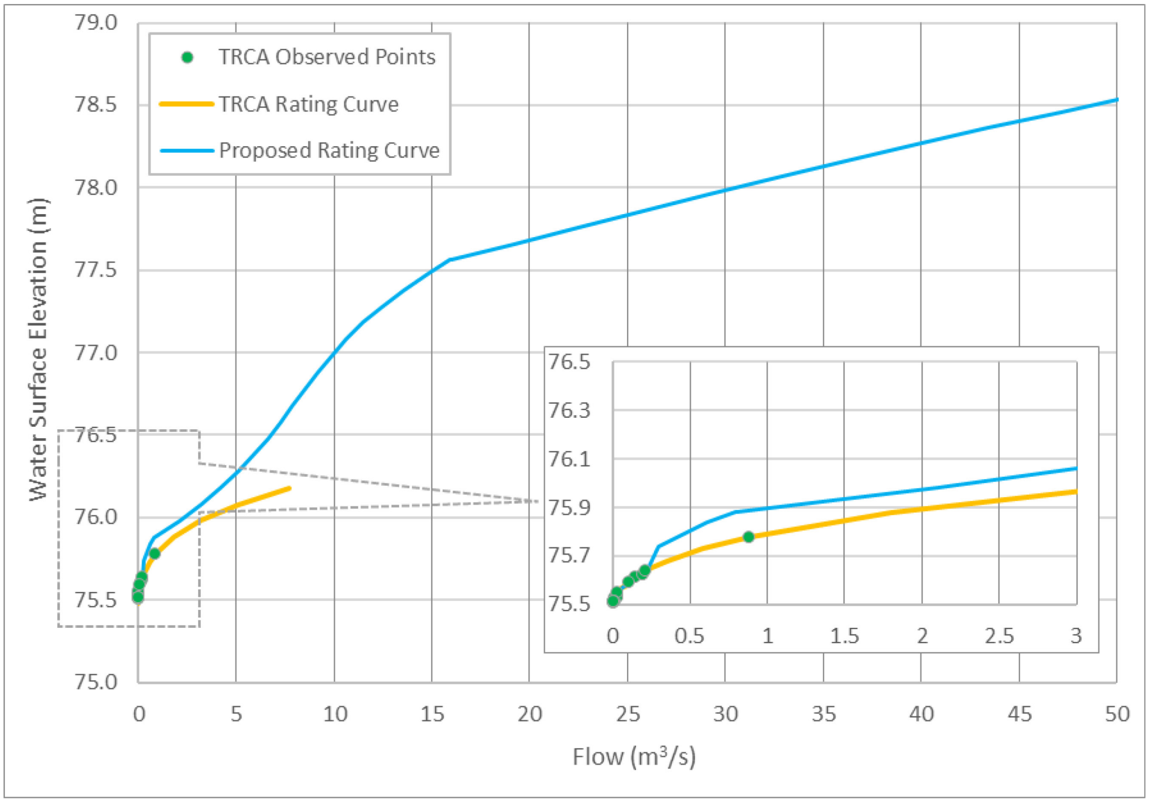


Figure 21 Krosno Creek Proposed Rating Curve Extension

4.5 Derived Flows

Water level data was provided by TRCA for the Krosno Creek gauge between December 3, 2000, and September 30, 2023. Prior to 2012, the data was provided in 1-hour increments, where post-2012, the data was provided in 15-minute increments. Maximum daily derived flows for the existing TRCA rating curve and the Matrix derived rating curve are provided on Figure 22. The Matrix rating curve generally reduces the flow estimates (e.g., July 25, 2009, previous estimated peak flow was 16.83 m^3/s and new estimated peak flow is 12.85 m^3/s). Post-2012, the extended rating curve provides estimates of peak flows for events that were not previously estimated, and shows some reduction in peak flow estimates compared to what previously estimated.

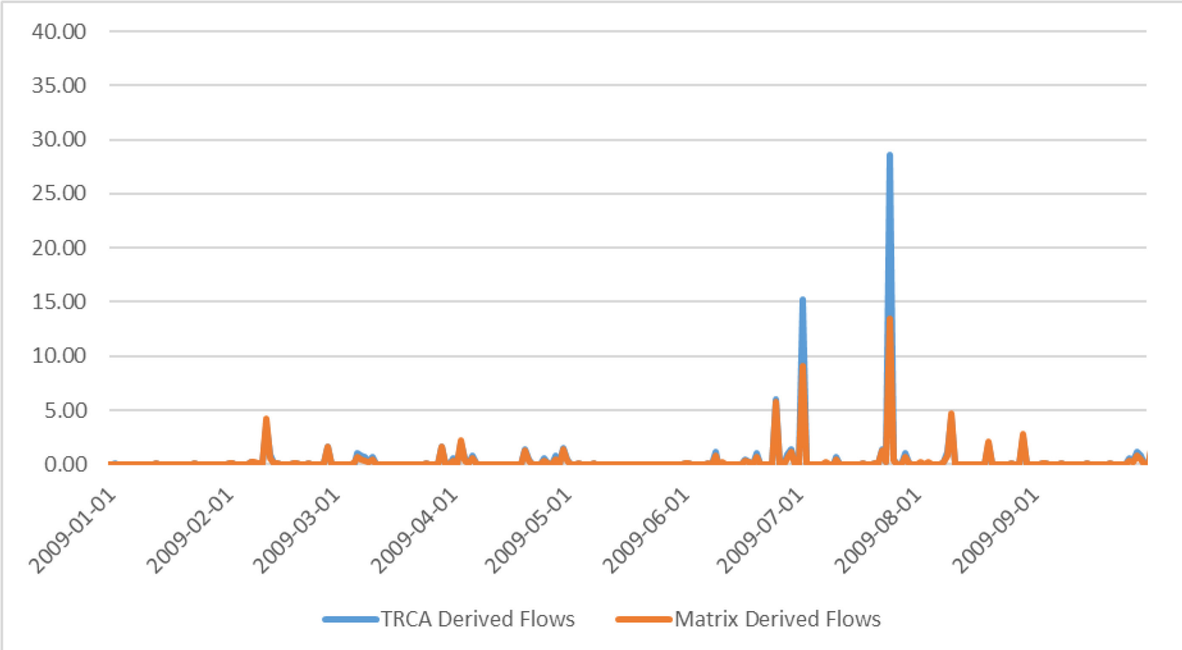


Figure 22 Daily Maximum Derived Flow Comparison for Krosno Creek (2009)

Table 5 shows a comparison of rainfall/runoff volumes for several events pre-2012. The analysis was completed to determine the reasonableness of the derived flows. For context, the total impervious area of the Krosno Creek watershed upstream of the gauging location is 67.8%. The results show that the previous TRCA rating curve in some instances estimate runoff volume is in excess of the rainfall that is estimated to have occurred within the watershed (runoff greater than 100%). The analysis would indicate that the Matrix derived rating curve is providing more reasonable estimate of flows for the Krosno gauging location.

Table 5 Rainfall/Runoff Analysis Comparison – Krosno Creek

Event Date	Matrix Rating Curve (Event Volume – m^3)	TRCA Rating Curve (Event Volume – m^3)	Rainfall (m^3)	Runoff as a % of Matrix Rating Curve	Runoff as a % of TRCA Rating Curve
2012-09-04	72,650	99,690	156,506	46	64
2011-08-21	36,570	68,540	83,401	44	82
2011-08-09	29,290	36,640	90,705	32	40
2010-07-23	76,030	97,620	142,641	53	68
2010-07-09	54,290	59,490	110,532	49	54
2009-07-25	83,790	139,700	124,850	67	112
2009-07-02	73,200	97,460	94,047	78	104
2005-08-19	150,200	282,500	263,022	57	107

5 SUMMARY AND RECOMMENDATIONS

Matrix completed an investigation into extending rating curves for gauging stations on Pine Creek and Krosno Creek in Frenchman's Bay. Several methods were reviewed to determine the most suitable rating curve based on the provided data and localized conditions:

- For Pine Creek, two methods were reviewed: the DCM and a 1D hydraulic model. The DCM involved segmenting the channel and floodplain, determining Manning's n for each, and combining the curves. The 1D model refined the existing model, considering structures and road embankments. The recommended approach was the 1D hydraulic model, producing a reliable rating curve extension.

- For Krosno Creek, the DCM and 1D hydraulic model were reviewed, along with a 2D model due to complex flow paths. The 2D model was deemed the most suitable method to extend the rating curve as there is overtopping conditions on Sandy Beach Road.

Both rating curves were compared with existing TRCA curves, indicating a reduction in flow estimates, particularly in flows reported prior to 2012.

5.1 Recommendations

Several recommendations were identified during the review and development of the extended rating curves:

- Survey data should be collected at each gauging location where rating curve extension is desired. The survey should include a cross-section directly at the gauging location, as well as at any hydraulic controls downstream. Channel profile surveys should also be completed to confirm the friction slope.

- The DCM method can be used to extend rating curve in locations where water levels are not affected by structures, embankments, or constrictions downstream (i.e., normal flow conditions). In general, we would recommend a comparison of the DCM method to the result of a simple 1D hydraulic model to determine the DCM validity.

- Increasing the gauging frequency to a minimum of 15-minutes, in areas that are highly urbanized; it is recommended that the recording frequency be increased to 5-minute intervals.

- Strive to obtain flow and water level measurements during high flow events.

6 CLOSURE

We trust that this letter report suits your present requirements. If you have any questions or comments, please call either of the undersigned at 519.772.3777.

Yours truly,

MATRIX SOLUTIONS INC.
A Montrose Environmental Company

Natalie Burrows, M.A.Sc., P.Eng.
Water Resources Engineer

Reviewed by

Karen Hofbauer, M.A.Sc., P.Eng.
Principal Water Resources Engineer

NB/pg
Attachments

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VERSION CONTROL

Version	Date	Issue Type	Filename	Description
V0.1	12-Jan-2024	Draft	35765-531 Rating Curve Memo LR 2024-01-12 draft V0.1.docx	Issued to client for review
V1.0	26-Feb-2024	Final	35765-531 Rating Curve Memo LR 2024-02-26 final v1.0.docx	Issued to client

REFERENCES

Matrix Solutions Inc., A Montrose Environmental Company (Matrix). 2024. “Frenchman’s Bay Watershed Hydraulic Model Update.” Version 0.1. Draft prepared for Toronto Region Conservation Authority. Guelph, Ontario. January 2024.

Ramsbottom D.M. and C.D. Whitlow. 2003. *Extension of Rating Curves at Gauging Stations Best Practice Guidance Manual*. R&D Manual W6-061/M. Bristol, United Kingdom. October 2003.

Technical Memo

To: Amanda McKay, P.Eng. (Matrix Solutions Inc.)
From: Christina Bright, M.A.Sc., P.Eng. (TRCA FRM); Qiao Ying, M.Sc., P.Eng.(TRCA FRM)
Cc: Ziyang Zhang, M.Sc., P.Eng.(TRCA FRM)
Date: January 29, 2024
Re: Frenchman's Bay: Krosno Creek Rating Curve Extension – Integrated 1D-2D MIKE Flood Model Development & Results

INTRODUCTION

As part of the rating curve extension for the Krosno Creek gauge at Sandy Beach Road, an integrated one and two-dimensional (1D-2D) modelling exercise was undertaken. There are two other methods that were investigated for the rating curve extension: Divided Channel Method (DCM) and a purely one-dimensional method using HEC-RAS. This memo only deals with the integrated 1D-2D modelling exercise, and summarizes the key points concerning model development, i.e., the set-up of the MIKE Flood model as well as the resulting rating curve.

The study area was modelled using the MIKE Flood interface that features the dynamic coupling of the MIKE HYDRO and MIKE 21 hydrodynamic modules. River reaches and all crossings were handled using the 1D MIKE HYDRO modelling routine, with overland surfaces being modelled using the 2D MIKE 21 modelling routine. MIKE Flood integrates these two models into a single dynamically coupled model.

Figure 1 shows the model domain of the 1D-2D Krosno Creek MIKE Flood Model. A section of Krosno Creek Reach 3 (as named in the HEC-RAS model) was modelled in MIKE Flood with the upstream boundary located approximately 90 m south of Bayly Street, and the downstream boundary located approximately 50 m upstream of its confluence with Krosno Creek Trib 2. The extent of the model domain (shown in a yellow polygon in *Figure 1*)was chosen based on expected flood extents using the previous Regional floodline as a guide. Model domain refinements were made throughout the modelling process to cut down on the excessive areas which were shown to remain dry. The goal was to minimize unnecessary computation while maintaining a sufficient buffer from the expected floodline extents.

Also shown in *Figure 1* is the location of the TRCA gauge HY040 – Krosno Creek at Sandy Beach Road, the gauge for which this extension project is updated.

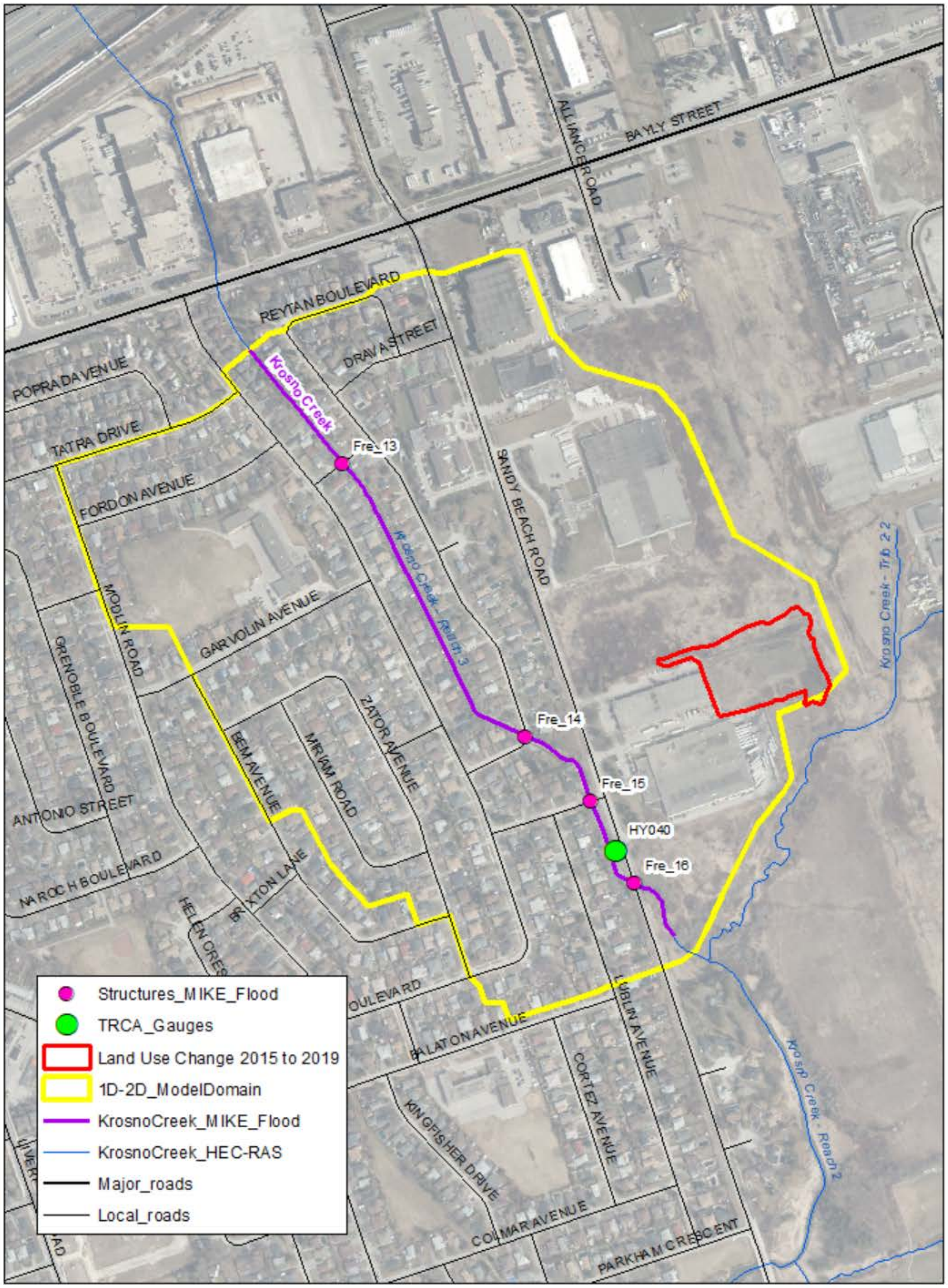

Figure 1: Model Domain of the 1D-2D Krosno Creek MIKE Flood Model

MIKE HYDRO 1D MODEL

The part of the main branch of the Krosno Creek was the only reach modelled using the MIKE HYDRO 1D hydrodynamic (HD) module. Cross sections were cut in about a 10 to 15 m spacing (see *Figure 2*) using 2015 Lidar with 2019 Lidar data spliced in within areas of landuse change. These cross sections only cover the main channel, i.e., up to the top of bank as overbank areas are modelled in 2D domain. High density of spacing of cross-sections allows better capturing details of riverbanks where lateral exchange flows with 2D domain occur.

Figure 2: Layout of MIKE Hydro cross-sections and boundary conditions

Crossings

The model includes 4 road crossings (FRE_013, FRE_014, FRE_015, and FRE_016) whose locations are shown in *Figure 1*. All crossings except for FRE_016, are corrugated metal pipe-arch culverts. FRE_016 is coded as a concrete rectangular culvert. The culvert details were obtained from the structure inventory conducted by Matrix Solutions Inc. For each crossing coded, a corresponding weir was also coded (examples shown in *Figure 3*).

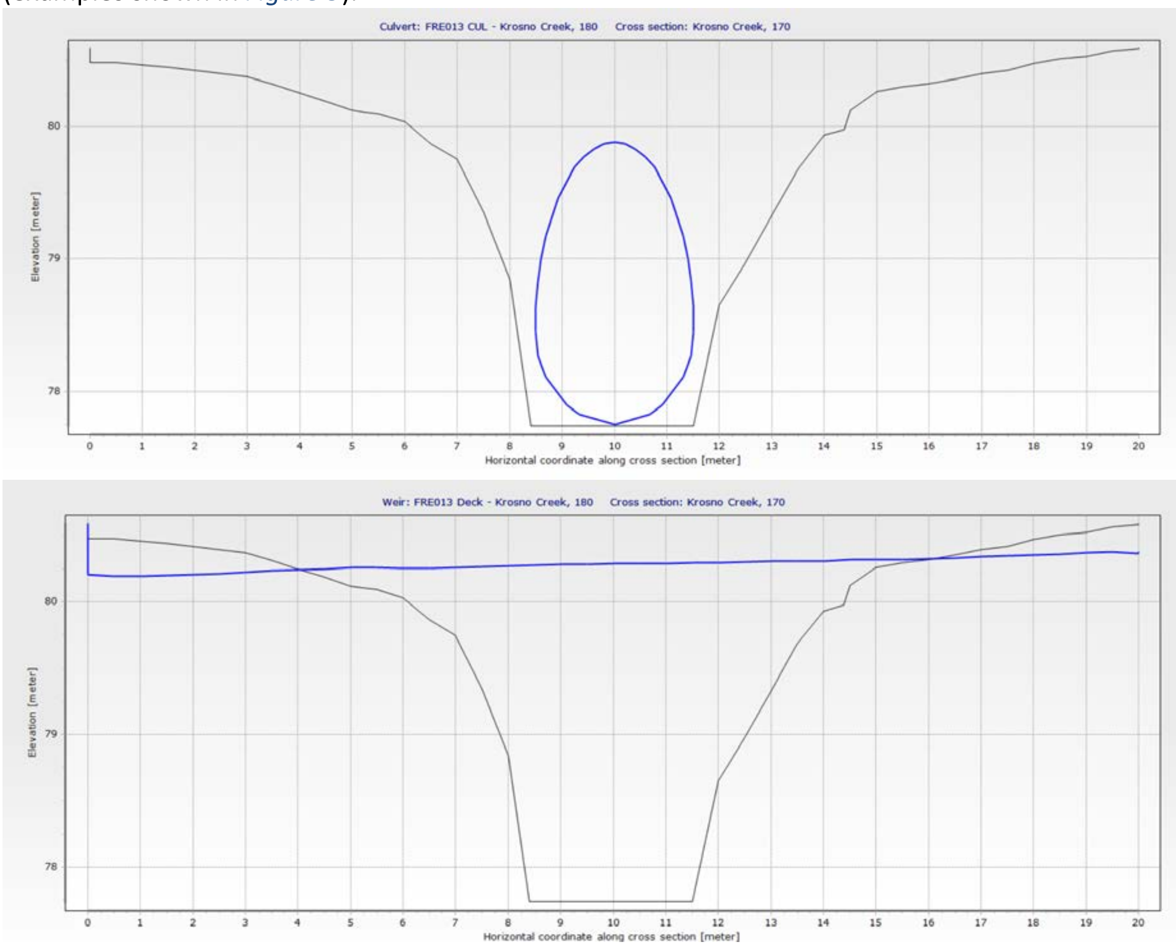

Figure 3: Example of a culvert and weir coded in MIKE Hydro

Boundary Conditions

All inflows are included in the 1D model. There are two points of inflows, one at the top of the reach and the other closer to the end of the reach coded as a point source. Both of these flows are based on the total flow that is larger than the Regional flow for this reach, i.e., 46.92 m^3/s, as per existing HEC-RAS model. The peak flow at the input of the reach used is 55.6 m^3/s, and the peak flow at the node closer to the end of the modelled reach is 2.3 m^3/s based on the additional flow change node within the updated HEC-RAS model at this location.

In additional to flow inputs, a downstream boundary condition was also coded in the model as a Q/h relation (see *Table 1*) extracted from an updated version of the new HEC-RAS model refined to include multiple flow profiles to aid in the rating curve extension. All three boundary conditions are shown in *Figure 2*.

Table 1: Q/h Relation for Downstream Boundary Condition

h	Q	h	Q
74	0	76.95	12
74.46	0	77.03	13
75.76	1	77.1	14
75.82	2	77.15	15
75.9	3	77.21	16
76	4	77.38	25.2
76.1	5	77.51	31.7
76.22	6	77.73	38.9
76.35	7	77.74	39.1
76.51	8	77.83	39.8
76.64	9	77.98	45.9
76.77	10	78.09	53.9
76.86	11		

MIKE 21 2D OVERLAND MODEL

The overland area was modelled using MIKE 21 Flexible Mesh (FM) HD, which is a fully dynamic modelling system for 2D free-surface flows. The MIKE 21 editors were used to constructure and store various basic and hydrodynamic data layers. The following are the main elements of the MIKE 21 model setup:

- Mesh Generation
- Roughness parameters
- Boundary conditions
- Model settings

Mesh Generation

MIKE 21 FM model uses a mesh-based bathymetry for hydrodynamic computations. The details and the desired accuracy of the model results depend on how the mesh has been designed. In addition, the mesh resolution has a significant impact on the accuracy of the results. A high-resolution mesh is required to retain higher variability of the ground elevation surface. High resolution also required to represent in detail topographic features (such as channels, buildings, paved roads, walkways, retaining walls, flood walls, etc.). As such, the mesh was designed as follows:

- A high-resolution mesh size of 10 m^2 was used along the roads as floodwater tends to follow the roads
- A high-resolution mesh size of 16 m^2 was used in the potential flood extent
- A mesh size of 50 m^2 was used in the rest of the model area

The building polygons were excluded from the mesh generation to avoid computational mesh triangulation from occurring within these polygons. River reaches covered by cross sections were also excluded from the mesh to avoid double accounting for the conveyance, and finally 1m LiDAR data was interpolated to each mesh node (see *Figure 4*).

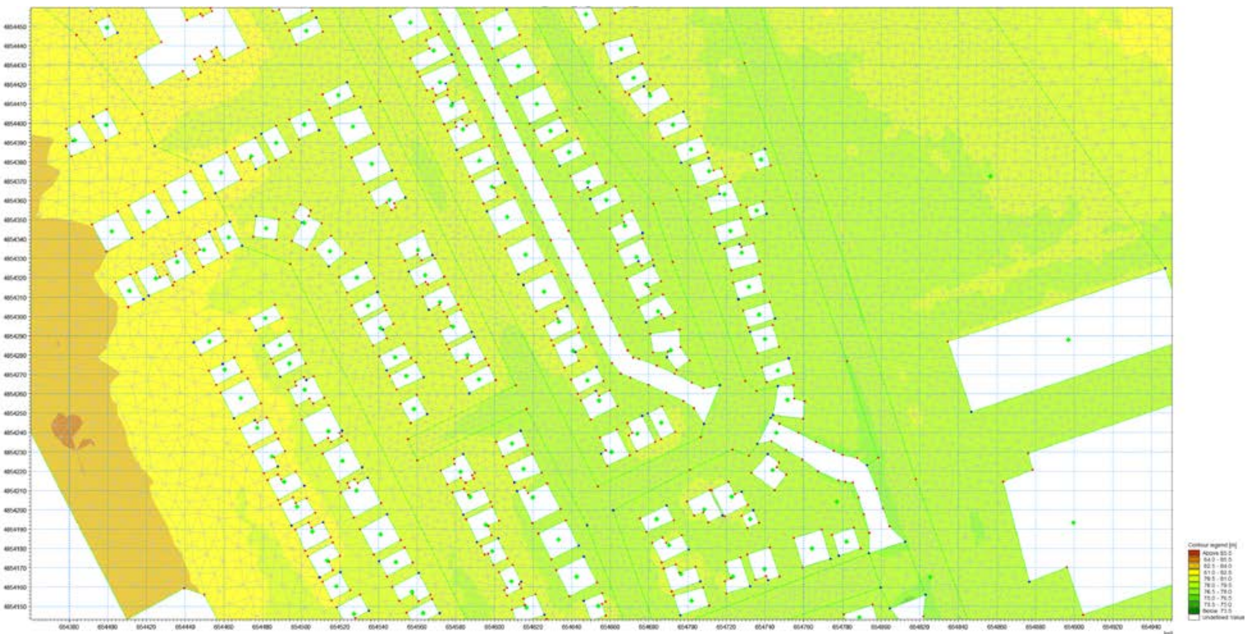

Figure 4: Close up view of mesh showing a diversity of mesh sizes

Roughness Parameters

MIKE 21 uses roughness parameters for each mesh when completing computations. The land use map (see *Figure 5*) prepared using the TRCA's available land use/land cover information was converted in a MIKE 21 roughness map. In MIKE 21, the roughness was designed in terms of MIKE system's Manning's resistance number (M) which is the inverse of the Manning's n roughness coefficient values (i.e., 1/n). The Manning's resistance number (M-value) map was prepared based on the TRCA's standard roughness values; the corresponding Resistance numbers used in MIKE 21 are:

- Natural areas: 0.08 (M = 12.5)
- Roads and large parking area: 0.025 (M = 40)
- Urban larger pervious areas: 0.05 (M = 20)
- Streams/Waterbodies: 0.035 (M = 28.57)

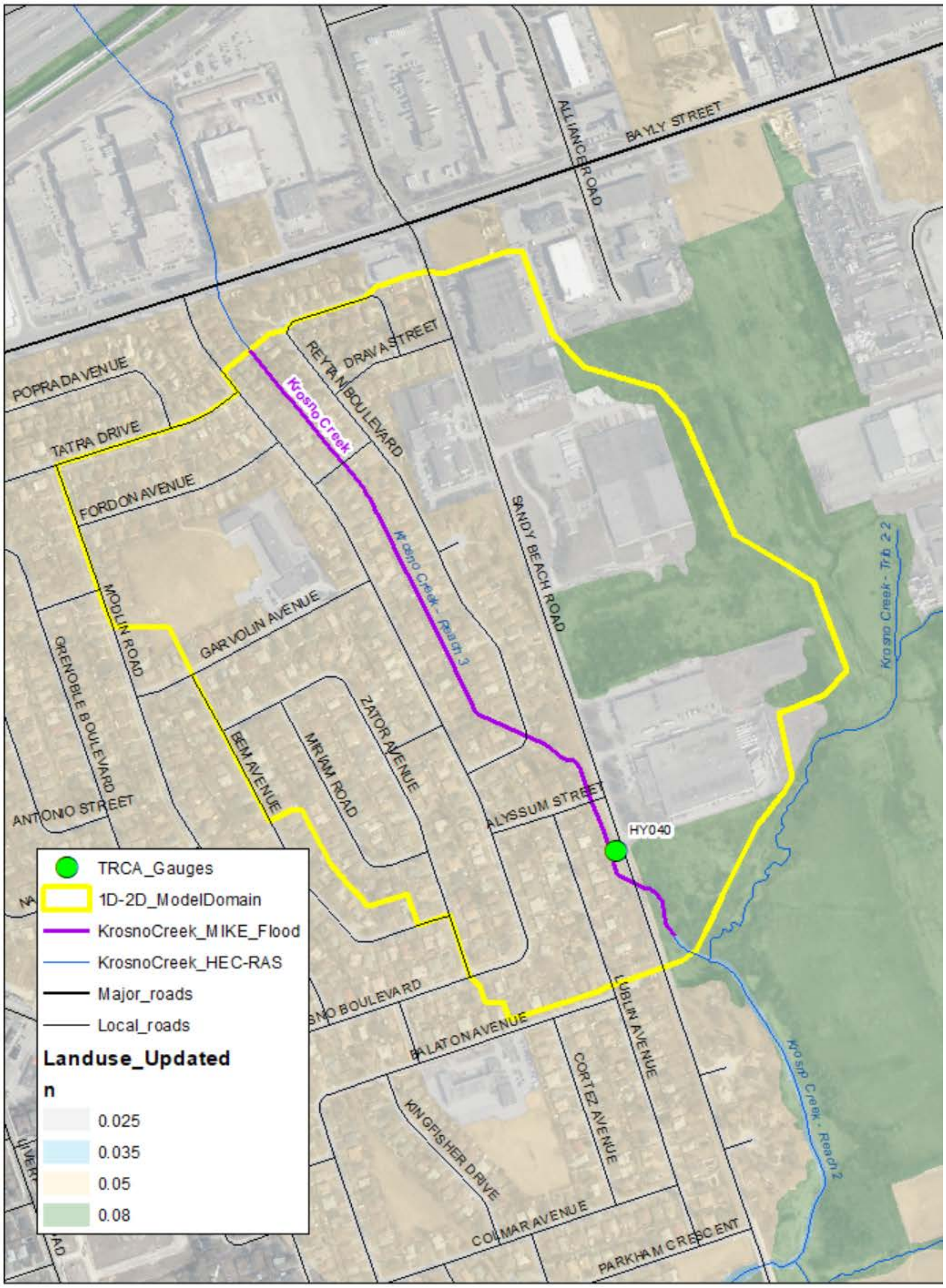

Figure 5: Landuse map used for the Krono Creek MIKE model

Boundary Conditions

Boundary conditions for the MIKE 21 model define how the flow and water levels will be controlled at the peripheral edges of the 2D model domain defined by the bathymetry limits. Since all inflows were handled in 1D model, there are no inflow boundaries defined in 2D model. Also, the outflows on the river reach were handled in 1D model using Q/h relationship, so the only downstream boundary defined in 2D model is at the location of low points in the terrain draining to the tributary Krosno Creek – Trib 2-2 which was modelled in HEC-RAS, but not in MIKE Flood. The boundary is shown in red in *Figure 6* and is defined as a Free outflow boundary which allows the floodwater to leave the system without piling up along the edge of 2D domain.

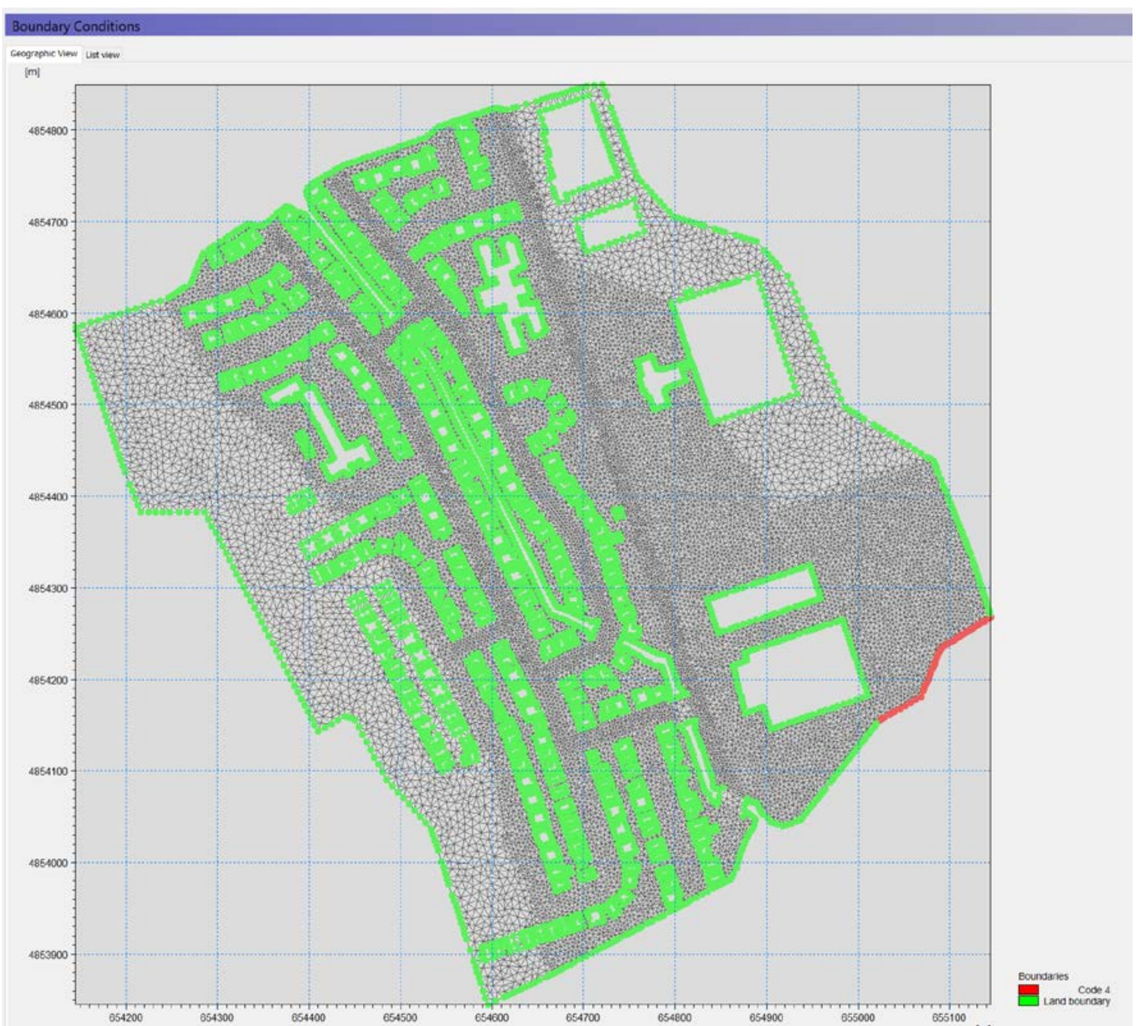

Figure 6: Free outflow boundary defined at the 2D model domain

Model Settings

The MIKE 21 FM Flow Model setup contains descriptions of several parameters. The key parameters are simulation period, start and end time, time step interval, flooding and drying depths, output saving duration and saving interval details.

A 9-hour 45-minute simulation period was used for the steady peak inflow hydrograph simulation. The simulation period was entered using an arbitrary start date (October 1, 2023), end date, time with a specified total number of time steps, and time step interval. In this case, the total number of time steps was 175,500 with a time step interval of 0.2 seconds.

The drying and flooding depths used were 0.01m and 0.02m, respectively.

The dynamic outputs were saved with a time interval of 600 (i.e., 2 min interval). The saving output variables were surface elevation, total water depth, U velocity (x-direction), V velocity (y-direction), and current speed. The dynamic output file type used was "2D (horizontal)" while the output format was selected as "Area Series" with only real wet areas that ensures the saving of specified information at every computational point.

1D and 2D COUPLED MODEL

The final step for model setup was the integration of the 1D MIKE HYDRO model with the 2D MIKE 21 model using the MIKE Flood model interface. Lateral links were used to connect the branches in the 1D MIKE HYDRO model with the corresponding mesh elements of the 2D MIKE 21 model. A lateral link enables the coupling of the models at the left and right banks of the 1D channel with the 2D area.

Figure 7 shows the bathymetry of 1D and 2D coupled model, where the building areas are represented (blocked white cells) and the lateral link lines between the 1D and 2D models is shown as a series of red lines.

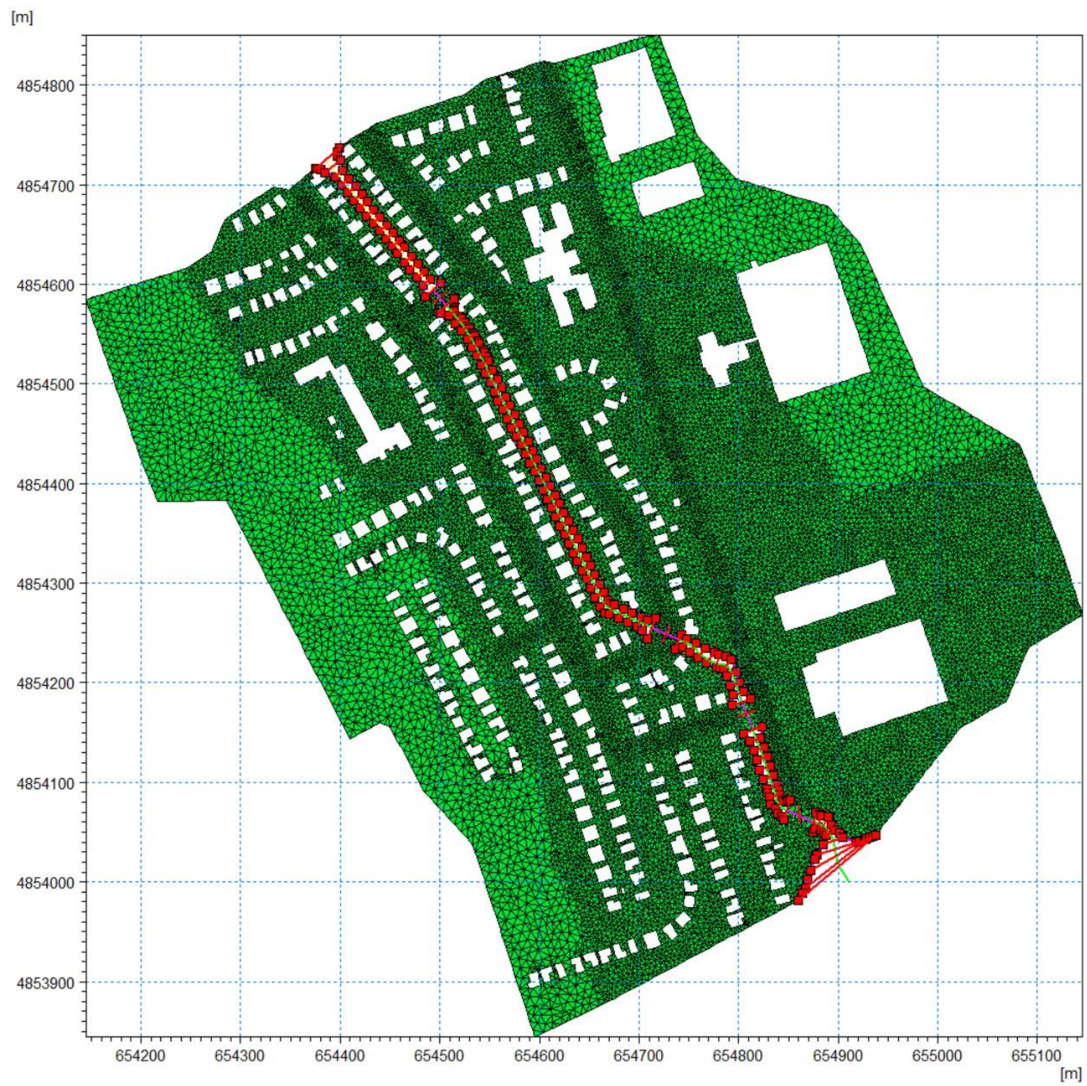

Figure 7: Lateral links used to connect 1D branch to 2D area

RESULTS

Based on the 1D-2D MIKE Flood model simulations, modelled discharge results were extracted at a cross section closest to the location at which the rating curve for the gauge HY040 was developed. The discharge extraction cross section as well as the maximum flood depth results are shown in *Figure 8*. This extraction cross section spans both the channel modelled in 1D as well as the adjoining floodplain modelled in 2D. The resulting discharge hydrograph is shown in *Figure 9*.

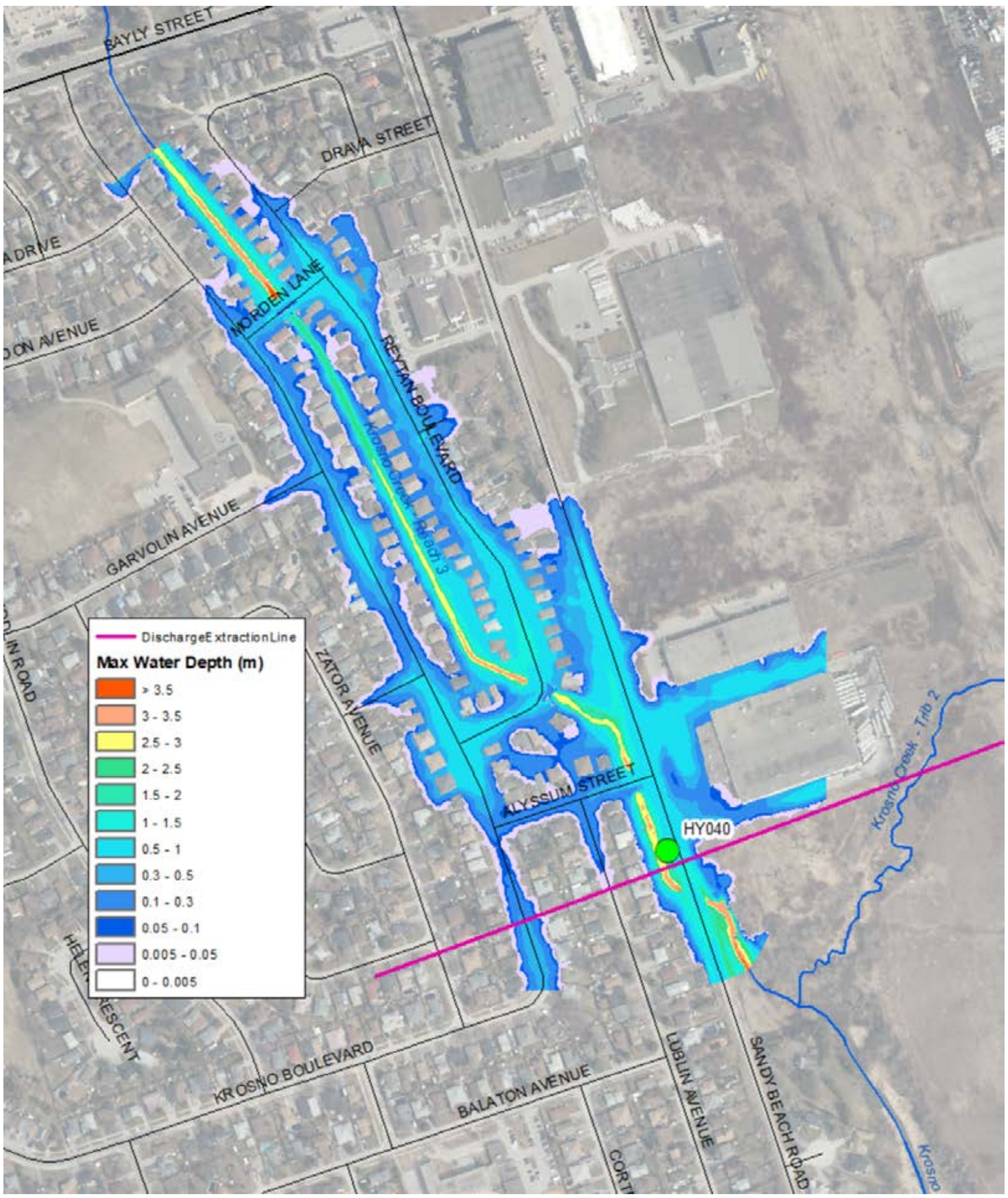

Figure 8: Depth results map showing the location of discharge extraction

Shown in *Figure 9*, are the TRCA rating curve (established by field measure stage-discharge readings) and the MIKE Flood derived rating curve. Due to field safety limitations, the TRCA field measured readings did not surpass the stage elevation of 75.775m which corresponds to a discharge of 0.88 m^3/s. The MIKE Flood model simulated stages corresponding to the larger discharges as high as 51.3 m^3/s. It is interesting to note the hysteresis effect on the modelled discharge which for most part, shows two distinct stage values for each discharge value. This phenomenon is a result of the backwater effect of the hydraulic constraint posed by the culvert at Sandy Beach Road. The road is located less than 50 m downstream of the gauge and the control cross section for the rating curve establishment.

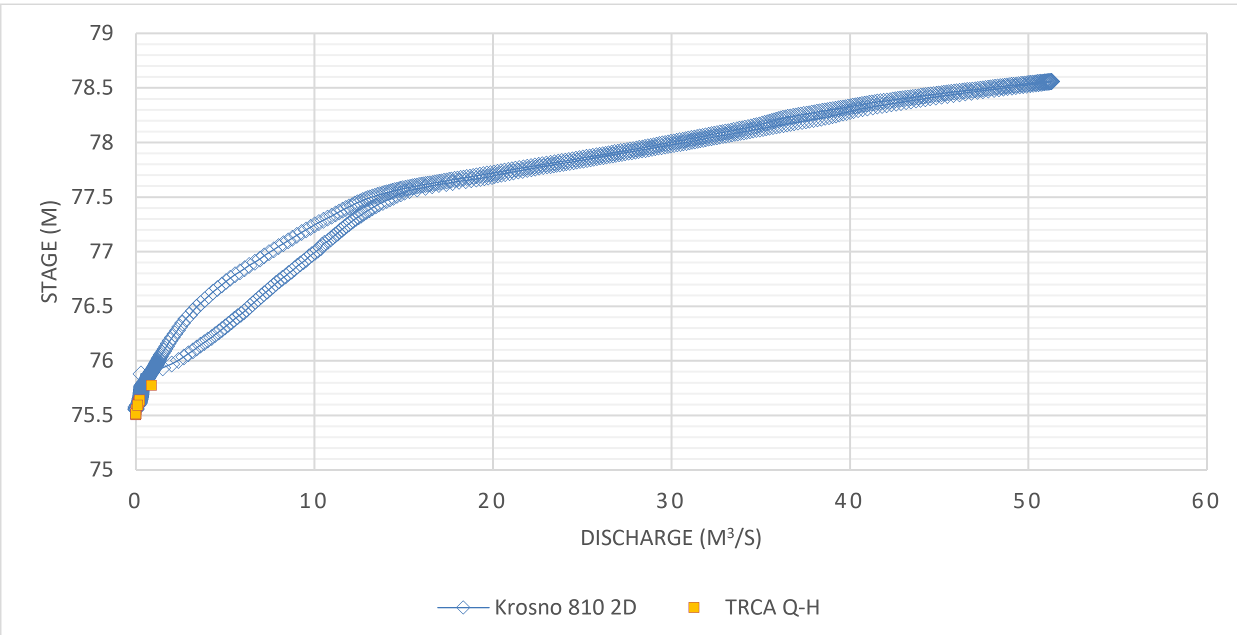

Figure 9: Rating Curve (TRCA and MIKE Flood derived)

These MIKE Flood discharge results may be used to extend the TRCA rating curve. It is recommended that the higher discharge values associated with a given stage value, i.e., values associated with the rising limb of the curve be used. These results should also be used in conjunction with the results of the other two methods being investigated (DCM and 1D HECRAS) to make the final determination of the extended rating curve.

APPENDIX D
Calibrated Hydrologic Model Values

Table D1: Calibrated Subbasin Hydrologic Parameters

Name	X-Coordinate	Y-Coordinate	Tag	Rain Gage	Outlet	Area (ha)	Width (m)	Flow Length (m)	Slope (%)	Imperv. (%)	N Imperv	N Perv	Dstore Imperv (mm)	Dstore Perv (mm)	Zero Imperv (%)	Subarea Routing	Percent Routed (%)	Suction Head (mm)	Conductivity (mm/hour)	Initial Deficit (frac.)
FB001	650273	4854912	Amberlea	HY102	J22	7.70	251	307	1.22	61	0.011	0.15	1	5	25	PERVIOUS	51	89	3.3	0.35
FB002	652300	4853927	Amberlea	HY102	J1106.4	4.05	172	235	1.36	50	0.011	0.28	1	7	25	PERVIOUS	11	201	2.8	0.30
FB003	651678	4853859	Amberlea	HY102	J1443	8.55	266	321	4.50	59	0.011	0.20	1	6	25	PERVIOUS	35	102	4.6	0.36
FB004	652049	4853869	Amberlea	HY102	J1540	4.58	185	248	5.03	49	0.011	0.24	1	7	25	PERVIOUS	16	187	3.2	0.31
FB005	652592	4853792	Amberlea	HY102	J28	7.06	238	296	1.39	46	0.011	0.26	1	7	25	PERVIOUS	36	253	1.3	0.26
FB006	651500	4853676	Amberlea	HY102	J1308	8.85	272	326	2.07	81	0.011	0.15	1	5	25	PERVIOUS	12	109	5.4	0.37
FB007	651918	4854014	Amberlea	HY102	J1720	5.46	205	267	0.73	49	0.011	0.24	1	7	25	PERVIOUS	42	138	3.7	0.33
FB008	651910	4852995	Amberlea	HY102	J11	8.05	257	313	2.83	64	0.011	0.16	1	5	25	PERVIOUS	38	110	5.5	0.37
FB009	649511	4856010	Amberlea	HY102	J1	27.30	283	963	1.13	3	0.011	0.20	1	7	25	PERVIOUS	74	84	8.3	0.36
FB010	649736	4855562	Amberlea	HY102	J23	14.20	193	735	0.80	30	0.011	0.33	1	8	25	PERVIOUS	48	77	14.4	0.36
Fb011	650098	4855848	Amberlea	HY102	J301	22.07	250	882	1.30	5	0.011	0.51	1	11	25	PERVIOUS	38	89	3.3	0.35
FB012	651315	4853863	Amberlea	HY102	J9	3.23	151	214	0.93	45	0.011	0.31	1	7	25	PERVIOUS	39	101	4.6	0.36
FB013	650609	4855144	Amberlea	HY102	J21	75.04	956	785	0.91	61	0.011	0.16	1	5	25	PERVIOUS	46	92	3.7	0.35
FB014	651064	4854224	Amberlea	HY102	J698	33.76	597	566	2.82	59	0.011	0.16	1	5	25	PERVIOUS	52	110	5.4	0.37
FB015	651773	4853556	Amberlea	HY102	J1036	13.51	348	388	2.86	62	0.011	0.22	1	6	25	PERVIOUS	4	131	4.8	0.35
FB016	651962	4853539	Amberlea	HY102	J644	9.36	281	333	4.28	75	0.011	0.19	1	6	25	PERVIOUS	1	179	3.5	0.31
FB017	652034	4853433	Amberlea	HY102	J495.54	12.38	331	374	4.92	40	0.011	0.30	1	7	25	PERVIOUS	28	151	4.3	0.34
FB018	650414	4855931	Dunbarton	HY009	J790	4.66	101	463	1.49	7	0.011	0.40	1	11	25	PERVIOUS	77	89	3.3	0.35
FB019	650668	4855917	Dunbarton	HY009	J790	1.31	90	146	0.62	64	0.011	0.15	1	5	25	PERVIOUS	45	89	3.3	0.35
FB020	650296	4855645	Amberlea	HY102	J8	3.73	164	227	1.58	54	0.011	0.17	1	5	25	PERVIOUS	52	89	3.3	0.35
FB021	652212	4854785	Dunbarton	HY102	J923	10.10	294	344	0.07	46	0.011	0.26	1	7	25	PERVIOUS	55	164	15	0.32
FB022	652703	4856851	Pine	HY009	J100	8.41	263	319	1.32	31	0.011	0.25	1	6	25	PERVIOUS	67	65	25.9	0.38
FB023	652745	4854658	Dunbarton	HY102	J16	2.60	133	196	3.41	62	0.011	0.15	1	5	25	PERVIOUS	49	61	30	0.39
FB024	651422	4855551	Dunbarton	HY102	J1847	34.26	602	569	1.95	47	0.011	0.26	1	7	25	PERVIOUS	53	118	13.5	0.35
FB025	651628	4855795	Dunbarton	HY009	J6	7.36	244	302	1.94	63	0.011	0.15	1	5	25	PERVIOUS	47	61	30	0.39
FB026	652478	4854523	Dunbarton	HY102	J435	19.07	427	447	3.83	51	0.011	0.21	1	6	25	PERVIOUS	54	140	16.3	0.34
FB027	651111	4855397	Dunbarton	HY102	J323	20.73	448	463	1.71	56	0.011	0.17	1	5	25	PERVIOUS	51	100	4.5	0.36
FB028	651750	4855000	Dunbarton	HY102	J1389	52.30	773	677	1.77	57	0.011	0.18	1	5	25	PERVIOUS	54	113	10.8	0.36
FB029	652817	4854227	Dunbarton	HY102	J83	22.29	467	477	3.19	64	0.011	0.23	1	6	25	PERVIOUS	10	131	12.6	0.35
FB030	652108	4854322	Dunbarton	HY102	J797	24.16	490	493	1.20	60	0.011	0.19	1	6	25	PERVIOUS	38	112	5.4	0.37
FB031	652637	4854336	Dunbarton	HY102	J357	7.87	254	310	13.11	66	0.011	0.19	1	6	25	PERVIOUS	16	110	14.7	0.36
FB032	651464	4854469	Amberlea	HY102	J2384	53.36	781	683	2.59	57	0.011	0.17	1	5	25	PERVIOUS	53	104	4.8	0.36
FB033	651012	4855897	Dunbarton	HY009	J2851	12.70	336	378	4.11	46	0.011	0.26	1	7	25	PERVIOUS	48	95	7.6	0.35
FB034	650555	4855775	Dunbarton	HY102	SU1	8.07	258	313	2.29	59	0.011	0.17	1	5	25	PERVIOUS	53	89	3.3	0.35
FB035	650882	4856672	Pine	HY009	J24	11.69	172	679	2.18	1	0.011	0.51	1	11	25	PERVIOUS	55	89	3.3	0.35
FB036	650677	4856590	Pine	HY009	J25	13.35	186	717	1.35	16	0.011	0.43	1	9	25	PERVIOUS	55	89	3.3	0.35
FB037	651252	4856357	Pine	HY009	J8065	2.57	132	195	0.94	43	0.011	0.26	1	7	25	PERVIOUS	55	64	27.2	0.39
FB038	651315	4856392	Pine	HY009	J5	2.02	115	176	2.58	61	0.011	0.15	1	5	25	PERVIOUS	53	61	30	0.39
FB039	651298	4856204	Pine	HY009	J7723	6.41	225	285	1.11	35	0.011	0.35	1	8	25	PERVIOUS	54	81	10.9	0.36
FB040	651606	4856185	Pine	HY009	J7525	5.40	109	493	11.34	30	0.011	0.39	1	8	25	PERVIOUS	63	79	13	0.36
FB041	650377	4856185	Pine	HY009	J692	3.61	161	224	1.09	59	0.011	0.15	1	5	25	PERVIOUS	55	89	3.3	0.35
FB042	652566	4856063	Pine	HY009	J6000	4.56	185	247	1.34	44	0.011	0.29	1	7	25	PERVIOUS	41	100	11.2	0.35
FB043	652673	4856093	Pine	HY009	J2727	3.62	161	225	0.99	57	0.011	0.16	1	5	25	PERVIOUS	56	69	27.6	0.38
FB044	652003	4856063	Pine	HY009	J7000	2.47	69	356	8.81	28	0.011	0.39	1	9	25	PERVIOUS	43	84	7.7	0.35
FB045	653889	4854107	Pine	HY102	J12	12.64	335	377	1.47	60	0.011	0.15	1	5	25	PERVIOUS	54	271	0.8	0.24
FB046	653470	4854352	Pine	HY102	J13	3.91	169	232	1.70	75	0.011	0.15	1	5	25	PERVIOUS	34	61	30	0.39
FB047	650526	4857331	Pine	HY009	J18	47.89	395	1213	2.12	10	0.011	0.31	1	8	25	PERVIOUS	76	95	5.7	0.35
FB048	653309	4856735	Pine	HY009	J147	12.64	335	377	0.49	57	0.011	0.17	1	5	25	PERVIOUS	54	62	29.6	0.39
FB049	653674	4856217	Pine	HY009	J772	72.96	940	776	0.78	60	0.011	0.16	1	5	25	PERVIOUS	47	156	10.2	0.33
FB050	651341	4857783	Pine	HY009	J12469	40.07	356	1127	1.75	17	0.011	0.45	1	9	25	PERVIOUS	53	94	5	0.35
FB051	651634	4857291	Pine	HY009	J111	36.38	624	583	0.93	69	0.011	0.21	1	6	25	PERVIOUS	8	89	3.4	0.35
FB052	653545	4855089	Pine	HY009	J1385	6.20	221	281	1.80	73	0.011	0.19	1	6	25	PERVIOUS	4	252	1.1	0.27
FB053	653382	4855096	Pine	HY009	J1467	6.01	217	277	1.65	59	0.011	0.23	1	6	25	PERVIOUS	8	270	1.6	0.25
FB054	650713	4857970	Pine	HY009	J35	14.42	195	740	2.05	10	0.011	0.29	1	7	25	PERVIOUS	81	98	6.5	0.36
FB055	651819	4856824	Pine	HY009	J742	29.84	555	538	2.43	42	0.011	0.29	1	7	25	PERVIOUS	26	74	17.3	0.37

Table D1: Calibrated Subbasin Hydrologic Parameters

Name	X-Coordinate	Y-Coordinate	Tag	Rain Gage	Outlet	Area (ha)	Width (m)	Flow Length (m)	Slope (%)	Imperv. (%)	N Imperv	N Perv	Dstore Imperv (mm)	Dstore Perv (mm)	Zero Imperv (%)	Subarea Routing	Percent Routed (%)	Suction Head (mm)	Conductivity (mm/hour)	Initial Deficit (frac.)
FB056	652171	4856405	Pine	HY009	J819	19.07	427	447	2.24	60	0.011	0.15	1	5	25	PERVIOUS	53	68	23.5	0.38
FB057	652618	4856475	Pine	HY009	J171	12.09	326	371	0.95	61	0.011	0.16	1	5	25	PERVIOUS	45	70	21.5	0.38
FB058	653694	4854749	Pine	HY102	J927	8.58	267	321	0.78	52	0.011	0.25	1	6	25	PERVIOUS	36	175	6.1	0.32
FB059	653493	4854839	Pine	HY102	J1215	8.34	262	318	2.46	32	0.011	0.31	1	8	25	PERVIOUS	6	210	6.8	0.29
FB060	651458	4856379	Pine	HY009	J8000	1.04	42	247	6.78	23	0.011	0.46	1	10	25	PERVIOUS	24	61	30	0.39
FB061	652258	4857542	Pine	HY009	J11500	20.64	241	858	3.24	19	0.011	0.37	1	8	25	PERVIOUS	46	73	18.7	0.37
FB062	652542	4857202	Pine	HY009	J10253	26.56	518	513	1.98	42	0.011	0.29	1	7	25	PERVIOUS	55	65	25.8	0.38
FB063	651985	4857836	Pine	HY009	J12028	16.20	208	777	2.52	2	0.011	0.51	1	11	25	PERVIOUS	1	89	3.3	0.35
FB064	652852	4856971	Pine	HY009	J10080	3.68	162	227	3.91	34	0.011	0.36	1	7	25	PERVIOUS	88	65	26.1	0.38
FB065	653683	4854443	Pine	HY102	J546	11.19	312	359	1.25	60	0.011	0.26	1	6	25	PERVIOUS	32	106	12.9	0.35
FB066	652973	4856736	Pine	HY009	J834	15.09	372	406	1.13	59	0.011	0.19	1	6	25	PERVIOUS	40	72	22	0.38
FB067	653001	4856037	Pine	HY009	J2266	41.96	678	619	0.99	59	0.011	0.15	1	5	25	PERVIOUS	54	174	7.3	0.32
FB068	652122	4855378	Pine	HY009	J311	17.33	403	430	1.25	60	0.011	0.15	1	5	25	PERVIOUS	55	61	30	0.39
FB069	653719	4854201	Pine	HY102	J382	2.32	125	186	4.88	37	0.011	0.29	1	8	25	PERVIOUS	61	137	3.9	0.32
FB070	652790	4855081	Pine	HY102	J1778	57.02	812	702	1.19	63	0.011	0.15	1	5	25	PERVIOUS	47	62	29.9	0.39
FB071	651934	4855861	Pine	HY009	J2896	15.65	380	412	2.10	59	0.011	0.16	1	5	25	PERVIOUS	53	61	29.5	0.39
FB072	652299	4855863	Pine	HY009	J2896	16.58	393	422	2.17	42	0.011	0.35	1	7	25	PERVIOUS	52	75	22.8	0.37
FB073	652495	4855918	Pine	HY009	J2839	7.12	239	298	3.67	62	0.011	0.17	1	5	25	PERVIOUS	42	117	17.7	0.35
FB074	652594	4855556	Pine	HY009	J2353	21.14	453	467	1.78	50	0.011	0.20	1	6	25	PERVIOUS	53	110	23.5	0.36
FB075	650140	4856507	Pine	HY009	J189	47.08	391	1204	1.77	17	0.011	0.39	1	9	25	PERVIOUS	65	95	5.4	0.35
FB076	650508	4856148	Pine	HY009	J825	6.31	120	526	1.90	24	0.011	0.39	1	9	25	PERVIOUS	46	89	3.3	0.35
FB077	651335	4856776	Pine	HY009	J9103	3.04	78	388	2.37	18	0.011	0.37	1	8	25	PERVIOUS	15	83	9	0.36
FB078	650958	4857400	Pine	HY009	J19	18.06	222	812	1.62	6	0.011	0.37	1	9	25	PERVIOUS	44	97	6.3	0.36
FB079	651494	4856617	Pine	HY009	J4500_1	7.85	136	576	3.19	26	0.011	0.39	1	9	25	PERVIOUS	29	67	23.9	0.38
FB080	651131	4856699	Pine	HY009	J5106	13.03	184	710	7.00	7	0.011	0.45	1	10	25	PERVIOUS	40	83	9.1	0.36
FB081	651538	4857591	Pine	HY009	J12585	5.78	212	273	0.45	45	0.011	0.31	1	7	25	PERVIOUS	9	89	3.3	0.35
FB082	651795	4856337	Pine	HY009	J3640	16.48	391	421	2.47	37	0.011	0.31	1	7	25	PERVIOUS	55	67	24.4	0.38
FB083	650911	4856308	Pine	HY009	J9500	9.55	153	624	2.25	8	0.011	0.48	1	10	25	PERVIOUS	58	89	3.3	0.35
FB084	651504	4856040	Pine	HY009	J7205	8.20	260	316	1.96	44	0.011	0.32	1	6	25	PERVIOUS	62	69	22.2	0.38
FB085	652233	4857257	Pine	HY009	J10950	3.74	88	423	5.00	12	0.011	0.51	1	11	25	PERVIOUS	55	63	28.1	0.39
FB086	652108	4857355	Pine	HY009	SU3	3.79	165	229	2.25	60	0.011	0.16	1	5	25	PERVIOUS	53	81	11.1	0.36
FB087	653472	4855575	Pine	HY009	J808	12.14	327	371	0.52	76	0.011	0.15	1	5	25	PERVIOUS	22	270	0.5	0.26
FB088	650822	4856147	Pine	HY009	J9800	13.91	191	729	2.20	22	0.011	0.41	1	9	25	PERVIOUS	52	89	3.3	0.35
FB089	653192	4855420	Pine	HY009	J1672	15.24	373	408	3.13	57	0.011	0.19	1	6	25	PERVIOUS	54	238	5.8	0.27
FB090	651298	4857063	Pine	HY009	J9320	6.02	217	278	1.14	52	0.011	0.30	1	7	25	PERVIOUS	6	89	3.3	0.35
FB091	650947	4856972	Pine	HY009	J5255	10.81	164	657	1.45	16	0.011	0.56	1	11	25	PERVIOUS	96	89	3.3	0.35
FB092	652372	4856799	Pine	HY009	J17	19.34	430	450	2.14	51	0.011	0.19	1	5	25	PERVIOUS	58	68	23.2	0.38
FB094	654822	4854462	Krosno	HY004	J2276	19.32	429	450	2.11	76	0.011	0.16	1	5	25	PERVIOUS	12	270	0.5	0.26
FB095	654724	4853952	Krosno	HY004	J2158	4.79	190	252	0.55	62	0.011	0.15	1	5	25	PERVIOUS	50	288	0.3	0.23
FB097	655367	4855466	Krosno	HY004	J746	44.38	701	633	2.13	81	0.011	0.17	1	5	25	PERVIOUS	8	274	0.5	0.26
FB098	654519	4854389	Krosno	HY004	J2403	25.22	502	502	1.87	59	0.011	0.16	1	5	25	PERVIOUS	51	264	0.6	0.25
FB099	655461	4854402	Krosno	HY004	J5490	12.52	333	376	1.36	82	0.011	0.16	1	5	25	PERVIOUS	6	290	0.3	0.23
FB100	655159	4854818	Krosno	HY004	J2	31.27	571	548	0.71	61	0.011	0.21	1	6	25	PERVIOUS	8	271	0.5	0.26
FB101	655980	4853993	Krosno	HY004	J4450	19.59	433	452	0.32	84	0.011	0.15	1	5	25	PERVIOUS	5	283	0.3	0.24
FB102	654514	4855067	Krosno	HY004	J3100	44.68	704	635	1.71	68	0.011	0.18	1	5	25	PERVIOUS	8	262	0.8	0.26
FB103	654486	4855315	Krosno	HY004	J3337	16.93	397	426	4.41	69	0.011	0.21	1	5	25	PERVIOUS	17	270	0.6	0.26
FB104	654083	4855540	Krosno	HY009	J3540	74.18	950	781	1.25	78	0.011	0.16	1	5	25	PERVIOUS	14	267	0.6	0.26
FB106	655019	4854501	Krosno	HY004	J5013	5.33	109	490	1.77	27	0.011	0.36	1	7	25	PERVIOUS	37	278	0.8	0.25
FB107	655222	4854478	Krosno	HY004	J5400	2.60	133	196	0.90	60	0.011	0.26	1	6	25	PERVIOUS	16	286	0.3	0.23
FB108	654132	4854421	Krosno	HY102	J3	3.13	148	211	1.30	60	0.011	0.15	1	5	25	PERVIOUS	55	278	0.6	0.24
FB109	655280	4854088	Krosno	HY004	J4705	10.38	161	646	1.42	23	0.011	0.27	1	7	25	PERVIOUS	7	288	0.6	0.23
FB110	654884	4854076	Krosno	HY004	J2028	4.36	180	243	1.52	34	0.011	0.27	1	7	25	PERVIOUS	44	274	0.5	0.24
FB111	654178	4854635	Krosno	HY102	J2820	15.24	374	408	2.05	63	0.011	0.15	1	5	25	PERVIOUS	47	230	1.6	0.28
FB112	654265	4853573	Krosno	HY102	J696	18.20	415	439	1.10	63	0.011	0.16	1	5	25	PERVIOUS	45	290	0.3	0.23
FB113	654562	4853551	Krosno	HY102	J934	3.82	166	230	1.25	59	0.011	0.16	1	5	25	PERVIOUS	57	290	0.3	0.23

Table D1: Calibrated Subbasin Hydrologic Parameters

Name	X-Coordinate	Y-Coordinate	Tag	Rain Gage	Outlet	Area (ha)	Width (m)	Flow Length (m)	Slope (%)	Imperv. (%)	N Imperv	N Perv	Dstore Imperv (mm)	Dstore Perv (mm)	Zero Imperv (%)	Subarea Routing	Percent Routed (%)	Suction Head (mm)	Conductivity (mm/hour)	Initial Deficit (frac.)
FB114	654337	4853979	Krosno	HY102	J1058	32.13	580	554	1.18	57	0.011	0.16	1	5	25	PERVIOUS	55	289	0.3	0.23
FB115	655722	4854698	Krosno	HY004	J417	41.47	673	616	1.02	80	0.011	0.16	1	5	25	PERVIOUS	5	290	0.3	0.23
FB116	655604	4853866	Krosno	HY004	J4344	11.68	320	365	1.57	74	0.011	0.18	1	5	25	PERVIOUS	5	282	0.4	0.24
FB117	655520	4853522	Krosno	HY004	J4000	21.98	464	474	1.40	45	0.011	0.26	1	6	25	PERVIOUS	19	281	0.4	0.23
FB118	655380	4854188	Krosno	HY004	J4965	7.59	248	306	3.26	55	0.011	0.24	1	6	25	PERVIOUS	6	290	0.3	0.23
FB119	655307	4853291	Krosno	HY004	J1267	17.60	407	433	0.67	33	0.011	0.25	1	6	25	PERVIOUS	42	198	1.6	0.28
FB120	654746	4853141	Krosno	HY102	J495	48.41	738	656	0.12	57	0.011	0.34	1	7	25	PERVIOUS	93	197	37.1	0.30
FB121	655072	4853799	Krosno	HY004	J1500_1	22.30	467	477	1.54	36	0.011	0.26	1	7	25	PERVIOUS	65	289	0.8	0.23

Table D2: Future Conditions Subbasin Hydrologic Parameters

Name	X-Coordinate	Y-Coordinate	Tag	Rain Gage	Outlet	Area (ha)	Width (m)	Flow Length (m)	Slope (%)	Imperv. (%)	N Imperv	N Perv	Dstore Imperv (mm)	Dstore Perv (mm)	Zero Imperv (%)	Subarea Routing	Percent Routed (%)	Suction Head (mm)	Conductivity (mm/hour)	Initial Deficit (frac.)
FB001	650273	4854912	Amberlea	HY102	J22	7.70	251	307	1.22	61	0.011	0.15	1	5	25	PERVIOUS	51	89	3.3	0.35
FB002	652300	4853927	Amberlea	HY102	J1106.4	4.05	172	235	1.36	71	0.011	0.22	1	6	25	PERVIOUS	9	201	2.8	0.30
FB003	651678	4853859	Amberlea	HY102	J1443	8.55	266	321	4.50	64	0.011	0.18	1	5	25	PERVIOUS	32	102	4.6	0.36
FB004	652049	4853869	Amberlea	HY102	J1540	4.58	185	248	5.03	65	0.011	0.20	1	6	25	PERVIOUS	6	187	3.2	0.31
FB005	652592	4853792	Amberlea	HY102	J28	7.06	238	296	1.39	46	0.011	0.26	1	7	25	PERVIOUS	36	253	1.3	0.26
FB006	651500	4853676	Amberlea	HY102	J1308	8.85	272	326	2.07	81	0.011	0.15	1	5	25	PERVIOUS	12	109	5.4	0.37
FB007	651918	4854014	Amberlea	HY102	J1720	5.46	205	267	0.73	58	0.011	0.21	1	6	25	PERVIOUS	37	138	3.7	0.33
FB008	651910	4852995	Amberlea	HY102	J11	8.05	257	313	2.83	64	0.011	0.16	1	5	25	PERVIOUS	38	110	5.5	0.37
FB009	649511	4856010	Amberlea	HY102	J1	27.30	283	963	1.13	3	0.011	0.20	1	7	25	PERVIOUS	74	84	8.3	0.36
FB010	649736	4855562	Amberlea	HY102	J23	14.20	193	735	0.80	39	0.011	0.27	1	7	25	PERVIOUS	49	77	14.4	0.36
Fb011	650098	4855848	Amberlea	HY102	J301	22.07	250	882	1.30	5	0.011	0.51	1	11	25	PERVIOUS	38	89	3.3	0.35
FB012	651315	4853863	Amberlea	HY102	J9	3.23	151	214	0.93	45	0.011	0.31	1	7	25	PERVIOUS	39	101	4.6	0.36
FB013	650609	4855144	Amberlea	HY102	J21	75.04	956	785	0.91	62	0.011	0.15	1	5	25	PERVIOUS	46	92	3.7	0.35
FB014	651064	4854224	Amberlea	HY102	J698	33.76	597	566	2.82	59	0.011	0.16	1	5	25	PERVIOUS	52	110	5.4	0.37
FB015	651773	4853556	Amberlea	HY102	J1036	13.51	348	388	2.86	62	0.011	0.22	1	6	25	PERVIOUS	4	131	4.8	0.35
FB016	651962	4853539	Amberlea	HY102	J644	9.36	281	333	4.28	75	0.011	0.19	1	6	25	PERVIOUS	1	179	3.5	0.31
FB017	652034	4853433	Amberlea	HY102	J495.54	12.38	331	374	4.92	40	0.011	0.30	1	7	25	PERVIOUS	28	151	4.3	0.34
FB018	650414	4855931	Dunbarton	HY009	J790	4.66	101	463	1.49	7	0.011	0.40	1	11	25	PERVIOUS	77	89	3.3	0.35
FB019	650668	4855917	Dunbarton	HY009	J790	1.31	90	146	0.62	64	0.011	0.15	1	5	25	PERVIOUS	45	89	3.3	0.35
FB020	650296	4855645	Amberlea	HY102	J8	3.73	164	227	1.58	54	0.011	0.17	1	5	25	PERVIOUS	52	89	3.3	0.35
FB021	652212	4854785	Dunbarton	HY102	J923	10.10	294	344	0.07	46	0.011	0.26	1	7	25	PERVIOUS	55	164	15	0.32
FB022	652703	4856851	Pine	HY009	J100	8.41	263	319	1.32	31	0.011	0.25	1	6	25	PERVIOUS	67	65	25.9	0.38
FB023	652745	4854658	Dunbarton	HY102	J16	2.60	133	196	3.41	62	0.011	0.15	1	5	25	PERVIOUS	49	61	30	0.39
FB024	651422	4855551	Dunbarton	HY102	J1847	34.26	602	569	1.95	47	0.011	0.26	1	7	25	PERVIOUS	53	118	13.5	0.35
FB025	651628	4855795	Dunbarton	HY009	J6	7.36	244	302	1.94	63	0.011	0.15	1	5	25	PERVIOUS	47	61	30	0.39
FB026	652478	4854523	Dunbarton	HY102	J435	19.07	427	447	3.83	51	0.011	0.21	1	6	25	PERVIOUS	54	140	16.3	0.34
FB027	651111	4855397	Dunbarton	HY102	J323	20.73	448	463	1.71	56	0.011	0.17	1	5	25	PERVIOUS	51	100	4.5	0.36
FB028	651750	4855000	Dunbarton	HY102	J1389	52.30	773	677	1.77	58	0.011	0.17	1	5	25	PERVIOUS	54	113	10.8	0.36
FB029	652817	4854227	Dunbarton	HY102	J83	22.29	467	477	3.19	65	0.011	0.23	1	6	25	PERVIOUS	10	131	12.6	0.35
FB030	652108	4854322	Dunbarton	HY102	J797	24.16	490	493	1.20	60	0.011	0.18	1	5	25	PERVIOUS	39	112	5.4	0.37
FB031	652637	4854336	Dunbarton	HY102	J357	7.87	254	310	13.11	66	0.011	0.19	1	6	25	PERVIOUS	16	110	14.7	0.36
FB032	651464	4854469	Amberlea	HY102	J2384	53.36	781	683	2.59	57	0.011	0.17	1	5	25	PERVIOUS	53	104	4.8	0.36
FB033	651012	4855897	Dunbarton	HY009	J2851	12.70	336	378	4.11	46	0.011	0.26	1	7	25	PERVIOUS	48	95	7.6	0.35
FB034	650555	4855775	Dunbarton	HY102	SU1	8.07	258	313	2.29	59	0.011	0.17	1	5	25	PERVIOUS	53	89	3.3	0.35
FB035	650882	4856672	Pine	HY009	J24	11.69	172	679	2.18	1	0.011	0.51	1	11	25	PERVIOUS	55	89	3.3	0.35
FB036	650677	4856590	Pine	HY009	J25	13.35	186	717	1.35	16	0.011	0.43	1	9	25	PERVIOUS	55	89	3.3	0.35
FB037	651252	4856357	Pine	HY009	J8065	2.57	132	195	0.94	43	0.011	0.26	1	7	25	PERVIOUS	55	64	27.2	0.39
FB038	651315	4856392	Pine	HY009	J5	2.02	115	176	2.58	61	0.011	0.15	1	5	25	PERVIOUS	53	61	30	0.39
FB039	651298	4856204	Pine	HY009	J7723	6.41	225	285	1.11	35	0.011	0.35	1	8	25	PERVIOUS	54	81	10.9	0.36
FB040	651606	4856185	Pine	HY009	J7525	5.40	109	493	11.34	30	0.011	0.39	1	8	25	PERVIOUS	63	79	13	0.36
FB041	650377	4856185	Pine	HY009	J692	3.61	161	224	1.09	60	0.011	0.15	1	5	25	PERVIOUS	55	89	3.3	0.35
FB042	652566	4856063	Pine	HY009	J6000	4.56	185	247	1.34	44	0.011	0.29	1	7	25	PERVIOUS	41	100	11.2	0.35
FB043	652673	4856093	Pine	HY009	J2727	3.62	161	225	0.99	57	0.011	0.16	1	5	25	PERVIOUS	56	69	27.6	0.38
FB044	652003	4856063	Pine	HY009	J7000	2.47	69	356	8.81	28	0.011	0.39	1	9	25	PERVIOUS	43	84	7.7	0.35
FB045	653889	4854107	Pine	HY102	J12	12.64	335	377	1.47	60	0.011	0.15	1	5	25	PERVIOUS	54	271	0.8	0.24
FB046	653470	4854352	Pine	HY102	J13	3.91	169	232	1.70	75	0.011	0.15	1	5	25	PERVIOUS	34	61	30	0.39
FB047	650526	4857331	Pine	HY009	J18	47.89	395	1213	2.12	10	0.011	0.31	1	8	25	PERVIOUS	76	95	5.7	0.35
FB048	653309	4856735	Pine	HY009	J147	12.64	335	377	0.49	60	0.011	0.15	1	5	25	PERVIOUS	54	62	29.6	0.39
FB049	653674	4856217	Pine	HY009	J772	72.96	940	776	0.78	60	0.011	0.16	1	5	25	PERVIOUS	47	156	10.2	0.33
FB050	651341	4857783	Pine	HY009	J12469	40.07	356	1127	1.75	17	0.011	0.45	1	9	25	PERVIOUS	53	94	5	0.35
FB051	651634	4857291	Pine	HY009	J111	36.38	624	583	0.93	69	0.011	0.21	1	6	25	PERVIOUS	8	89	3.4	0.35
FB052	653545	4855089	Pine	HY009	J1385	6.20	221	281	1.80	81	0.011	0.16	1	5	25	PERVIOUS	4	252	1.1	0.27
FB053	653382	4855096	Pine	HY009	J1467	6.01	217	277	1.65	81	0.011	0.17	1	5	25	PERVIOUS	7	270	1.6	0.25
FB054	650713	4857970	Pine	HY009	J35	14.42	195	740	2.05	10	0.011	0.29	1	7	25	PERVIOUS	81	98	6.5	0.36
FB055	651819	4856824	Pine	HY009	J742	29.84	555	538	2.43	50	0.011	0.24	1	6	25	PERVIOUS	30	74	17.3	0.37

Table D2: Future Conditions Subbasin Hydrologic Parameters

Name	X-Coordinate	Y-Coordinate	Tag	Rain Gage	Outlet	Area (ha)	Width (m)	Flow Length (m)	Slope (%)	Imperv. (%)	N Imperv	N Perv	Dstore Imperv (mm)	Dstore Perv (mm)	Zero Imperv (%)	Subarea Routing	Percent Routed (%)	Suction Head (mm)	Conductivity (mm/hour)	Initial Deficit (frac.)
FB056	652171	4856405	Pine	HY009	J819	19.07	427	447	2.24	60	0.011	0.15	1	5	25	PERVIOUS	53	68	23.5	0.38
FB057	652618	4856475	Pine	HY009	J171	12.09	326	371	0.95	61	0.011	0.16	1	5	25	PERVIOUS	45	70	21.5	0.38
FB058	653694	4854749	Pine	HY102	J927	8.58	267	321	0.78	62	0.011	0.23	1	6	25	PERVIOUS	29	175	6.1	0.32
FB059	653493	4854839	Pine	HY102	J1215	8.34	262	318	2.46	66	0.011	0.21	1	6	25	PERVIOUS	5	210	6.8	0.29
FB060	651458	4856379	Pine	HY009	J8000	1.04	42	247	6.78	23	0.011	0.46	1	10	25	PERVIOUS	24	61	30	0.39
FB061	652258	4857542	Pine	HY009	J11500	20.64	241	858	3.24	19	0.011	0.37	1	8	25	PERVIOUS	46	73	18.7	0.37
FB062	652542	4857202	Pine	HY009	J10253	26.56	518	513	1.98	44	0.011	0.27	1	7	25	PERVIOUS	55	65	25.8	0.38
FB063	651985	4857836	Pine	HY009	J12028	16.20	208	777	2.52	2	0.011	0.51	1	11	25	PERVIOUS	1	89	3.3	0.35
FB064	652852	4856971	Pine	HY009	J10080	3.68	162	227	3.91	34	0.011	0.36	1	7	25	PERVIOUS	88	65	26.1	0.38
FB065	653683	4854443	Pine	HY102	J546	11.19	312	359	1.25	68	0.011	0.25	1	6	25	PERVIOUS	27	106	12.9	0.35
FB066	652973	4856736	Pine	HY009	J834	15.09	372	406	1.13	63	0.011	0.16	1	5	25	PERVIOUS	41	72	22	0.38
FB067	653001	4856037	Pine	HY009	J2266	41.96	678	619	0.99	59	0.011	0.15	1	5	25	PERVIOUS	54	174	7.3	0.32
FB068	652122	4855378	Pine	HY009	J311	17.33	403	430	1.25	60	0.011	0.15	1	5	25	PERVIOUS	55	61	30	0.39
FB069	653719	4854201	Pine	HY102	J382	2.32	125	186	4.88	37	0.011	0.29	1	8	25	PERVIOUS	61	137	3.9	0.32
FB070	652790	4855081	Pine	HY102	J1778	57.02	812	702	1.19	63	0.011	0.15	1	5	25	PERVIOUS	46	62	29.9	0.39
FB071	651934	4855861	Pine	HY009	J2896	15.65	380	412	2.10	61	0.011	0.15	1	5	25	PERVIOUS	53	61	29.5	0.39
FB072	652299	4855863	Pine	HY009	J2896	16.58	393	422	2.17	42	0.011	0.35	1	7	25	PERVIOUS	52	75	22.8	0.37
FB073	652495	4855918	Pine	HY009	J2839	7.12	239	298	3.67	62	0.011	0.17	1	5	25	PERVIOUS	42	117	17.7	0.35
FB074	652594	4855556	Pine	HY009	J2353	21.14	453	467	1.78	51	0.011	0.19	1	5	25	PERVIOUS	53	110	23.5	0.36
FB075	650140	4856507	Pine	HY009	J189	47.08	391	1204	1.77	17	0.011	0.39	1	9	25	PERVIOUS	65	95	5.4	0.35
FB076	650508	4856148	Pine	HY009	J825	6.31	120	526	1.90	28	0.011	0.37	1	9	25	PERVIOUS	46	89	3.3	0.35
FB077	651335	4856776	Pine	HY009	J9103	3.04	78	388	2.37	18	0.011	0.37	1	8	25	PERVIOUS	15	83	9	0.36
FB078	650958	4857400	Pine	HY009	J19	18.06	222	812	1.62	6	0.011	0.37	1	9	25	PERVIOUS	44	97	6.3	0.36
FB079	651494	4856617	Pine	HY009	J4500_1	7.85	136	576	3.19	26	0.011	0.39	1	9	25	PERVIOUS	29	67	23.9	0.38
FB080	651131	4856699	Pine	HY009	J5106	13.03	184	710	7.00	7	0.011	0.45	1	10	25	PERVIOUS	40	83	9.1	0.36
FB081	651538	4857591	Pine	HY009	J12585	5.78	212	273	0.45	45	0.011	0.31	1	7	25	PERVIOUS	9	89	3.3	0.35
FB082	651795	4856337	Pine	HY009	J3640	16.48	391	421	2.47	37	0.011	0.31	1	7	25	PERVIOUS	55	67	24.4	0.38
FB083	650911	4856308	Pine	HY009	J9500	9.55	153	624	2.25	8	0.011	0.48	1	10	25	PERVIOUS	58	89	3.3	0.35
FB084	651504	4856040	Pine	HY009	J7205	8.20	260	316	1.96	44	0.011	0.32	1	6	25	PERVIOUS	62	69	22.2	0.38
FB085	652233	4857257	Pine	HY009	J10950	3.74	88	423	5.00	27	0.011	0.40	1	9	25	PERVIOUS	55	63	28.1	0.39
FB086	652108	4857355	Pine	HY009	SU3	3.79	165	229	2.25	60	0.011	0.16	1	5	25	PERVIOUS	53	81	11.1	0.36
FB087	653472	4855575	Pine	HY009	J808	12.14	327	371	0.52	76	0.011	0.15	1	5	25	PERVIOUS	22	270	0.5	0.26
FB088	650822	4856147	Pine	HY009	J9800	13.91	191	729	2.20	22	0.011	0.41	1	9	25	PERVIOUS	52	89	3.3	0.35
FB089	653192	4855420	Pine	HY009	J1672	15.24	373	408	3.13	57	0.011	0.19	1	6	25	PERVIOUS	54	238	5.8	0.27
FB090	651298	4857063	Pine	HY009	J9320	6.02	217	278	1.14	52	0.011	0.30	1	7	25	PERVIOUS	6	89	3.3	0.35
FB091	650947	4856972	Pine	HY009	J5255	10.81	164	657	1.45	16	0.011	0.56	1	11	25	PERVIOUS	96	89	3.3	0.35
FB092	652372	4856799	Pine	HY009	J17	19.34	430	450	2.14	51	0.011	0.19	1	5	25	PERVIOUS	58	68	23.2	0.38
FB094	654822	4854462	Krosno	HY004	J2276	19.32	429	450	2.11	76	0.011	0.16	1	5	25	PERVIOUS	12	270	0.5	0.26
FB095	654724	4853952	Krosno	HY004	J2158	4.79	190	252	0.55	62	0.011	0.15	1	5	25	PERVIOUS	50	288	0.3	0.23
FB097	655367	4855466	Krosno	HY004	J746	44.38	701	633	2.13	81	0.011	0.17	1	5	25	PERVIOUS	8	274	0.5	0.26
FB098	654519	4854389	Krosno	HY004	J2403	25.22	502	502	1.87	60	0.011	0.16	1	5	25	PERVIOUS	50	264	0.6	0.25
FB099	655461	4854402	Krosno	HY004	J5490	12.52	333	376	1.36	82	0.011	0.16	1	5	25	PERVIOUS	6	290	0.3	0.23
FB100	655159	4854818	Krosno	HY004	J2	31.27	571	548	0.71	64	0.011	0.20	1	6	25	PERVIOUS	7	271	0.5	0.26
FB101	655980	4853993	Krosno	HY004	J4450	19.59	433	452	0.32	84	0.011	0.15	1	5	25	PERVIOUS	5	283	0.3	0.24
FB102	654514	4855067	Krosno	HY004	J3100	44.68	704	635	1.71	68	0.011	0.18	1	5	25	PERVIOUS	8	262	0.8	0.26
FB103	654486	4855315	Krosno	HY004	J3337	16.93	397	426	4.41	69	0.011	0.21	1	5	25	PERVIOUS	17	270	0.6	0.26
FB104	654083	4855540	Krosno	HY009	J3540	74.18	950	781	1.25	82	0.011	0.15	1	5	25	PERVIOUS	13	267	0.6	0.26
FB106	655019	4854501	Krosno	HY004	J5013	5.33	109	490	1.77	27	0.011	0.36	1	7	25	PERVIOUS	37	278	0.8	0.25
FB107	655222	4854478	Krosno	HY004	J5400	2.60	133	196	0.90	60	0.011	0.26	1	6	25	PERVIOUS	16	286	0.3	0.23
FB108	654132	4854421	Krosno	HY102	J3	3.13	148	211	1.30	60	0.011	0.15	1	5	25	PERVIOUS	55	278	0.6	0.24
FB109	655280	4854088	Krosno	HY004	J4705	10.38	161	646	1.42	51	0.011	0.25	1	6	25	PERVIOUS	6	288	0.6	0.23
FB110	654884	4854076	Krosno	HY004	J2028	4.36	180	243	1.52	38	0.011	0.26	1	7	25	PERVIOUS	43	274	0.5	0.24
FB111	654178	4854635	Krosno	HY102	J2820	15.24	374	408	2.05	63	0.011	0.15	1	5	25	PERVIOUS	47	230	1.6	0.28
FB112	654265	4853573	Krosno	HY102	J696	18.20	415	439	1.10	61	0.011	0.15	1	5	25	PERVIOUS	49	290	0.3	0.23
FB113	654562	4853551	Krosno	HY102	J934	3.82	166	230	1.25	59	0.011	0.16	1	5	25	PERVIOUS	57	290	0.3	0.23

Table D2: Future Conditions Subbasin Hydrologic Parameters

Name	X-Coordinate	Y-Coordinate	Tag	Rain Gage	Outlet	Area (ha)	Width (m)	Flow Length (m)	Slope (%)	Imperv. (%)	N Imperv	N Perv	Dstore Imperv (mm)	Dstore Perv (mm)	Zero Imperv (%)	Subarea Routing	Percent Routed (%)	Suction Head (mm)	Conductivity (mm/hour)	Initial Deficit (frac.)
FB114	654337	4853979	Krosno	HY102	J1058	32.13	580	554	1.18	57	0.011	0.16	1	5	25	PERVIOUS	55	289	0.3	0.23
FB115	655722	4854698	Krosno	HY004	J417	41.47	673	616	1.02	84	0.011	0.15	1	5	25	PERVIOUS	5	290	0.3	0.23
FB116	655604	4853866	Krosno	HY004	J4344	11.68	320	365	1.57	75	0.011	0.18	1	5	25	PERVIOUS	5	282	0.4	0.24
FB117	655520	4853522	Krosno	HY004	J4000	21.98	464	474	1.40	45	0.011	0.26	1	6	25	PERVIOUS	19	281	0.4	0.23
FB118	655380	4854188	Krosno	HY004	J4965	7.59	248	306	3.26	66	0.011	0.21	1	6	25	PERVIOUS	6	290	0.3	0.23
FB119	655307	4853291	Krosno	HY004	J1267	17.60	407	433	0.67	33	0.011	0.25	1	6	25	PERVIOUS	40	198	1.6	0.28
FB120	654746	4853141	Krosno	HY102	J495	48.41	738	656	0.12	58	0.011	0.33	1	7	25	PERVIOUS	92	197	37.1	0.30
FB121	655072	4853799	Krosno	HY004	J1500_1	22.30	467	477	1.54	49	0.011	0.25	1	6	25	PERVIOUS	49	289	0.8	0.23

Table D3: Junction Parameters

Name	X-Coordinate	Y-Coordinate	Invert Elev. (m)	Rim Elev. (m)	Depth (m)
AC_J1	652435	4853745	81	90	8.68
AC_J2	652151	4853876	87	94	7.07
J1	649835	4855861	142	142	0
J10	651425	4853928	105	105	0.075
J100	652882	4856773	97	97	0
J10073	652879	4856876	98	102	3.878
J10080	652874	4856889	98	102	4.321
J10152	652863	4856948	99	103	4.362
J10253	652791	4856973	100	106	6.327
J1030	652209	4854670	91	100	8.98
J10336	652734	4857024	101	106	5.4
J1036	651994	4853742	93	96	3.7
J1038	651993	4853741	93	97	3.8
J10439	652668	4857092	102	110	8.39
J10579	652562	4857143	103	115	12.29
J1058	654872	4853474	75	80	5.79
J10678	652497	4857201	104	118	13.57
J1072	651962	4853726	93	98	4.38
J1076.6	652357	4853799	86	89	3.478
J1080.3	652355	4853803	86	89	3.04
J1095	652175	4854723	91	100	8.59
J10950	652384	4857276	111	120	9.171
J11	652052	4853472	94	94	0
J11000	652337	4857264	113	121	7.83
J11052	652286	4857256	115	122	6.65
J1106.4	652341	4853826	86	90	3.088
J111	652021	4857124	126	129	3
J11106	652210	4857309	117	123	6.84
J1129.2	652333	4853847	87	90	2.762
J1139	654931	4853528	75	80	5.18
J11500	652421	4857336	107	120	13.54
J1155	651898	4853771	95	98	3.82
J1157	652140	4854769	92	100	7.98
J11598	652358	4857380	110	123	13.153
J11702	652356	4857473	112	125	13.47
J11838	652357	4857597	115	124	9.164
J11918	652319	4857666	117	124	7.6
J12	653768	4854171	82	87	5
J12028	652248	4857722	119	125	6.693
J12128	652155	4857692	123	127	4.718
J1215	653480	4854790	80	91	11.4
J1217	652113	4854809	92	101	8.717
J12242	652050	4857707	127	129	2.094
J123	652734	4853824	76	90	14.15

Name	X-Coordinate	Y-Coordinate	Invert Elev. (m)	Rim Elev. (m)	Depth (m)
J12324	651971	4857694	129	130	1.06
J1233	655004	4853587	75	79	4.28
J12434	651865	4857677	130	133	3
J12469	651832	4857675	131	132	1.375
J1252	651817	4853736	96	99	3.16
J12531	651782	4857639	132	134	2.12
J12585	651738	4857596	131	134	2.41
J1267	655041	4853592	75	78	3.601
J1269	652300	4853982	88	92	4.206
J13	653579	4854290	85	90	5
J1302	653420	4854851	80	91	11.25
J1303	652296	4854016	89	95	6.77
J1308	651773	4853754	96	99	3.62
J1319	652069	4854867	93	104	10.54
J1385	653386	4854918	80	88	8.63
J1389	652043	4854919	93	104	10.81
J14	652707	4855189	91	97	6
J1443	651684	4853816	98	101	2.958
J1467	653361	4854996	81	88	6.83
J147	653277	4856579	98	98	0
J1475	652008	4854991	94	106	11.81
J1492	651637	4853848	99	102	3.09
J15	651447	4856302	117	121	4.282
J1500_1	655079	4853645	75	78	3.59
J1540	652064	4853925	90	98	7.92
J1549	651593	4853890	100	103	2.74
J1550	655096	4853701	75	79	3.952
J1567	653327	4855089	81	87	6.32
J16	652804	4854713	94	94	0
J1600	651945	4855084	95	106	11.58
J1611	653312	4855136	81	88	7.271
J1627	655075	4853766	75	79	4.48
J1672	653295	4855188	80	88	7.819
J1675	652026	4853967	92	99	7.13
J17	652473	4856623	104	104	0
J171	652788	4856377	95	95	0
J1716	655048	4853849	75	79	4.23
J1720	651990	4854016	94	101	7.09
J173	652669	4853809	77	91	14.172
J1741	651864	4855150	95	102	6.85
J1772	651966	4854040	95	100	5.13
J1774	655018	4853899	75	79	4.48
J1778	653213	4855233	81	89	7.77
J18	650856	4857184	139	139	0
J1847	651807	4855235	96	104	8.04

Name	X-Coordinate	Y-Coordinate	Invert Elev. (m)	Rim Elev. (m)	Depth (m)
J1879	653131	4855281	81	89	7.89
J189	650519	4856392	135	135	0
J19	651206	4856928	132	132	0
J1911	651760	4855244	97	104	6.77
J1967	651714	4855273	98	108	10.24
J1979	653091	4855364	81	89	7.41
J2	655049	4854547	80	80	0
J20	652825	4853864	75	81	5.86
J2004	654948	4853974	75	79	3.965
J2028	654924	4853984	75	79	4.3
J2064	653058	4855437	82	89	7.4
J2065	651660	4855341	99	108	8.69
J21	651041	4854654	117	117	0
J2124	654877	4854060	75	80	4.776
J2132	653036	4855498	82	89	7.32
J2158	654845	4854074	75	80	4.594
J2160	651641	4855417	100	109	9.02
J22	650493	4854741	124	124	0
J2218	653006	4855576	82	89	6.89
J2243	654814	4854153	76	80	4.1
J2255	651618	4855491	100	110	9.84
J2266	652979	4855616	82	89	6.99
J2276	654802	4854183	76	80	3.66
J23	649970	4855481	135	135	0
J2353	652903	4855650	83	89	6.16
J2363	651544	4855560	101	110	8.6
J2367	654741	4854242	76	80	3.817
J2384	651921	4854085	96	102	5.85
J24	651129	4856414	122	122	0
J2403	654708	4854257	76	80	3.898
J2474	652794	4855673	84	90	5.63
J2488	654649	4854310	77	82	4.982
J2496	651456	4855636	103	116	12.92
J25	650986	4856427	128	128	0
J2540.00	654617	4854375	77	81	3.766
J2548	652731	4855713	84	90	5.61
J2592	654585	4854438	77	82	4.472
J2601	651393	4855705	105	118	13.82
J2624	652666	4855747	85	90	5.8
J268	652568	4853761	79	91	11.957
J2684	652617	4855778	85	90	5.3
J2711	651333	4855779	106	120	14.7
J2712	654549	4854511	77	82	4.59
J2727	652580	4855794	85	90	5.225
J2788	654509	4854575	78	82	4.37

Name	X-Coordinate	Y-Coordinate	Invert Elev. (m)	Rim Elev. (m)	Depth (m)
J28	652818	4853859	75	83	7.97
J2812	651262	4855846	109	121	12.14
J282	650735	4855795	129	129	0
J2820	654489	4854599	78	82	4.62
J2839	652510	4855839	86	92	6.15
J2851	651237	4855882	110	121	10.298
J2896	652461	4855867	87	92	5.08
J292	653640	4854079	75	84	9.5
J2927	651173	4855870	113	124	10.13
J293	650000	4855485	135	135	0
J295	652738	4854263	77	94	16.64
J2952.50	654409	4854697	78	84	5.23
J298	652735	4854264	78	94	16.79
J2984	652419	4855940	88	94	5.21
J3	654245	4854299	85	88	3
J301	650287	4855741	133	133	0
J302	654471	4852889	75	78	3.396
J3037	651085	4855898	119	126	7.2
J3055	654349	4854787	79	84	5.47
J3093	652332	4855961	90	96	6.32
J3100	654344	4854832	80	85	5.64
J311	652326	4855277	98	103	5
J3150	650975	4855905	124	126	1.84
J3185	654322	4854906	80	86	5.88
J323	651388	4855258	110	115	5
J3246	650874	4855906	126	128	1.4
J3267	652205	4856046	91	100	9.56
J328	650529	4855320	126	126	0
J3337	654259	4855043	81	86	5.39
J341	656140	4855389	88	88	0
J35	650922	4857891	154	157	3
J3509	652134	4856121	92	99	7.334
J3535	654137	4855193	82	86	4
J3540	654130	4855202	82	86	4.22
J3567	652089	4856157	94	104	9.981
J357	652678	4854277	79	88	9.28
J360	652506	4853765	80	91	10.27
J3640	652030	4856161	96	104	8.78
J369	652672	4854287	80	93	13.175
J3713	652007	4856214	96	106	9.97
J3782	651974	4856265	98	109	10.72
J382	653699	4854110	75	85	10.206
J3872	651913	4856317	101	114	12.9
J389	655762	4855256	87	87	0
J3936	651857	4856329	104	116	12.45

Name	X-Coordinate	Y-Coordinate	Invert Elev. (m)	Rim Elev. (m)	Depth (m)
J4	651126	4854683	112	112	0
J4000	655084	4853563	75	78	3.678
J4045	651758	4856323	107	118	10.96
J4078	655153	4853591	76	78	2.373
J4121	651691	4856304	109	120	10.3
J4147	655216	4853614	77	78	1.44
J417	655511	4854742	83	83	0
J4205	651623	4856321	111	120	8.65
J4210	655275	4853632	77	79	1.66
J4328	655360	4853661	78	80	1.5
J4344	655375	4853669	79	80	1.47
J435	652641	4854344	82	96	13.72
J445	653719	4854175	76	86	10.283
J4450	655481	4853686	81	84	2.42
J4500_1	651487	4856424	115	123	8.46
J4501	654955	4853973	75	79	3.88
J4526	654957	4853998	75	79	3.253
J457	652626	4854351	82	94	11.846
J4597	651425	4856487	116	124	7.8
J4635	651401	4856515	117	124	7.09
J4705	655028	4854085	75	83	7.33
J4773	655043	4854130	76	82	6.578
J4828.00	655075	4854194	76	80	3.74
J4883	655088	4854242	76	80	3.51
J492	652594	4854376	83	95	12.088
J4944	655144	4854259	77	80	3.1
J495	654753	4852932	74	84	9.878
J495.54	652419	4853745	82	89	7.56
J4965	655164	4854269	78	80	2.732
J5	651424	4856364	119	122	3
J5004	651370	4856563	119	121	2.524
J501	653709	4854230	77	87	10.31
J5013	655185	4854306	78	82	3.73
J5027	651353	4856565	119	121	2.268
J5106	651292	4856619	122	129	7.301
J5164	651270	4856673	124	130	5.673
J5228	655220	4854387	79	81	1.935
J5255	651215	4856760	128	130	2.49
J5400	655185	4854397	78	81	2.328
J546	653705	4854274	77	88	11.42
J5490	655335	4854437	80	82	2.03
J5504	655186	4854503	79	81	1.9
J564	652531	4854401	84	95	11.73
J6	651724	4855576	106	106	0
J6000	652613	4855845	87	91	3.79

Name	X-Coordinate	Y-Coordinate	Invert Elev. (m)	Rim Elev. (m)	Depth (m)
J610	654775	4853104	75	87	12.702
J6103	652661	4855929	89	92	3.19
J6188	652646	4856009	90	92	2.9
J622	652495	4854440	85	99	14.29
J6245	652610	4856052	90	93	3.37
J640.5	652282	4853791	85	90	5.192
J6409	652491	4856254	92	95	3.44
J644	652279	4853793	85	90	5.049
J688	653657	4854385	77	91	13.67
J692	650587	4856227	131	131	0
J696	654743	4853192	75	89	14.67
J698	651376	4853921	105	105	0
J7	651359	4854748	110	111	1.072
J7000	652063	4856080	94	101	7.65
J701	652429	4854470	87	100	12.94
J7060	652018	4856048	95	103	8.48
J7148	651933	4856062	97	107	9.96
J7205	651881	4856082	100	107	6.77
J7257	651838	4856076	102	110	8.89
J728	650412	4855620	130	130	0
J7349	651750	4856091	103	113	9.64
J7367	651734	4856096	104	112	7.98
J740	653072	4855633	85	88	3
J742	652219	4856544	108	111	3
J7435	651673	4856123	105	115	10.07
J746	655491	4855184	85	88	3
J750	655704	4855408	86	89	3
J7525	651621	4856179	107	120	13.06
J7598	651561	4856191	110	120	10.12
J7664	651500	4856210	112	120	8.37
J772	653704	4855642	90	95	5
J7723	651445	4856190	113	120	7.22
J775	652381	4854524	88	98	10.09
J7787	651386	4856174	114	122	7.98
J781	653703	4854452	77	93	15.57
J7866	651312	4856152	114	121	7.33
J790	650717	4855857	129	131	2
J792	652153	4853871	87	94	7
J7958	651228	4856127	115	124	9.41
J797	652390	4854102	94	99	5
J8	650391	4855615	130	130	0
J8000	651453	4856359	116	121	5.05
J8065	651410	4856320	118	121	2.76
J808	653386	4855280	85	87	2
J8129	651350	4856297	119	123	4.19

Name	X-Coordinate	Y-Coordinate	Invert Elev. (m)	Rim Elev. (m)	Depth (m)
J8182	651298	4856290	119	123	3.89
J819	652361	4856233	97	100	3
J8246	651240	4856317	121	124	3.52
J825	650650	4856042	130	130	0
J83	652915	4854170	75	81	5.604
J834	652962	4856424	94	97	3
J835	652342	4854561	88	97	9.06
J8369	651148	4856389	121	128	6.688
J8442	651014	4856434	123	128	4.54
J851	654714	4853347	75	89	14.422
J89	653529	4853999	75	84	9.42
J890	652116	4853823	92	95	3
J891	652318	4854605	89	98	9.18
J9	651375	4853897	108	108	0
J9020	651355	4856615	120	126	5.691
J9103	651370	4856680	124	129	5.24
J923	652289	4854617	90	97	7.06
J9236	651360	4856811	129	133	4.19
J927	653661	4854568	78	95	17.172
J9320	651343	4856900	129	132	3.13
J934	654766	4853416	75	82	7.68
J9500	651088	4856241	119	127	7.99
J9603	650891	4856326	122	127	4.92
J968	652051	4853781	92	96	3.61
J976	652250	4854639	90	98	7.52
J9800	651088	4856096	118	126	8.46
J9933	650862	4856040	122	127	4.7
J995.96	652420	4853751	82	89	7.56
KC_J1	655059	4853599	75	78	3.678
KC_J2	654954	4853970	75	79	4
KC_J3	655185	4854340	78	81	3.015
PC_J1	652568	4855804	85	91	6.1
PC_J2	652440	4857295	105	120	15.2
PC_J3	652138	4856100	91	100	8.92
PC_J4	651214	4856125	115	125	9.41
PC_J5	651520	4856380	113	122	8.46
PC_J6	651376	4856565	118	127	8.59

Table D4: Conduit Parameters

Name	Inlet Node	Outlet Node	Tag	Length (m)	Roughness	Inlet Offset (m)	Outlet Offset (m)	Flow Limit (m^3/s)	Flap Gate	Cross-Section	Geom1 (m)	Geom2 (m)	Geom3	Geom4	Barrels	Transect
c	J1	J293	Routing	410.806	0.013	0	0	0	NO	STREET	0	0	0	0	1	
C10	J728	J328	Routing	322.048	0.013	0	0	0	NO	STREET	0	0	0	0	1	
C102	J742	J819	Routing	349.237	0.013	0	0	0	NO	STREET	0	0	0	0	1	
C11	J328	J21	Routing	839.948	0.013	0	0	0	NO	STREET	0	0	0	0	1	
C12_2	J7	J2384	Routing	1104.933	0.013	0	1	0	NO	STREET	0	0	0	0	1	
C121	J282	J790	Routing	65.474	0.013	0	0	0	NO	STREET	0	0	0	0	1	
C13	J6	J2255	Split/Major	136.53	0.05	1	0	0	NO	TRAPEZOIDAL	1	5	1	1	1	
C159	J323	J1319	Split/Major	974.313	0.013	1	0	0	NO	STREET	0	0	0	0	1	
C16	J797	J369	Split/Major	370.171	0.013	1	2	0	NO	STREET	0	0	0	0	1	
C18	J8	J728	Split/Major	20.903	0.013	1	0	0	NO	STREET	0	0	0	0	1	
C2	J825	J9933	Split/Major	212.739	0.05	1	0	0	NO	TRAPEZOIDAL	1	5	1	3	1	
C202	J293	J728	Routing	441.61	0.013	0	0	0	NO	STREET	0	0	0	0	1	
C21	J9	J10	Split/Major	58.635	0.05	1	1	0	NO	TRAPEZOIDAL	1	5	1	1	1	
C212	J14	J1778	Routing	825.385	0.013	0	2	0	YES	STREET	0	0	0	0	1	
C212_1	J311	J14	Routing	613.357	0.013	0	0	0	NO	STREET	0	0	0	0	1	
C22	J11	J995.96	Split/Minor	462.287	0.01	0	0	0.42	YES	CIRCULAR	1	0	0	0	1	
C23	J11	OF7	Split/Major	947.179	0.013	1	0	0	NO	STREET	0	0	0	0	1	
C24	J12	J445	Split/Minor	48.41	0.01	0	0	0.639	YES	CIRCULAR	1	0	0	0	1	
C25	J12	OF8	Split/Major	92.944	0.013	1	0	0	NO	STREET	0	0	0	0	1	
C26	J13	J501	Split/Minor	142.807	0.01	0	0	0.203	YES	CIRCULAR	1	0	0	0	1	
C27	J13	OF9	Split/Major	188.477	0.013	1	0	0	NO	STREET	0	0	0	0	1	
C271	J341	J389	Routing	418.416	0.05	0	0	0	NO	TRAPEZOIDAL	1	5	1	1	1	
C28	J16	J14	Split/Minor	485.276	0.01	0	0	0.224	YES	CIRCULAR	1	0	0	0	1	
C29	J16	OF10	Split/Major	596.598	0.013	1	0	0	NO	STREET	0	0	0	0	1	
C293	J100	J834	Routing	480.672	0.013	0	0	0	NO	STREET	0	0	0	0	1	
C3	J790	J3246	Routing	165.229	0.05	0	0	0	NO	TRAPEZOIDAL	1	5	1	3	1	
C30	J808	J1611	Routing	160.999	0.013	0	2	0	YES	STREET	0	0	0	0	1	
C302	J171	J834	Routing	187.639	0.013	0	0	0	NO	STREET	0	0	0	0	1	
C305_1	J698	J10	Split/Major	52.441	0.05	1	1	0	NO	TRAPEZOIDAL	1	5	1	1	1	
C305_2	J10	J2384	Routing	526.794	0.05	0	1	0	NO	TRAPEZOIDAL	1	10	1	1	1	
C308	J750	J746	Routing	400.645	0.013	0	0	0	NO	STREET	0	0	0	0	1	
C309	J189	J692	Routing	187.915	0.013	0	0	0	NO	STREET	0	0	0	0	1	
C31	J147	J834	Routing	379.178	0.013	0	0	0	NO	STREET	0	0	0	0	1	
C32	J740	J2266	Routing	94.489	0.013	0	0	0	NO	STREET	0	0	0	0	1	
C33	J17	J171	Routing	512.367	0.013	0	0	0	NO	STREET	0	0	0	0	1	
C332	J111	J742	Routing	664.449	0.013	0	0	0	NO	STREET	0	0	0	0	1	
C339	J389	J746	Routing	330.903	0.013	0	0	0	NO	STREET	0	0	0	0	1	
C347	J301	J728	Routing	204.857	0.013	0	0	0	NO	STREET	0	0	0	0	1	
C35	J819	J2896	Routing	387.909	0.013	0	2	0	NO	STREET	0	0	0	0	1	
C36	J18	J5255	Routing	603.466	0.05	0	0	0	NO	TRAPEZOIDAL	1	5	1	1	1	
C37	J19	J5027	Routing	398.504	0.05	0	1	0	NO	TRAPEZOIDAL	1	5	1	10	1	
C39	J4	J10	Split/Major	815.767	0.013	0	0	0	NO	STREET	0	0	0	0	1	
C4	J35	J12434	Routing	1327.735	0.013	0	1	0	NO	STREET	0	0	0	0	1	
C40	J22	J4	Split/Minor	635.762	0.01	0	0	0.386	YES	CIRCULAR	1	0	0	0	1	
C41	J22	OF5	Split/Major	139.292	0.013	1	0	0	NO	STREET	0	0	0	0	1	
C42	J21	J4	Split/Minor	89.023	0.01	0	0	3.159	YES	CIRCULAR	1	0	0	0	1	
C43	J21	J4	Split/Major	89.026	0.013	1	0	0	NO	STREET	0	0	0	0	1	
C44	J5	J8000	Split/Major	29.17	0.013	1	1	0	NO	STREET	0	0	0	0	1	
C47	J23	J293	Split/Major	29.787	0.013	1	0	0	NO	STREET	0	0	0	0	1	
C50	J25	J8442	Split/Major	28.627	0.05	1	1	0	NO	TRAPEZOIDAL	1	5	1	1	1	
C51	J24	J8369	Split/Major	31.78	0.05	1	1	0	NO	TRAPEZOIDAL	1	5	1	1	1	
C52	J834	J740	Split/Major	977.6	0.013	1	2	0	NO	STREET	0	0	0	0	1	
C53	J834	J2684	Split/Minor	853.433	0.01	0	0	1.068	YES	CIRCULAR	1	0	0	0	1	
C54	J417	J2	Split/Major	534.025	0.035	1	1	0	NO	TRAPEZOIDAL	1	25	1	1	1	
C6	J417	J5504	Split/Minor	485.669	0.013	0	1	10.236	NO	STREET	0	0	0	0	1	
C7	J2	J5013	Routng	283.926	0.05	0	0	0	NO	TRAPEZOIDAL	1	25	1	1	1	
C8	J3	J2367	Split/Major	650.83	0.013	1	2	0	YES	STREET	0	0	0	0	1	
C82	J692	J825	Routing	196.966	0.013	0	0	0	NO	STREET	0	0	0	0	1	
C86	J746	J417	Routing	555.389	0.013	0	0	0	NO	STREET	0	0	0	0	1	

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C98	J772	J808	Split/Major	511.818	0.013	1	0	0	NO	STREET	0	0	0	0	1	
CAC_J2	AC_J2	J644		153.229	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	794
CJ0_1	J83	OF2		369.272	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	0_1
CJ0_3	J89	OF4		94.1	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	0_3
CJ10000	J10073	J100		105.525	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	10000
CJ10152_1	J10152	J10080		74.121	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	10152
CJ10152_2	J10080	J10073		14.511	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	10152
CJ10253	J10253	J10152		99.6	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	10253
CJ1030	J1030	J976		53.5	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	1030
CJ10336	J10336	J10253		82.8	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	10336
CJ10439	J10439	J10336		102.3	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	10439
CJ10579	J10579	J10439		140.9	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	10579
CJ1058	J1058	J934		124.2	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	1058
CJ10678	J10678	J10579		98.3	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	10678
CJ10758	PC_J2	J10678		157.858	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	10758
CJ1080.3	J1080.3	J995.96		83.043	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	1080.3
CJ1095	J1095	J1030		65.7	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	1095
CJ10950	J10950	PC_J2		142.43	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	10950
CJ11000	J11000	J10950		50.2	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	11000
CJ11052	J11052	J11000		51.5	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	11052
CJ11106	J11106	J11052		54.2	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	11106
CJ1129.2_1	J1129.2	J1106.4		22.269	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	1129.2
CJ1129.2_2	J1106.4	J1080.3		27.47	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	1129.2
CJ1139	J1139	J1058		80.4	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	1139
CJ11500	J11500	PC_J2		56.09	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	11500
CJ1155_1	J1155	J1036		119.293	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	1155
CJ1155_2	J1036	J968		68.497	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	1155
CJ1157	J1157	J1095		61.3	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	1157
CJ11598	J11598	J11500		98.3	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	11598
CJ11702	J11702	J11598		103.7	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	11702
CJ11838	J11838	J11702		137	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	11838
CJ11918	J11918	J11838		82.9	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	11918
CJ12028	J12028	J11918		106.6	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	12028
CJ12128	J12128	J12028		103.4	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	12128
CJ1217	J1217	J1157		60.3	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	1217
CJ1221	J1233	J1139		94.5	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	1221
CJ12242	J12242	J12128		110.2	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	12242
CJ123_1	J123	J28		95.098	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	123
CJ123_2	J28	J20		8.637	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	123
CJ12324	J12324	J12242		81.6	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	12324
CJ12414	J12434	J12324		110.1	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	12414
CJ1248	J1252	J1155		96.685	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	1248
CJ12531_1	J12531	J12469		62.293	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	12531
CJ12531_2	J12469	J12434		32.979	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	12531
CJ12585	J12585	J12531		54.3	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	12585
CJ1286_1	KC_J1	J1267		20.2	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	1286
CJ1286_2	J1267	J1233		37.152	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	1286
CJ1302_1	J1302	J1215		87.053	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	1302
CJ1302_2	J1215	J927		286.634	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	1302
CJ1303	J1303	J1129.2		174.298	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	1303
CJ1319	J1319	J1217		102.5	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	1319
CJ1385	J1385	J1302		83.7	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	1385
CJ1389	J1389	J1319		69.3	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	1389
CJ1467	J1467	J1385		81.6	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	1467
CJ1475	J1475	J1389		86.4	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	1475
CJ1479_1	J1492	J1443		76.106	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	1479
CJ1479_3	J1443	J1308		106.608	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	1479
CJ1479_4	J1308	J1252		48.03	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	1479
CJ1500_1	J1500_1	KC_J1		52.29	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	1500_1
CJ1510	J1540	AC_J2		122.693	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	1510

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CJ1533	J1549	J1492		57.9	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	1533
CJ1550	J1550	J1500_1		59.2	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	1550
CJ1564	J1600	J1475		124.872	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	1564
CJ1567	J1567	J1467		99.8	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	1567
CJ1596	J1611	J1567		50.4	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	1596
CJ1627	J1627	J1550		68.3	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	1627
CJ1693	J1741	J1600		141.39	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	1693
CJ1710	J1720	J1540		121.144	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	1710
CJ1716	J1716	J1627		88.2	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	1716
CJ173	J173	J123		71.4	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	173
CJ1774	J1774	J1716		58.6	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	1774
CJ1778_1	J1778	J1672		106.723	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	1778
CJ1778_2	J1672	J1611		54.389	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	1778
CJ1851	KC_J2	J1774		78.055	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	1851
CJ1879	J1879	J1778		100.8	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	1879
CJ1911_1	J1911	J1847		63.602	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	1911
CJ1911_2	J1847	J1741		102.49	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	1911
CJ1967	J1967	J1911		56.7	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	1967
CJ1979	J1979	J1879		100	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	1979
CJ2000	J2384	J1720		97.693	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	2000
CJ2000_1	J2004	KC_J2		33.01	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	2000_1
CJ2064	J2064	J1979		84.6	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	2064
CJ2065	J2065	J1967		97.9	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	2065
CJ2120_1	J2124	J2028		93.577	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	2120
CJ2120_2	J2028	J2004		26.257	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	2120
CJ2132	J2132	J2064		67.9	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	2132
CJ2160	J2160	J2065		94.7	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	2160
CJ2202	J2243	J2124		120.468	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	2202
CJ2209	J2218	J2132		86.5	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	2209
CJ221	J268	J173		119.512	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	221
CJ2255	J2255	J2160		94.8	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	2255
CJ2353_1	J2353	J2266		87.062	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	2353
CJ2353_2	J2266	J2218		47.955	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	2353
CJ2361_1	J2367	J2276		91.491	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	2361
CJ2361_2	J2276	J2243		32.991	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	2361
CJ2363	J2363	J2255		108	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	2363
CJ2474	J2474	J2353		120.4	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	2474
CJ2488_1	J2488	J2403		84.088	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	2488
CJ2488_2	J2403	J2367		36.458	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	2488
CJ2496	J2496	J2363		132.7	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	2496
CJ2540.00	J2540.00	J2488		72	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	2540
CJ2548	J2548	J2474		74.6	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	2548
CJ2592	J2592	J2540.00		70.8	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	2592
CJ2601	J2601	J2496		105	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	2601
CJ2624	J2624	J2548		75.5	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	2624
CJ2676	J2684	J2624		59.7	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	2676
CJ2711	J2711	J2601		110	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	2711
CJ2712	J2712	J2592		80.8	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	2712
CJ2777	J2788	J2712		76.7	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	2777
CJ2803	J2812	J2711		101.1	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	2803
CJ2833	J2839	PC_J1		70.135	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	2833
CJ2910_1	J2952.50	J2820		126.295	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	2910
CJ2910_2	J2820	J2788		31.369	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	2910
CJ292	J292	J89		202.9	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	292
CJ2927_1	J2927	J2851		71.49	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	2927
CJ2927_2	J2851	J2812		43.967	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	2927
CJ298	J298	J83		218.826	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	298
CJ2984_1	J2984	J2896		87.567	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	2984
CJ2984_2	J2896	J2839		56.944	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	2984
CJ2995	J3055	J2952.50		108.49	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	2995

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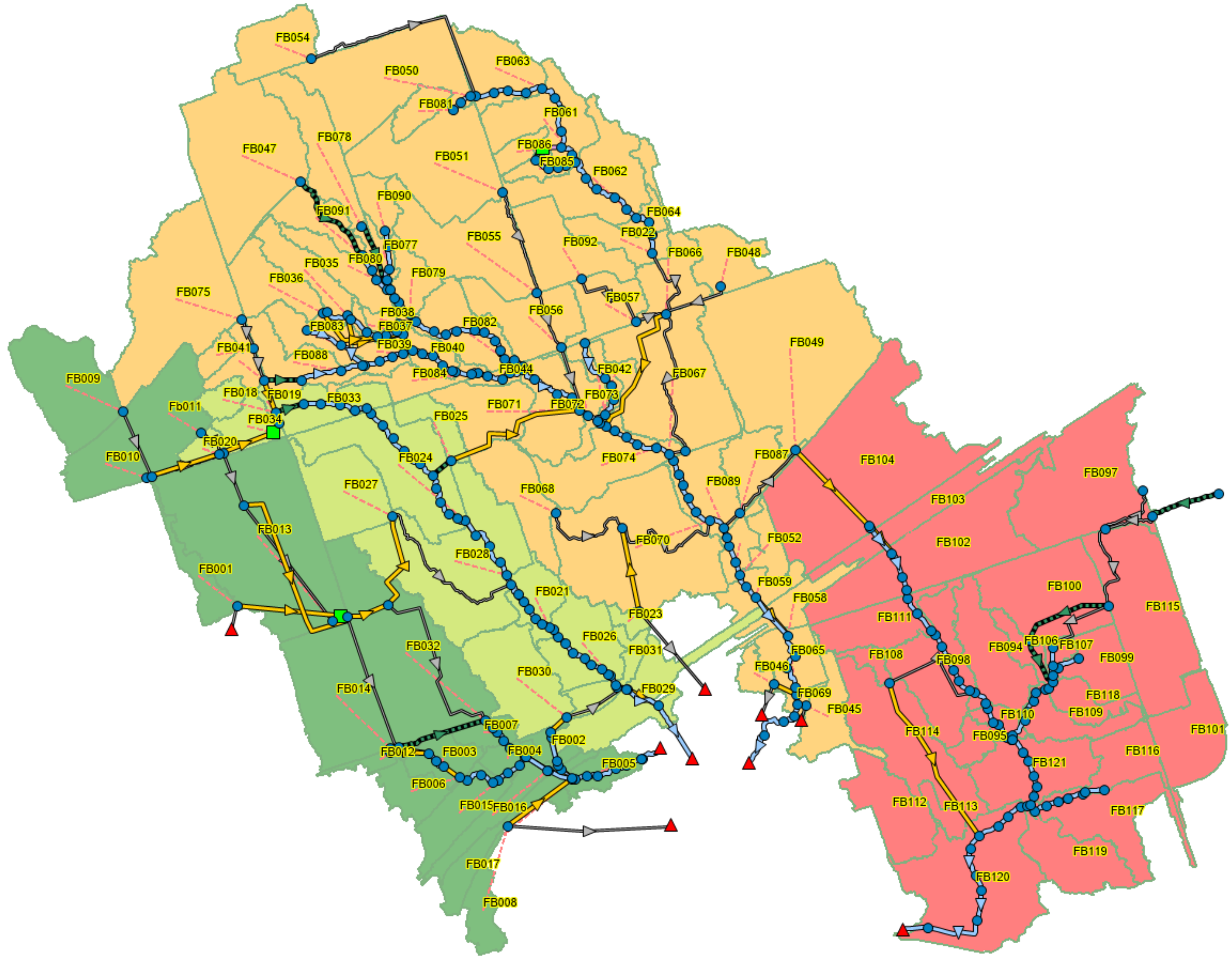
CJ3037	J3037	J2927		109.8	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	3037
CJ3093	J3093	J2984		109	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	3093
CJ3150	J3150	J3037		112.423	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	3150
CJ3177	J3267	J3093		174.192	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	3177
CJ3180	J3246	J3150		102.49	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	3180
CJ3185_1	J3185	J3100		77.825	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	3185
CJ3185_2	J3100	J3055		45.168	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	3185
CJ3275	J3337	J3185		158.589	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	3275
CJ330	J360	J268		67.775	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	330
CJ3365	PC_J3	J3267		108.09	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	3365
CJ3500	J3509	PC_J3		27.08	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	3500
CJ3540	J3540	J3337		205.088	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	3540
CJ3640	J3640	J3509		133.404	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	3640
CJ369_1	J369	J357		12.772	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	369
CJ369_2	J357	J298		58.929	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	369
CJ3713	J3713	J3640		72.6	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	3713
CJ3782	J3782	J3713		69.3	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	3782
CJ382	J382	J292		82	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	382
CJ3872	J3872	J3782		90.161	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	3872
CJ3936	J3936	J3872		63.9	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	3936
CJ4000	J4000	KC_J1		53.51	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	4000
CJ4045	J4045	J3936		109.1	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	4045
CJ405	AC_J1	J360		60.925	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	405
CJ4078	J4078	J4000		78.7	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	4078
CJ4100	J4147	J4078		69.117	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	4100
CJ4121	J4121	J4045		76	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	4121
CJ4205	J4205	J4121		83.7	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	4205
CJ4210	J4210	J4147		63.077	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	4210
CJ4316	PC_J5	J4205		129.886	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	4316
CJ4320	J4328	J4210		117.334	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	4320
CJ4430_1	J4450	J4344		115.006	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	4430
CJ4430_2	J4344	J4328		16.816	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	4430
CJ445	J445	J382		70.093	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	445
CJ449	J435	J369		82.402	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	449
CJ4500_1	J4500_1	PC_J5		56.32	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	4500_1
CJ4587	J4597	J4500_1		97	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	4587
CJ4705	J4705	KC_J2		174.503	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	4705
CJ4773	J4773	J4705		79.9	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	4773
CJ4828.00	J4828.00	J4773		78.8	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	4828
CJ485	J501	J445		57.5	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	485
CJ4883	J4883	J4828.00		52.4	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	4883
CJ4935	J4944	J4883		60.3	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	4935
CJ495	J495	J302		360.3	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	495
CJ495.54	J495.54	AC_J1		31.71	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	495.54
CJ-50	J20	OF1		132.964	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	-50
CJ5004	J5004	PC_J6		5.74	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	5004
CJ5013_1	J5013	J4965		45.041	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	5013
CJ5013_2	J4965	J4944		22.089	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	5013
CJ5043	KC_J3	J5013		33.506	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	5043
CJ5106_1	J5106	J5027		83.859	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	5106
CJ5106_2	J5027	J5004		16.932	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	5106
CJ5164	J5164	J5106		59	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	5164
CJ5228	J5228	KC_J3		65.28	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	5228
CJ5255	J5255	J5164		108.968	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	5255
CJ530	J564	J435		111.083	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	530
CJ5400	J5400	KC_J3		64.42	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	5400
CJ5490	J5490	J5228		128.041	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	5490
CJ5504	J5504	J5400		109.158	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	5504
CJ6000	J6000	PC_J1		83.64	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	6000
CJ610	J610	J495		175.3	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	610

Name	Inlet Node	Outlet Node	Tag	Length (m)	Roughness	Inlet Offset (m)	Outlet Offset (m)	Flow Limit (m^3/s)	Flap Gate	Cross-Section	Geom1 (m)	Geom2 (m)	Geom3	Geom4	Barrels	Transect
CJ6103	J6103	J6000		103.996	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	6103
CJ6188	J6188	J6103		85.4	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	6188
CJ622	J622	J564		57.4	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	622
CJ6245	J6245	J6188		56.5	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	6245
CJ631_1	J688	J546		142.189	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	631
CJ631_2	J546	J501		44.346	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	631
CJ6409	J6409	J6245		262.717	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	6409
CJ644	J644	J495.54		147.731	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	644
CJ696	J696	J610		94.9	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	696
CJ7000	J7000	PC_J3		110.25	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	7000
CJ701	J701	J622		79.3	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	701
CJ7060	J7060	J7000		59.9	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	7060
CJ7136	J7148	J7060		88.363	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	7136
CJ7257_1	J7257	J7205		52.489	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	7257
CJ7257_2	J7205	J7148		56.327	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	7257
CJ7308	J7349	J7257		92.062	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	7308
CJ7435	J7435	J7349		85.293	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	7435
CJ7525	J7525	J7435		89.6	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	7525
CJ7598	J7598	J7525		73.2	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	7598
CJ7657	J7664	J7598		66.4	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	7657
CJ77_1	J302	OF3		143.902	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	77_1
CJ775	J775	J701		73.6	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	775
CJ7787_1	J7787	J7723		63.074	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	7787
CJ7787_2	J7723	J7664		58.326	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	7787
CJ781	J781	J688		92.9	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	631
CJ7866	J7866	J7787		79.4	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	7866
CJ7958	J7958	J7866		92	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	7958
CJ8000	J8000	PC_J5		88.67	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	8000
CJ8060	J8065	J8000		64.5	0.01	0.5	0	0	NO	IRREGULAR	0	0	0	0	1	8060
CJ8129	J8129	J8065		64	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	8129
CJ8182	J8182	J8129		53.5	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	8182
CJ8246	J8246	J8182		64.4	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	8246
CJ8316	J8369	J8246		122.382	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	8316
CJ835	J835	J775		60.3	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	835
CJ8442	J8442	J8369		72.7	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	8442
CJ851	J851	J696		165.3	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	851
CJ884	J891	J835		55.7	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	884
CJ890	J890	AC_J2		63.815	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	890
CJ9000	J9020	PC_J6		86.39	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	9000
CJ914	J927	J781		145.37	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	914
CJ9236_1	J9236	J9103		132.767	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	9236
CJ9236_2	J9103	J9020		66.744	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	9236
CJ9320	J9320	J9236		91.827	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	9320
CJ933	J968	J890		78.194	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	933
CJ934	J934	J851		88	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	934
CJ9500	J9500	PC_J4		197.91	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	9500
CJ9603	J9603	J9500		103.2	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	9603
CJ976_1	J976	J923		53.432	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	976
CJ976_2	J923	J891		31.493	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	976
CJ9800	J9800	PC_J4		131.98	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	9800
CJ9933	J9933	J9800		133.4	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	9933
CJ995.96	J995.96	AC_J1		15.85	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	995.96
CPC_J1_1	PC_J1	J2727		15.579	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	2730
CPC_J1_2	J2727	J2684		40.423	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	2730
CPC_J4	PC_J4	J7958		65.99	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	7958
CPC_J6	PC_J6	J4597		97.762	0.01	0	0	0	NO	IRREGULAR	0	0	0	0	1	4665

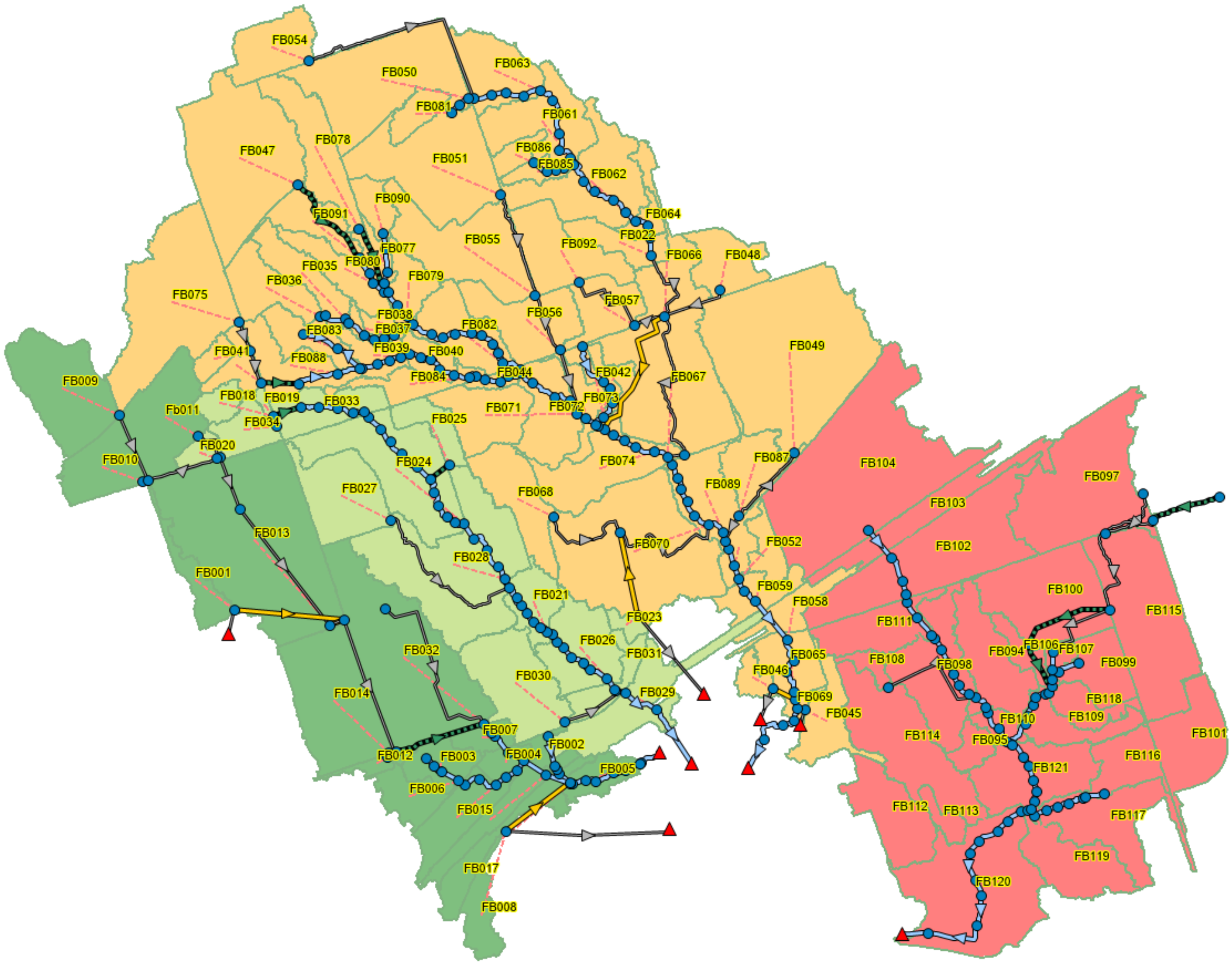


Frenchman's Bay Watershed Hydrologic Model Update

Model Schematic – Existing Conditions

Date:	Project:	Submitter:	Reviewer:
February 2024	35765-531	Z.Zimmer	A.McKay

Figure
D1



Frenchman's Bay Watershed Hydrologic Model Update

Model Schematic – Future Conditions

Date:	Project:	Submitter:	Reviewer:
February 2024	35765-531	Z.Zimmer	A.McKay

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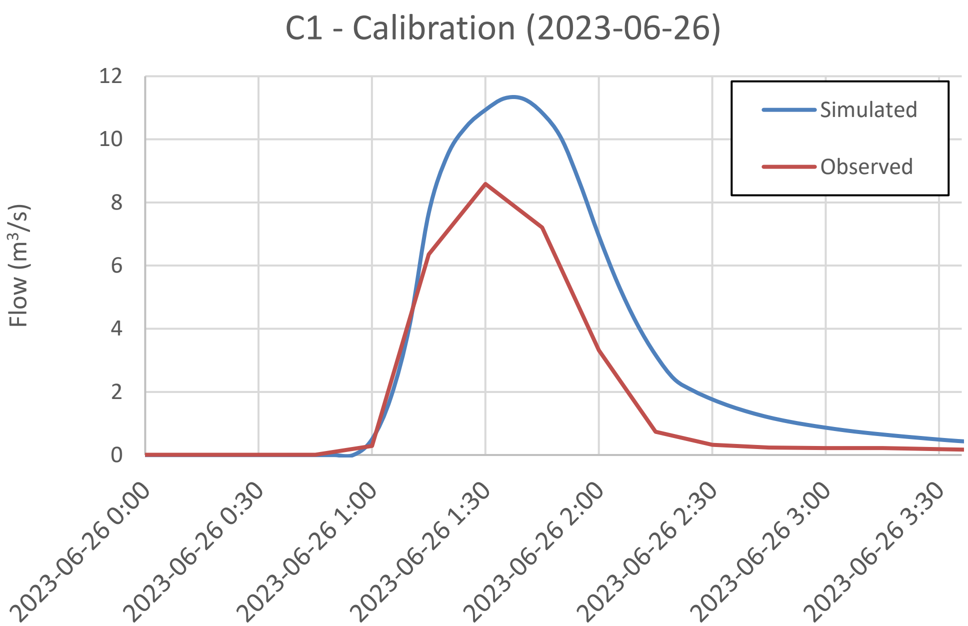
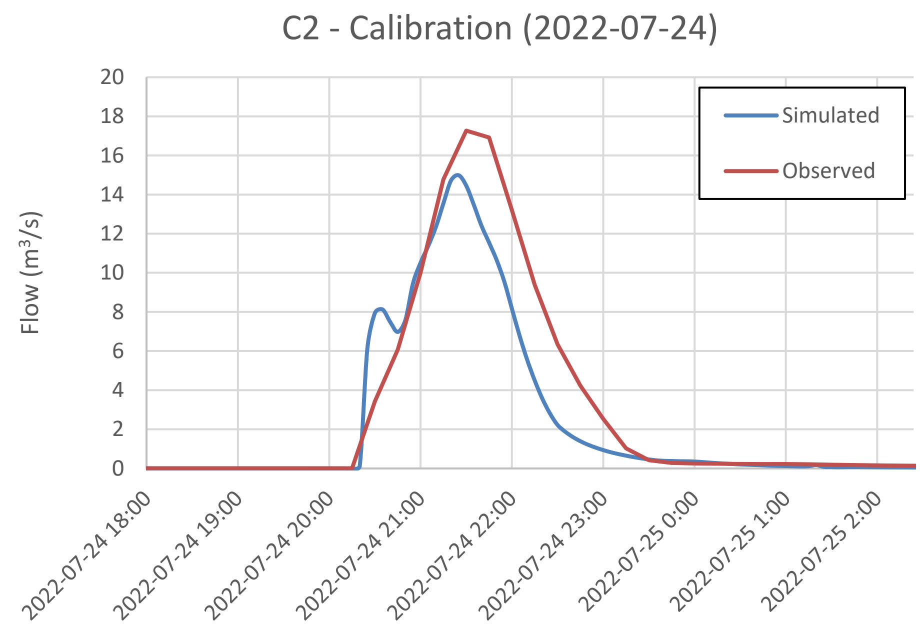
Figure
D2

APPENDIX E
Calibration and Validation Plots





Event ID	Date of Simulation	HY040 Peak Flow (m3/s)	HY040 Volume (m3)	Modelled Peak Flow m3/s)	Modelled Volume (m3)	Peak Flow Difference (%)	Volume Difference (%)	NSE	R2	ISE	ISE Rating
C1	2023-06-26	8.6	25,736	11.3	41,709	31.5%	62.1%	0.73	0.94	22.1	Fair
C2	2022-07-24	17.3	97,322	15.0	76,586	-13.2%	-21.3%	0.87	0.90	10.6	Fair

Frenchman's Bay Watershed Hydrologic Model Update

HY040 Results

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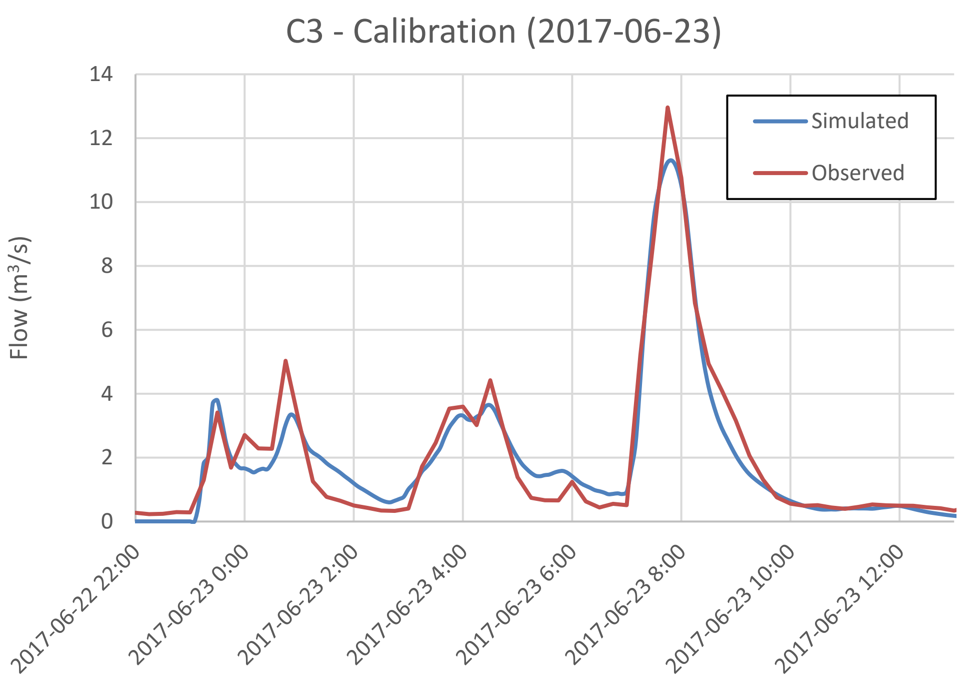
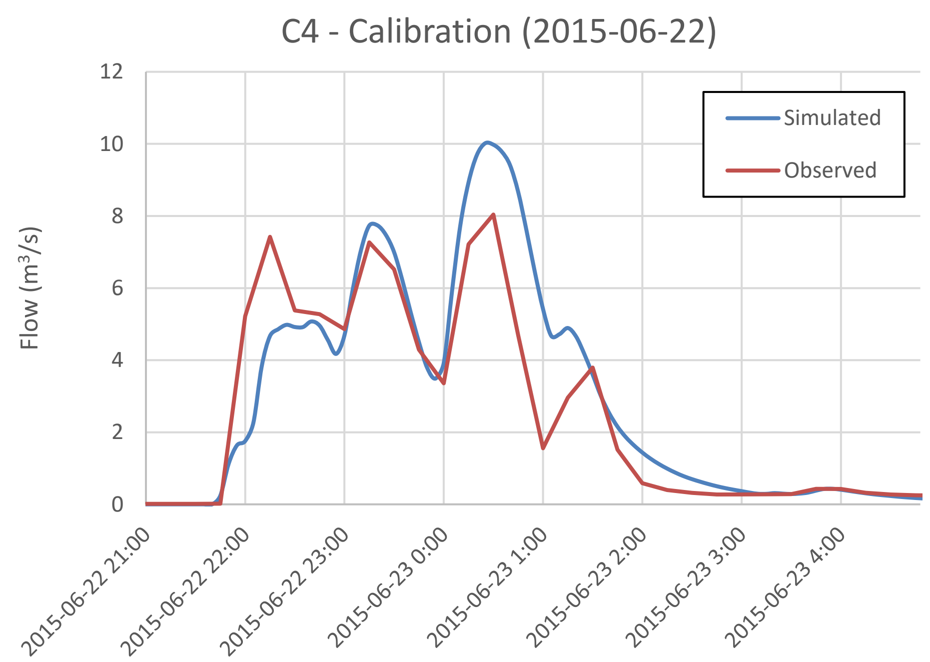
Figure E1





Event ID	Date of Simulation	HY040 Peak Flow (m3/s)	HY040 Volume (m3)	Modelled Peak Flow m3/s)	Modelled Volume (m3)	Peak Flow Difference (%)	Volume Difference (%)	NSE	R2	ISE	ISE Rating
C3	2017-06-23	13.0	114,940	11.3	108,640	-12.8%	-5.5%	0.94	0.94	3.9	Very good
C4	2015-06-22	8.0	78,316	10.0	85,701	24.6%	9.4%	0.79	0.84	9.17	Good

Frenchman's Bay Watershed Hydrologic Model Update

HY040 Results

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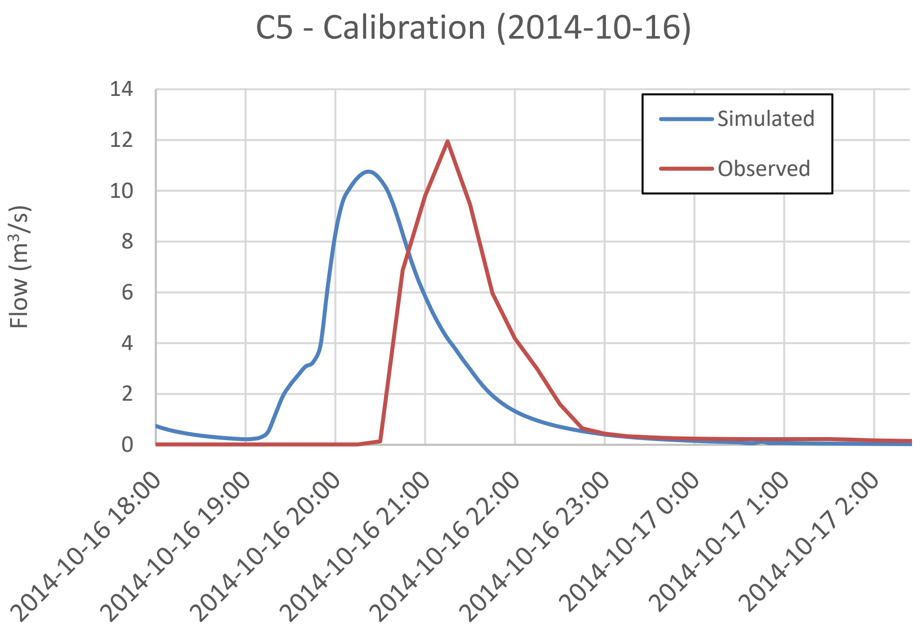
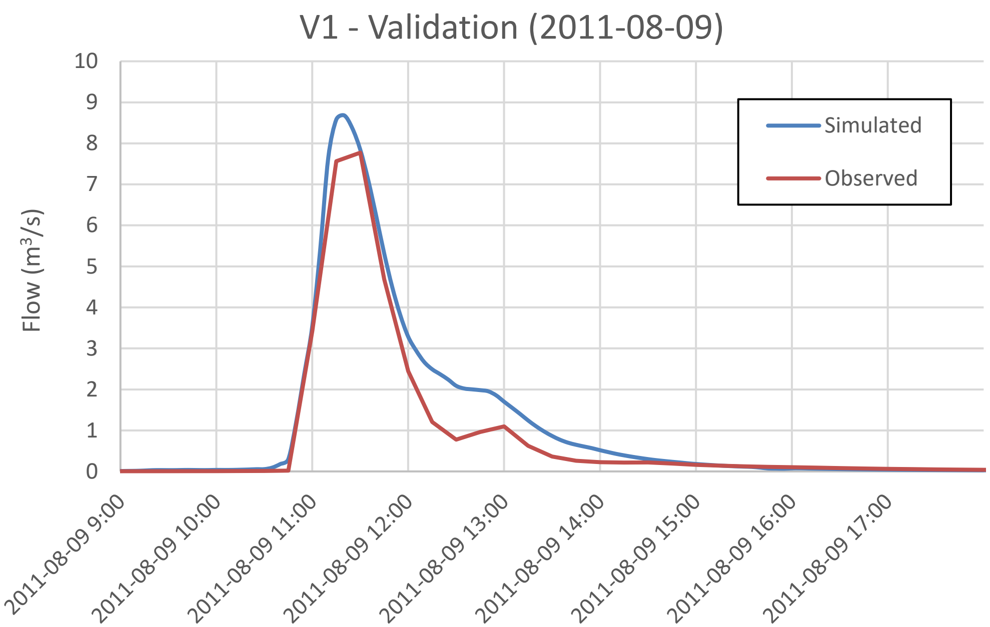
Figure E2





Event ID	Date of Simulation	HY040 Peak Flow (m3/s)	HY040 Volume (m3)	Modelled Peak Flow m3/s)	Modelled Volume (m3)	Peak Flow Difference (%)	Volume Difference (%)	NSE	R2	ISE	ISE Rating
C5	2014-10-16	11.9	51,781	10.7	61,260	-10.2%	18.3%	-0.18	0.15	36.5	Poor
V1	2011-08-09	7.8	29,875	8.7	38,488	11.7%	28.8%	0.94	0.97	8.53	Good

Frenchman's Bay Watershed Hydrologic Model Update

HY040 Results

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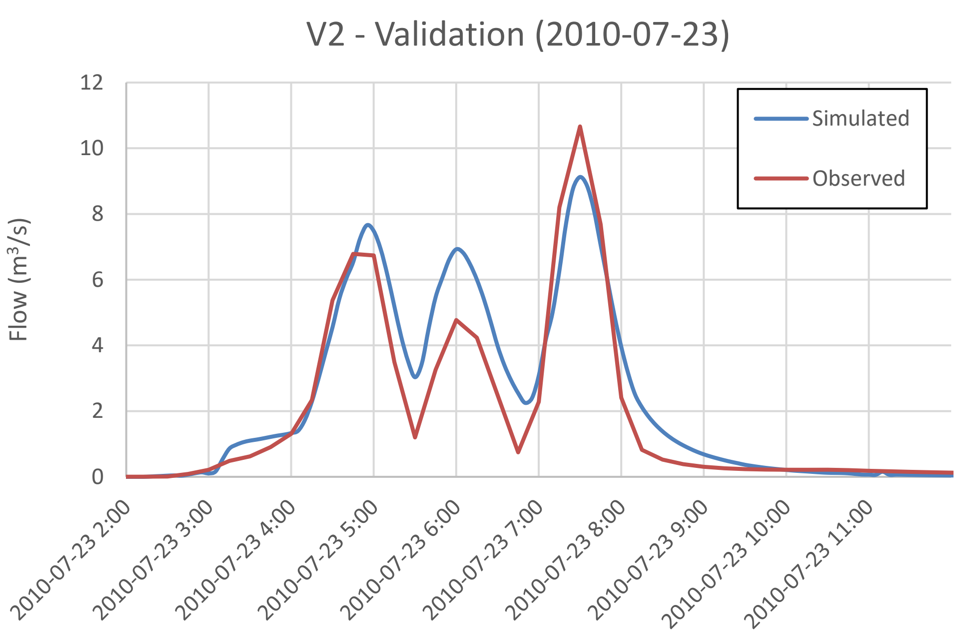
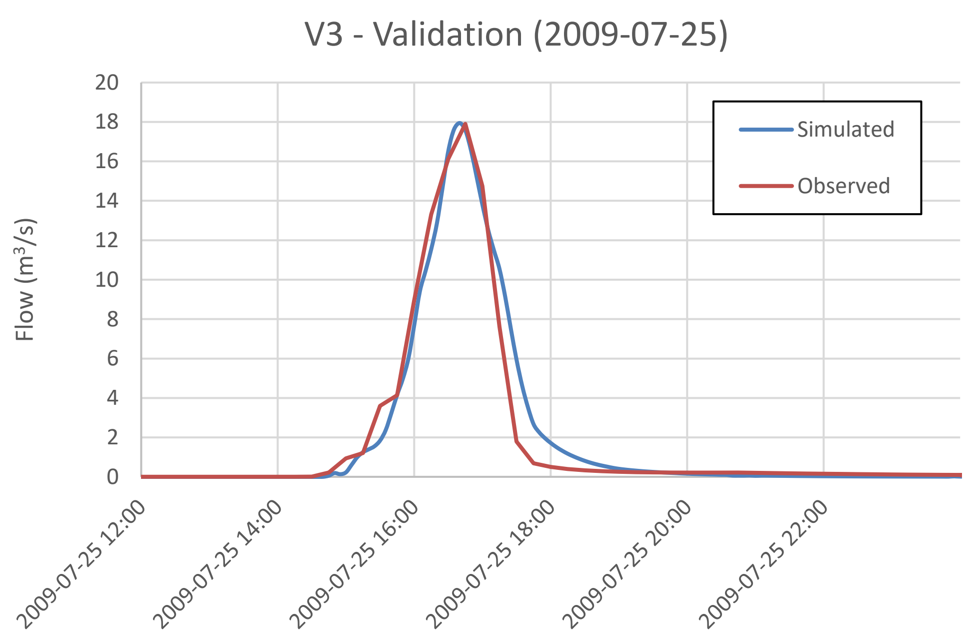
Figure E3





Event ID	Date of Simulation	HY040 Peak Flow (m3/s)	HY040 Volume (m3)	Modelled Peak Flow m3/s)	Modelled Volume (m3)	Peak Flow Difference (%)	Volume Difference (%)	NSE	R2	ISE	ISE Rating
V2	2010-07-23	10.7	73,548	9.1	86,542	-14.4%	17.7%	0.88	0.90	7.74	Good
V3	2009-07-25	17.9	86,776	17.9	90,145	0.2%	3.9%	0.97	0.97	5.92	Very good

Frenchman's Bay Watershed Hydrologic Model Update

HY040 Results

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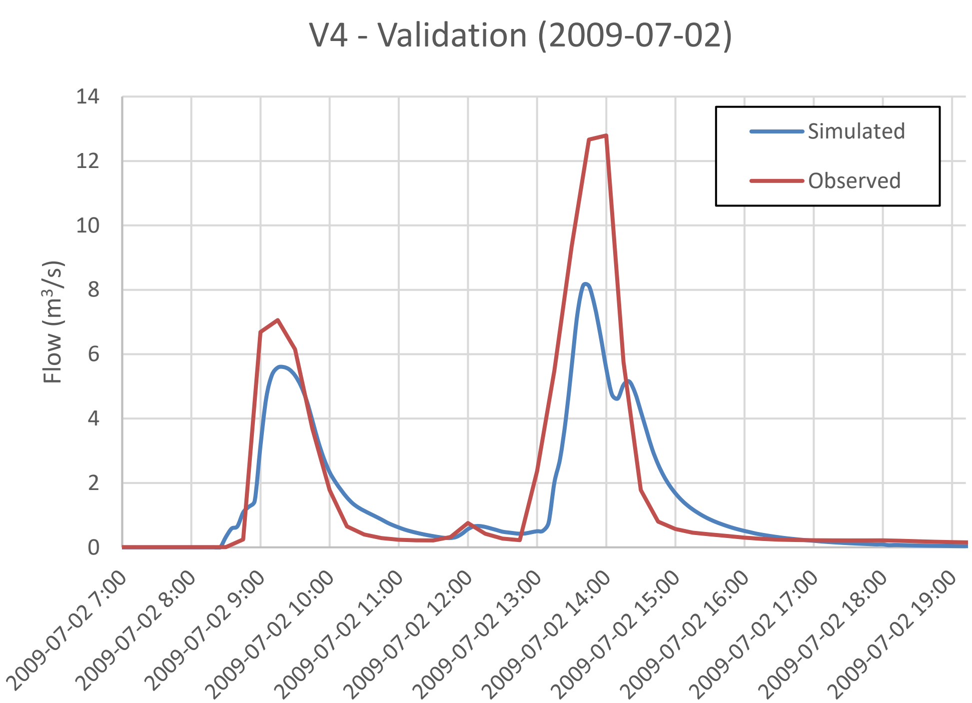
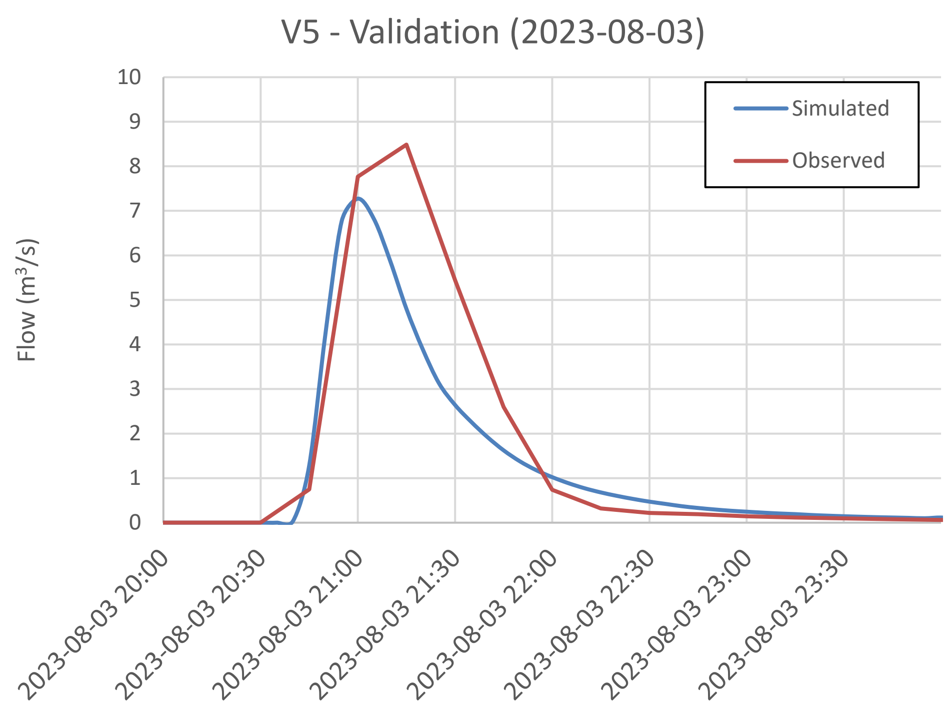
Figure
E4





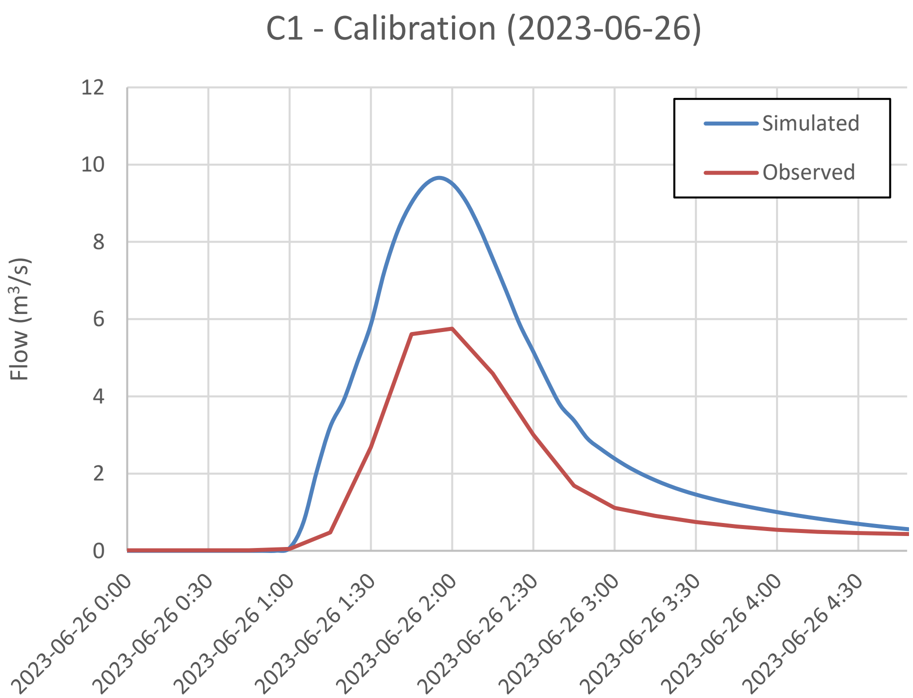
Event ID	Date of Simulation	HY040 Peak Flow (m3/s)	HY040 Volume (m3)	Modelled Peak Flow m3/s)	Modelled Volume (m3)	Peak Flow Difference (%)	Volume Difference (%)	NSE	R2	ISE	ISE Rating
V4	2009-07-02	12.8	77,661	8.1	62,234	-36.4%	-19.9%	0.74	0.82	13.5	Fair
V5	2023-08-03	8.5	24,837	7.3	19,961	-14.3%	-19.6%	0.84	0.91	17.9	Fair

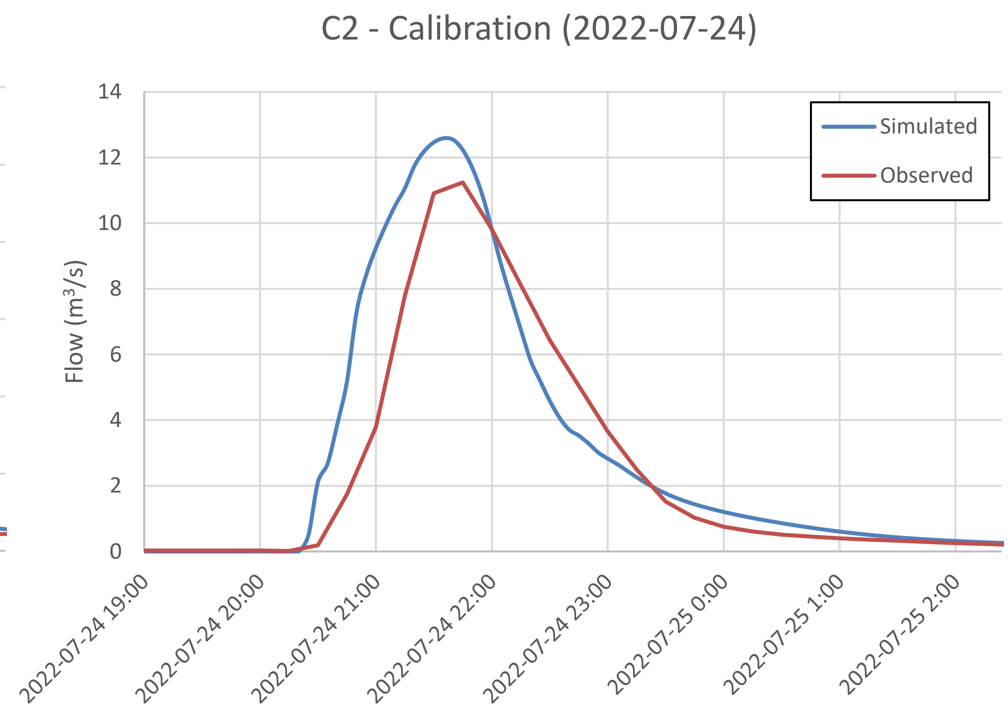
Frenchman's Bay Watershed Hydrologic Model Update

HY040 Results

Date: February 2024 | Project: 35765-531 | Submitter: Z.Zimmer | Reviewer: A.McKay

Figure E5





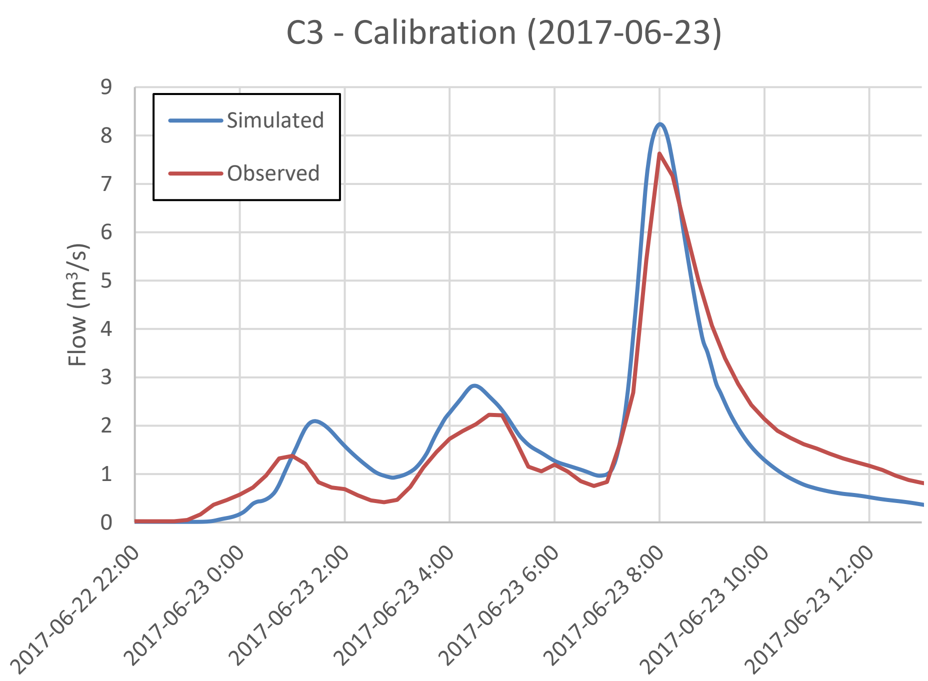
Event ID	Date of Simulation	HY052 Peak Flow (m3/s)	HY052 Volume (m3)	Modelled Peak Flow m3/s)	Modelled Volume (m3)	Peak Flow Difference (%)	Volume Difference (%)	NSE	R2	ISE	ISE Rating
C1	2023-06-26	5.75	27,800	9.7	49,914	67.9%	79.5%	0.20	0.96	24.1	Fair
C2	2022-07-24	11.24	70,754	12.6	82,788	12.0%	17.0%	0.86	0.90	10.2	Fair

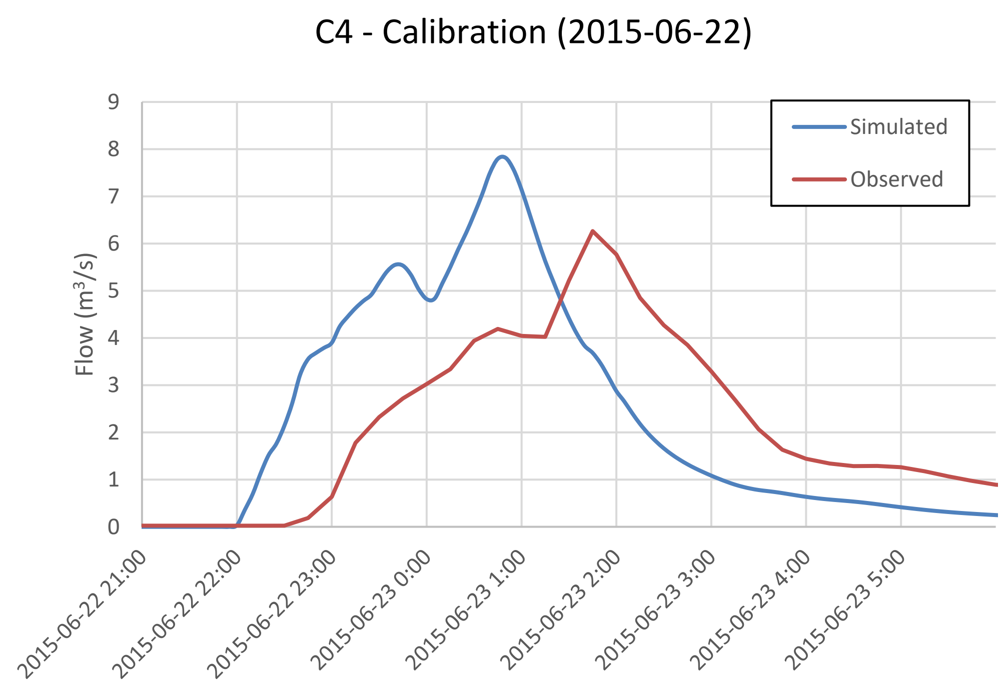
Frenchman's Bay Watershed Hydrologic Model Update

HY052 Results

Date: February 2024 | Project: 35765-531 | Submitter: Z.Zimmer | Reviewer: A.McKay

Figure E6





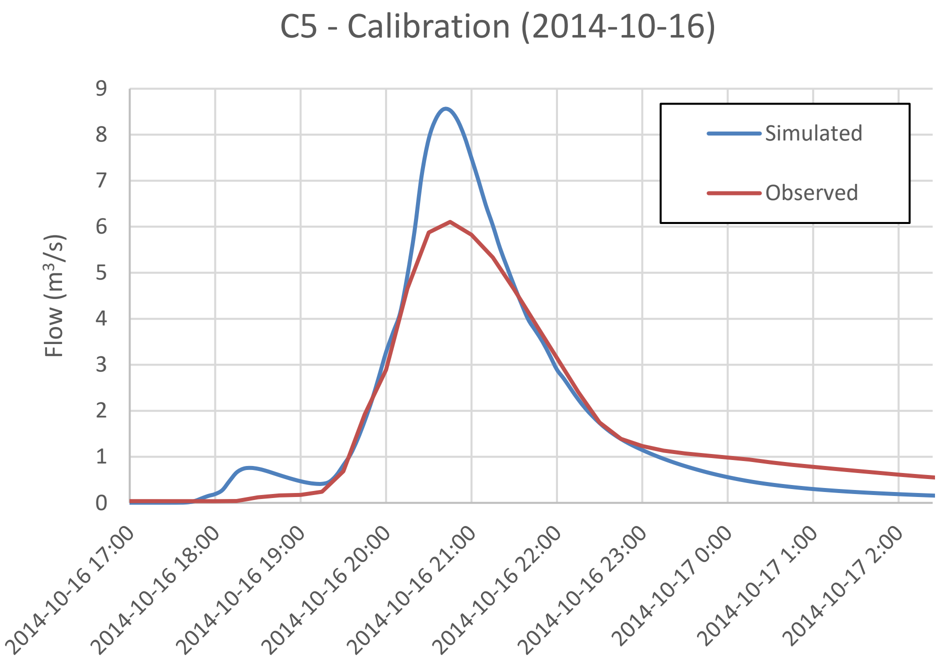
Event ID	Date of Simulation	HY052 Peak Flow (m3/s)	HY052 Volume (m3)	Modelled Peak Flow m3/s)	Modelled Volume (m3)	Peak Flow Difference (%)	Volume Difference (%)	NSE	R2	ISE	ISE Rating
C3	2017-06-23	7.63	94,053	8.2	90,297	7.9%	-4.0%	0.86	0.88	4.76	Very good
C4	2015-06-22	6.27	79,083	7.8	79,884	24.8%	1.0%	0.00	0.43	13.7	Fair

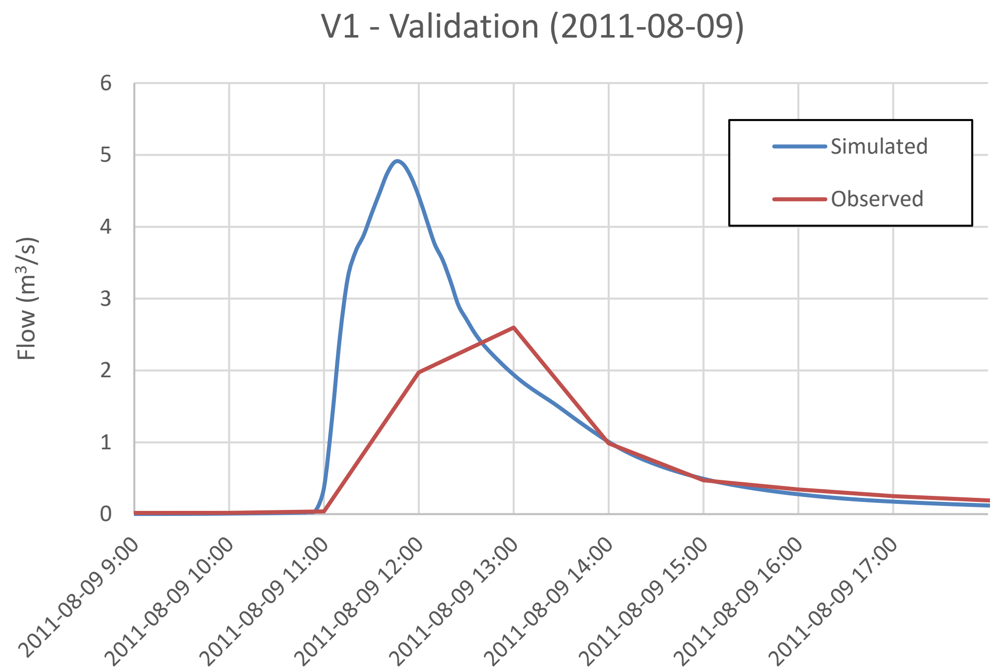
Frenchman’s Bay Watershed Hydrologic Model Update

HY052 Results

Date: February 2024 | Project: 35765-531 | Submitter: Z.Zimmer | Reviewer: A.McKay

Figure E7





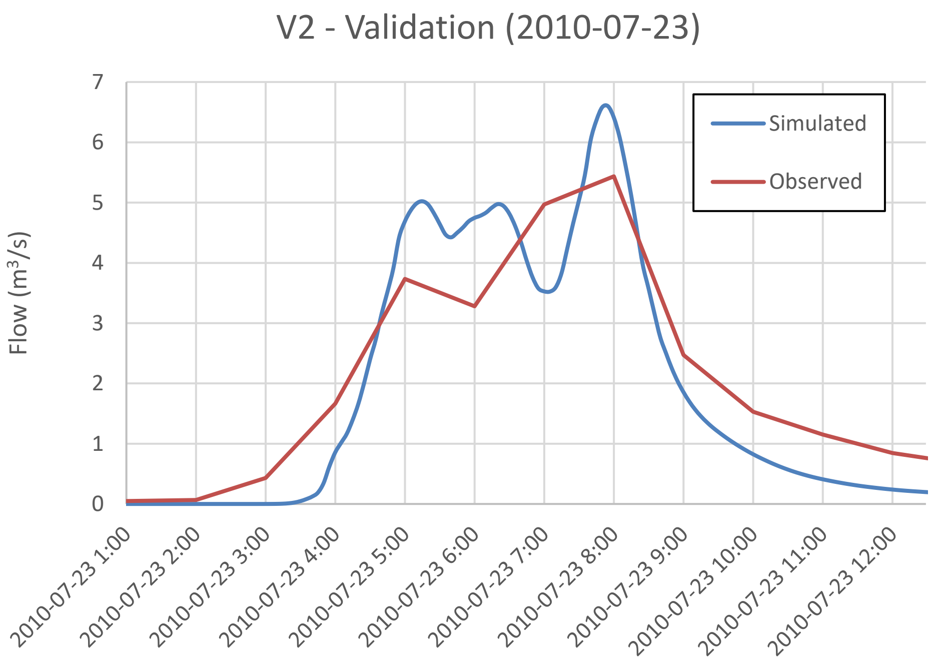
Event ID	Date of Simulation	HY052 Peak Flow (m3/s)	HY052 Volume (m3)	Modelled Peak Flow m3/s)	Modelled Volume (m3)	Peak Flow Difference (%)	Volume Difference (%)	NSE	R2	ISE	ISE Rating
C5	2014-10-16	6.11	58,475	8.5	60,836	40.0%	4.0%	0.89	0.96	6.16	Good
V1	2011-08-09	2.60	24,084	4.9	34,469	88.9%	43.1%	0.14	0.63	36.8	Poor

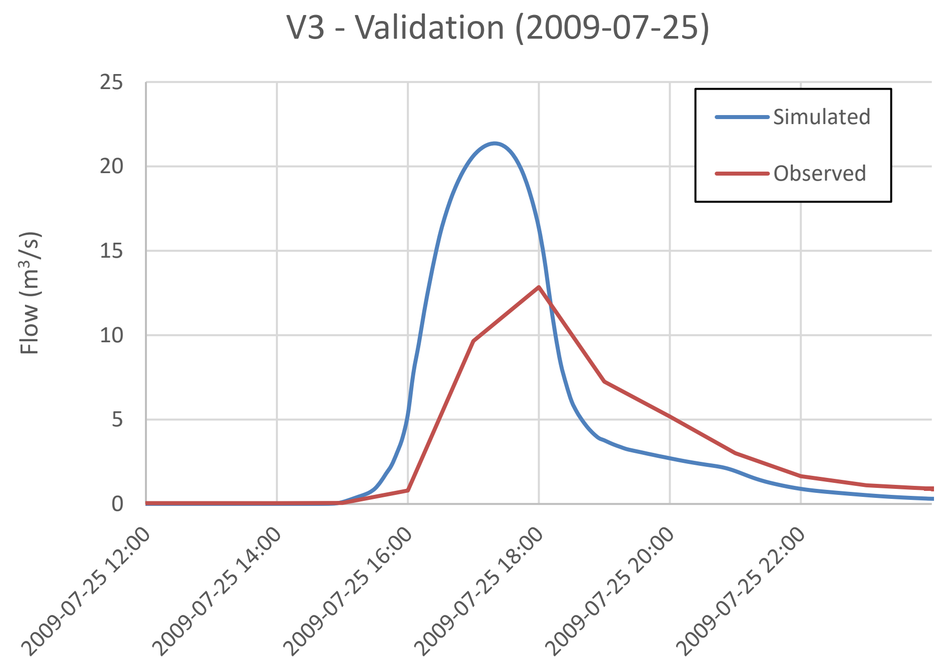
Frenchman's Bay Watershed Hydrologic Model Update

HY052 Results

Date: February 2024 | Project: 35765-531 | Submitter: Z.Zimmer | Reviewer: A.McKay

Figure E8





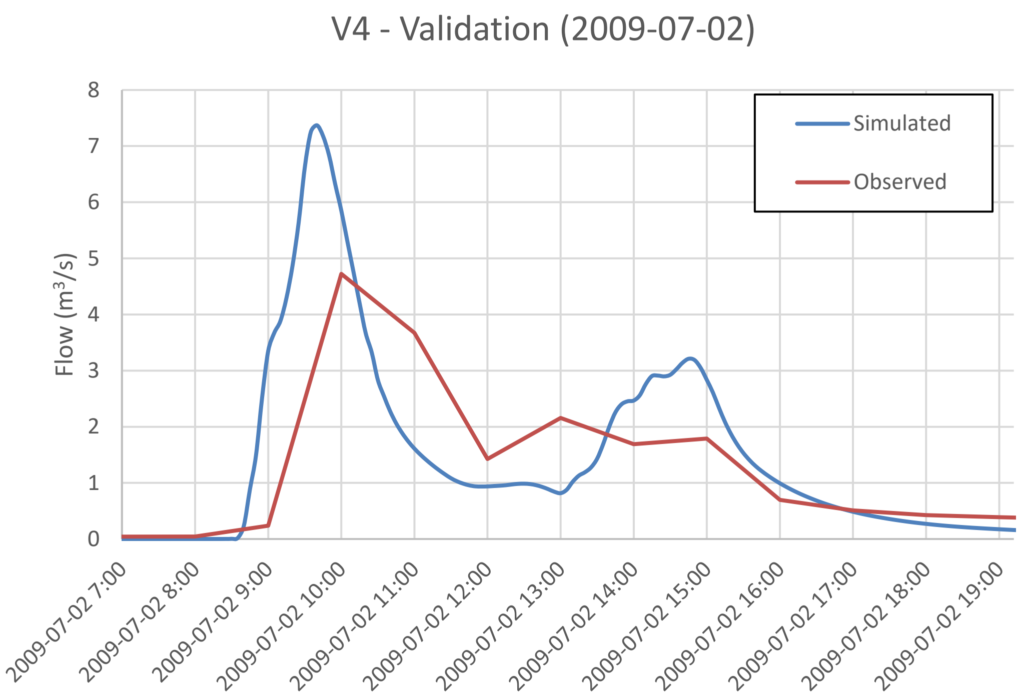
Event ID	Date of Simulation	HY052 Peak Flow (m3/s)	HY052 Volume (m3)	Modelled Peak Flow m3/s)	Modelled Volume (m3)	Peak Flow Difference (%)	Volume Difference (%)	NSE	R2	ISE	ISE Rating
V2	2010-07-23	5.44	96,979	6.6	83,981	21.4%	-13.4%	0.87	0.92	9.02	Good
V3	2009-07-25	12.85	150,299	21.4	188,284	66.2%	25.3%	0.25	0.57	29.5	Poor

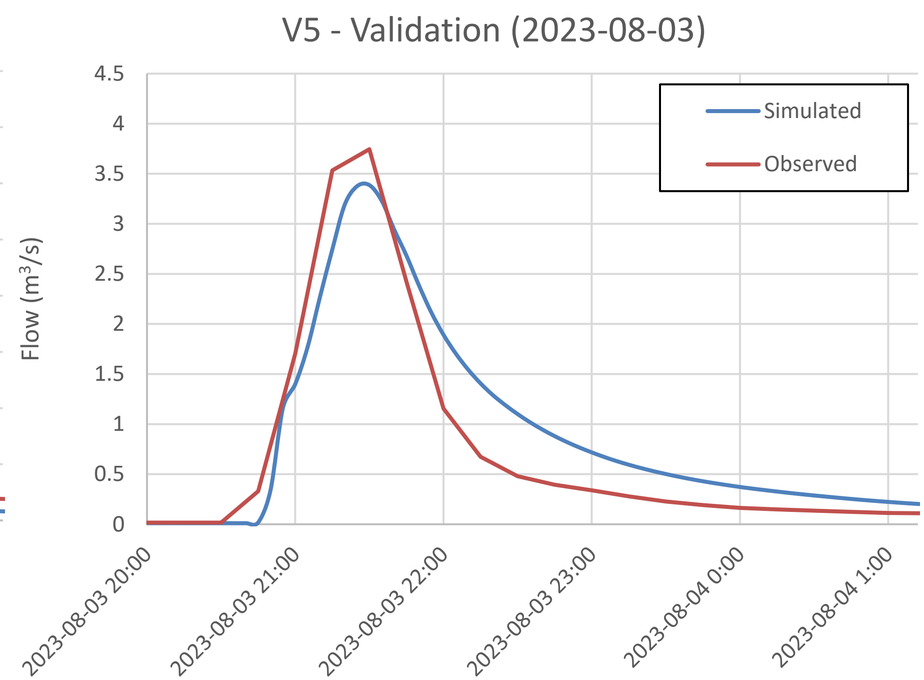
Frenchman's Bay Watershed Hydrologic Model Update

HY052 Results

Date: February 2024 | Project: 35765-531 | Submitter: Z.Zimmer | Reviewer: A.McKay

Figure E9





Event ID	Date of Simulation	HY052 Peak Flow (m3/s)	HY052 Volume (m3)	Modelled Peak Flow m3/s)	Modelled Volume (m3)	Peak Flow Difference (%)	Volume Difference (%)	NSE	R2	ISE	ISE Rating
V4	2009-07-02	4.72	65,606	7.4	69,561	56.0%	6.0%	0.52	0.62	20.1	Fair
V5	2023-08-03	3.75	15,867	3.4	19,116	-9.6%	20.5%	0.90	0.90	10.3	Fair

Frenchman's Bay Watershed Hydrologic Model Update

HY052 Results

Date: February 2024 | Project: 35765-531 | Submitter: Z.Zimmer | Reviewer: A.McKay

Figure E10

APPENDIX F
Existing Conditions Design Storm Results

Table F.1: Design Storm Flows - 1-hour AES Storm Distribution

PCSWMM Junction	River Name	Reach Name	River Station	AES 1-Hour Design Storm Flows (m^3/s)					
				2-yr (23.8 mm)	5-yr (32.6 mm)	10-yr (38.4 mm)	25-yr (45.7 mm)	50-yr (51.2 mm)	100-yr (56.6 mm)
J1308	Amberlea Creek	Reach 3	1549	2.87	4.52	5.22	6.13	6.81	7.47
J1036	Amberlea Creek	Reach 3	1248	4.05	5.43	6.44	7.69	8.66	9.65
J1720	Amberlea Creek	Trib 2	2384	3.59	6.55	7.89	9.72	11.21	12.78
J1540	Amberlea Creek	Trib 2	1680	3.66	6.68	8.10	10.05	11.62	13.25
J644	Amberlea Creek	Reach 2	794	7.32	11.80	14.24	16.35	17.42	18.43
J495.54	Amberlea Creek	Reach 2	644	8.04	12.79	15.19	17.39	18.53	19.64
J1106.4	Amberlea Creek	Trib 1	1303	1.39	1.84	1.92	1.96	2.01	2.09
J28	Amberlea Creek	Reach 1	441	9.30	14.38	16.91	19.25	20.49	21.73
J2851	Dunbarton Creek	Reach 1	3111	0.68	1.23	1.59	2.11	2.55	3.00
J1847	Dunbarton Creek	Reach 1	2803	1.13	1.69	2.08	2.64	3.61	4.65
J1389	Dunbarton Creek	Reach 1	1731	2.29	3.74	4.79	6.25	7.45	8.69
J923	Dunbarton Creek	Reach 1	1319	1.03	2.28	3.46	5.07	6.32	7.41
J435	Dunbarton Creek	Reach 1	884	1.05	2.34	3.63	5.36	6.69	7.61
J357	Dunbarton Creek	Reach 1	360	1.67	2.40	3.73	5.48	7.00	8.44
J83	Dunbarton Creek	Reach 1	298	3.51	5.14	6.27	8.14	9.74	11.40
J5400	Krosno Creek	Trib 2-2	5504	6.33	10.00	10.49	10.59	10.66	10.73
J5490	Krosno Creek	Trib 2-1	5490	1.27	2.00	2.51	3.18	3.70	4.22
J3337	Krosno Creek	Reach 3	3337	8.44	12.81	14.83	17.38	19.19	20.90
J3100	Krosno Creek	Reach 3	3318	11.50	16.89	19.16	22.61	25.54	28.53
J2820	Krosno Creek	Reach 3	3010	11.49	17.39	20.01	23.58	26.91	29.97
J2403	Krosno Creek	Reach 3	2777	11.03	17.78	21.32	25.38	29.48	33.18
J2276	Krosno Creek	Reach 3	2361	11.28	16.78	20.98	25.58	30.14	34.29
J2028	Krosno Creek	Reach 3	2240	10.62	16.69	21.04	25.88	30.45	34.66
J4344	Krosno Creek	Trib 1	4450	2.46	3.79	4.71	5.95	6.97	8.00
J4000	Krosno Creek	Trib 1	4320	3.44	5.29	6.60	8.34	9.69	11.07
J5013	Krosno Creek	Trib 2	5043	8.24	12.76	14.39	15.65	16.50	17.31
J4965	Krosno Creek	Trib 2	5013	8.20	12.08	13.67	14.80	15.61	16.41
J4705	Krosno Creek	Trib 2	4935	7.27	11.28	13.53	14.72	15.59	16.46
J1500_1	Krosno Creek	Reach 2	1851	16.10	26.14	33.03	39.13	44.00	48.72
J1267	Krosno Creek	Reach 1	1286	16.46	26.72	33.62	40.38	45.45	49.27
J495	Krosno Creek	Reach 1	1221	15.10	21.96	26.72	31.94	37.25	42.61
J9103	Pine Creek	Trib 3	9320	0.53	0.80	0.98	1.23	1.41	1.61
J5027	Pine Creek	Reach 4	5255	0.14	0.20	0.38	0.71	0.99	1.28
J4500_1	Pine Creek	Reach 3	4665	0.65	0.99	1.23	1.55	1.81	2.07
PC_J5	Pine Creek	Reach 3	4500	0.67	1.02	1.26	1.67	2.00	2.33
J3640	Pine Creek	Reach 3	4316	0.64	1.09	1.44	2.03	2.52	3.03
J9500	Pine Creek	Trib 2-1	9603	0.07	0.10	0.12	0.15	0.18	0.21
J9800	Pine Creek	Trib 2-2	9933	0.27	0.39	0.48	0.59	0.69	0.85
J7723	Pine Creek	Trib 2	7958	0.19	0.28	0.34	0.42	0.51	1.00
J7525	Pine Creek	Trib 2	7657	0.57	0.83	0.96	1.09	1.19	1.32
J7205	Pine Creek	Trib 2	7340	0.70	1.02	1.23	1.48	1.69	1.92
J7000	Pine Creek	Trib 2	7136	0.71	1.07	1.31	1.60	1.85	2.10
J6000	Pine Creek	Trib 1	6409	0.22	0.32	0.39	0.48	0.87	1.53

PCSWMM Junction	River Name	Reach Name	River Station	AES 1-Hour Design Storm Flows (m^3/s)					
				2-yr (23.8 mm)	5-yr (32.6 mm)	10-yr (38.4 mm)	25-yr (45.7 mm)	50-yr (51.2 mm)	100-yr (56.6 mm)
J10950	Pine Creek	Trib 1-2	11106	0.04	0.06	0.07	0.09	0.10	0.11
J12469	Pine Creek	Trib 1-3	12585	0.82	1.20	1.51	1.89	2.20	2.52
J12028	Pine Creek	Trib 1-3	12414	0.54	0.77	1.00	1.36	1.66	1.98
J11500	Pine Creek	Trib 1-3	12028	0.59	0.91	1.23	1.73	2.19	2.70
J2896	Pine Creek	Reach 2	3365	5.03	7.84	9.98	12.79	15.08	17.44
J2839	Pine Creek	Reach 2	2899	5.16	7.85	9.88	12.40	14.16	16.30
J2727	PIne Creek	Reach 1	2730	4.98	7.39	9.27	11.56	13.40	15.25
J2266	Pine Creek	Reach 1	2676	6.42	10.20	12.86	15.90	18.26	20.69
J1672	Pine Creek	Reach 1	2209	7.76	12.31	15.84	20.65	24.27	27.68
J1467	Pine Creek	Reach 1	1596	7.72	12.29	15.79	20.25	23.57	26.59
J1215	Pine Creek	Reach 1	1385	7.77	12.16	15.23	18.72	20.89	22.60
J546	Pine Creek	Reach 1	914	7.46	11.48	14.40	17.77	19.89	21.70
J382	Pine Creek	Reach 1	485	7.54	11.66	14.63	17.99	20.10	21.88
J10253	Pine Creek	Trib 1-1	10758	0.82	1.21	1.47	1.87	2.39	3.01
J10080	Pine Creek	Trib 1-1	10253	0.69	1.06	1.37	1.88	2.44	3.06
J100	Pine Creek	Trib 1-1	10053	0.55	0.81	1.12	1.64	2.17	2.53

APPENDIX G
Future Condition Regional Design Storm Results

Table G.1: Future Conditions Regional and Design Storm (1-hr AES Distribution) Results

PCSWMM Junction	River Name	Reach Name	River Station	100-yr (No Structures; 56.6 mm)	350-yr (No Structures; 72.7 mm)	Regional (No Structures; 285 mm)
J1308	Amberlea Creek	Reach 3	1549	5.24	7.15	2.47
J1036	Amberlea Creek	Reach 3	1248	8.17	11.23	4.30
J1720	Amberlea Creek	Trib 2	2384	16.21	25.88	24.03
J1540	Amberlea Creek	Trib 2	1680	16.40	26.25	24.54
J644	Amberlea Creek	Reach 2	794	22.04	31.18	29.62
J495.54	Amberlea Creek	Reach 2	644	23.52	32.38	31.03
J1106.4	Amberlea Creek	Trib 1	1303	1.34	1.79	0.58
J28	Amberlea Creek	Reach 1	441	25.84	34.93	32.83
J2851	Dunbarton Creek	Reach 1	3111	3.54	5.11	3.19
J1847	Dunbarton Creek	Reach 1	2803	6.92	10.02	7.05
J1389	Dunbarton Creek	Reach 1	1731	11.24	17.20	12.89
J923	Dunbarton Creek	Reach 1	1319	13.37	20.89	15.98
J435	Dunbarton Creek	Reach 1	884	14.15	22.55	17.77
J357	Dunbarton Creek	Reach 1	360	16.29	26.23	21.34
J83	Dunbarton Creek	Reach 1	298	17.35	28.23	23.60
J5400	Krosno Creek	Trib 2-2	5504	10.74	10.94	10.61
J5490	Krosno Creek	Trib 2-1	5490	4.32	5.83	1.83
J3337	Krosno Creek	Reach 3	3337	21.50	29.12	13.12
J3100	Krosno Creek	Reach 3	3318	30.09	39.28	19.34
J2820	Krosno Creek	Reach 3	3010	33.06	43.15	21.46
J2403	Krosno Creek	Reach 3	2777	37.07	48.38	24.89
J2276	Krosno Creek	Reach 3	2361	41.66	53.46	28.12
J2028	Krosno Creek	Reach 3	2240	41.99	54.23	29.29
J4344	Krosno Creek	Trib 1	4450	8.24	11.31	4.53
J4000	Krosno Creek	Trib 1	4320	11.54	15.79	7.22
J5013	Krosno Creek	Trib 2	5043	19.22	23.80	17.20
J4965	Krosno Creek	Trib 2	5013	20.51	25.09	18.27
J4705	Krosno Creek	Trib 2	4935	20.58	25.70	19.45
J1500_1	Krosno Creek	Reach 2	1851	59.93	77.71	50.90
J1267	Krosno Creek	Reach 1	1286	65.84	85.43	59.36
J495	Krosno Creek	Reach 1	1221	61.61	75.94	58.55
J9103	Pine Creek	Trib 3	9320	1.65	2.22	1.01
J5027	Pine Creek	Reach 4	5255	1.34	2.34	5.61
J4500_1	Pine Creek	Reach 3	4665	2.32	3.78	6.68
PC_J5	Pine Creek	Reach 3	4500	3.23	5.21	8.80
J3640	Pine Creek	Reach 3	4316	3.65	6.17	9.56
J9500	Pine Creek	Trib 2-1	9603	0.21	0.32	0.75
J9800	Pine Creek	Trib 2-2	9933	2.23	3.59	4.98
J7723	Pine Creek	Trib 2	7958	2.18	4.09	6.16
J7525	Pine Creek	Trib 2	7657	2.27	4.37	6.56
J7205	Pine Creek	Trib 2	7340	2.39	4.76	7.08
J7000	Pine Creek	Trib 2	7136	2.44	4.87	7.28
J6000	Pine Creek	Trib 1	6409	0.65	0.89	0.49
J10950	Pine Creek	Trib 1-2	11106	0.94	1.37	0.64
J12469	Pine Creek	Trib 1-3	12585	2.58	3.48	2.99

PCSWMM Junction	River Name	Reach Name	River Station	100-yr (No Structures; 56.6 mm)	350-yr (No Structures; 72.7 mm)	Regional (No Structures; 285 mm)
J12028	Pine Creek	Trib 1-3	12414	2.09	3.02	5.02
J11500	Pine Creek	Trib 1-3	12028	2.39	3.61	5.70
J2896	Pine Creek	Reach 2	3365	18.01	25.43	26.29
J2839	Pine Creek	Reach 2	2899	19.28	27.30	26.87
J2727	PIne Creek	Reach 1	2730	19.90	27.97	27.47
J2266	Pine Creek	Reach 1	2676	26.86	40.52	45.49
J1672	Pine Creek	Reach 1	2209	33.01	50.11	52.55
J1467	Pine Creek	Reach 1	1596	41.66	60.70	61.67
J1215	Pine Creek	Reach 1	1385	42.80	62.40	63.16
J546	Pine Creek	Reach 1	914	34.90	56.64	64.73
J382	Pine Creek	Reach 1	485	35.62	57.58	65.80
J10253	Pine Creek	Trib 1-1	10758	3.45	5.72	7.58
J10080	Pine Creek	Trib 1-1	10253	3.56	5.98	7.75
J100	Pine Creek	Trib 1-1	10053	3.56	6.22	8.10

APPENDIX H
Unitary Discharge Flows (TRCA)

Toronto and Region Conservation Authority

To: Amanda McKay, P.Eng. (Matrix Solutions Inc.)
From: Ziyang Zhang, M.Sc., P.Eng. (TRCA FRM); Qiao Ying, M.Sc., P.Eng.(TRCA FRM)
Date: February 15, 2024
Re: Frenchman's Bay Catchment Unitary Flow and Runoff Coefficient Analysis

---

During TRCA's review of Matrix's Frenchman's Bay PCSWMM hydrology model, TRCA has analyzed the hydrology model output using sub-catchment unitary flow and runoff coefficient. This letter provides a summary of this analysis.

The unitary flow ($m^3/s/ha$) here is defined as the simulated sub-catchment peak flow (m^3/s) divided by the sub-catchment area (ha). The runoff coefficient is sub-catchment runoff depth (mm) divided by sub-catchment rainfall depth (mm). Note that the unitary flow and runoff coefficient were analyzed in the sub-catchment element and not in conduit or junction elements.

The unitary flow and runoff coefficient results from the Frenchman's Bay model were compared with the results from 2018 Highland Creek and 2017 Don River PCSWMM hydrologic models. The Highland Creek and Don River watershed share a similar hydrologic character with the Frenchman's Bay watershed. They are all highly urbanized with commercial and residential development, and thus Frenchman's Bay unitary flow and runoff coefficients shall be similar to the numbers in the other two watersheds. It shall be noted that the Highland Creek and Don River drainage areas are much larger than Frenchman's Bay watershed. Some catchment characteristics such as catchment slope and catchment length-to-width ratio are also very different shown in Table 1.

Table 1 shows the watershed average unitary flow and runoff coefficient for the three watersheds. The runoff coefficients of the three watersheds are similar to each other, ranging from 0.55 to 0.68. The Frenchman's Bay and Highland Creek have the same unitary flow. The Don River has a higher unitary flow than the other two watersheds. The Don River is subject to a higher catchment slope and smaller catchment length-to-width ratio that will cause a shorter time of concentration and generate much higher peak flow. Overall, the Frenchman's Bay average unitary flow and runoff coefficient are within the expected range by compared with Highland Creek and Don River numbers.

Table 1: Watershed Average Unitary Flow and Runoff Coefficient, and Sub-catchment Characteristics

Watershed	Unitary Flow (m^3/s/ha)	Runoff Coefficient	Catchment Slope (%)	Imperviousness (%)	Catchment Length-to-Width Ratio
Frenchman's Bay	0.16	0.55	2.2	50	1.4
Highland Creek	0.16	0.68	2.0	53	2.8
Don River	0.25	0.61	9.2	42	0.04

Unitary flow and runoff coefficients for residential area have been sampled from several sub-catchments in three study watersheds (Frenchman's Bay, Highland Creek, and Don River), with results presented in Table 2. Similarly, unitary flow and runoff coefficients for highly impervious areas (e.g., commercial and industrial areas) were also sampled from the three watersheds, with results presented in Table 3.

Within the Frenchman's Bay watershed, Krosno Creek exhibits noticeably higher unitary flow and runoff coefficient than Amberlea, Dunbarton, and Pine Creeks. One of the possible reasons is that Krosno Creek is covered by less permeable soil type (silty clay) than Amberlea, Dunbarton, and Pine Creeks (loam, Sandy loam, loamy sand).

By comparing the residential area results and high impervious area results to Highland Creek and Don River, the unitary flow and runoff coefficients from Frenchman's Bay are within the expected range. Frenchman's Bay metrics are more similar to Highland Creek metrics; while the Don River exhibits somewhat higher unitary flow and runoff coefficients, possibly due to its high catchment slope and low catchment length-to-width ratio.

Table 2 Unitary Flow and Runoff Coefficient for Residential Area (Sampled from Several Sub-catchments)

Watershed		Unitary Flow (m^3/s/ha)	Runoff Coefficient
Frenchman's Bay	Amberlea & Dunbarton Creeks	0.15	0.6
	Pine Creek	0.15	0.5
	Krosno Creek	0.2	0.8
Highland Creek		0.15	0.7
Don River		0.22	0.7

Table 3 Unitary Flow and Runoff Coefficient for Commercial and Industrial Area (Sampled from Several Sub-catchments)

Watershed		Unitary Peak flow (m^3/s/ha)	Runoff Coefficient
Frenchman's Bay	Amberlea & Dunbarton Creeks	0.25	0.85
	Pine Creek	0.3	0.8
	Krosno Creek	0.3	0.9
Highland Creek		0.19	0.9
Don River		0.38	0.9

In conclusion, by comparing the same model output metrics with Highland Creek and Don River PCSWMM models, the unitary flow and runoff coefficient from Frenchman's Bay PCSWMM model are within the expected range. This analysis increases the confidence in Matrix's Frenchman's Bay PCSWWM model.