Shubenacadie Lakes Floodplain Study

HALIFAX

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CBCL

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[redacted]

191107.00

Youssef Habboush, P.Eng
Project Manager
Halifax Regional Municipality

Dear Mr Habboush:

RE: ***Shubenacadie Lakes Floodplain Study***

CBCL Limited is pleased to present our final report for the Shubenacadie Lakes Floodplain Study for the Halifax Regional Municipality.

This report describes the background, data collection, modelling, and assessments that were carried out to evaluate flows, water levels, and ultimately floodlines within the Shubenacadie Lakes system.

We would like to thank you for the opportunity to work on this extremely interesting project. Should you have any questions regarding the content of this report, please do not hesitate to contact us.

Yours very truly,

CBCL Limited

[redacted]

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Executive Summary

The Halifax Regional Municipality (HRM) has identified the Shubenacadie Lakes System as a high priority area for flood mitigation following a National Disaster Mitigation Program (NDMP) Study in 2018 (WSP, 2018). The Shubenacadie Lakes Floodplain Study presented in this report by CBCL has assessed the hydrology and hydraulic regime of the Shubenacadie Lakes System and its watershed, in order to delineate the floodplain for various flood scenarios.

Flood conditions were evaluated based on a calibrated hydrologic and hydraulic model using PCSWMM. Design flood scenarios included variations in rainfall, season, land development, and climate change projections for rainfall conditions.

The analysis presented in this report was carried out to support flood extents produced by the hydrologic and hydraulic models. The flood extents may be incorporated into future planning documents, which warrants a thorough analysis. Included in this assessment was also an in-depth analysis of climate change impacts on rainfall. Since climate change is to be considered in planning documents, it was essential to use the best science and tools available to evaluate those effects.

The Request for Proposal (RFP) required a recommendation for the selection of a Base Flood. This was defined by HRM as a pair of floodlines for the 1 in 20 year event and 1 in 100 year event, for planning and regulatory purposes. Since the scope of this study does not include stakeholder consultation, assessment of vulnerability of floodplain infrastructure, land uses and services, nor any review of existing and future planning challenges and opportunities, the current recommendation is strictly related to hydrodynamics and the current state of climate change science.

To ensure that risks to public safety are not overlooked, CBCL proposes to adopt a scenario with the following characteristics, which are the most commonly included characteristics in Nova Scotia, and follow the National Flood Hazard Mapping Guidelines:

- Spring seasonal watershed characteristics,
- Future development conditions for the watershed (as known at the time of this study by HRM),
- Climate change conditions from projections selected from the proposed three climate scenarios presented in this report,
- 1 in 20 year and 1 in 100 year return periods.

Important findings from this study include the identification of factors that lead to the flooding extents generated by the models. One of these significant factors is hydraulic constriction. Analysis of structure constrictions identified four structures that create notable impediments to the passage of water through the Shubenacadie Lakes System aside from Locks 2 and 3, which serve to act as water level control structures. These structures are the bridges at the Shubie Greenway Corridor south crossing, Rocky Lake Drive, Fletchers Lake Lock Trail (Lock 4), and Waverley Road at Meadow Walk. Structures at risk of surcharging during flooding events, and at higher risk of ice jam and debris blockage, include King's Road, Fall River Road, Highway 102, and the Shubie Greenway Corridor north of Lake Charles.

The assessment of wet/frozen ground conditions and snowmelt also yielded interesting results; The Shubenacadie Lakes System did show significant variation between models with unfrozen/dry conditions and models with wet/frozen ground and snowmelt. Development projections showed little influence, with a water level increase in the order of only 10cm at the Waverley Road Bridge at Meadow Walk, and limited increase elsewhere.

Projected rainfall events due to climate change were also modelled. Through two projection methods and a range of emission scenarios, three climate change projection scenarios were modelled and mapped for their respective 1 in 100 year rainfall events. Of these scenarios, Scenario A (IDF-CC tool RCP 8.5 95th percentile) was chosen in conjunction with HRM to model and map the future 1 in 5, 1 in 20, and 1 in 100 year projected rainfall events.

A discussion of potential flood mitigation options considers the benefits and challenges associated with each potential measure. Although this assessment did not investigate in detail, nor model, any flood mitigation option, certain high level aspects can be drawn from the results. The flood line delineation showed that climate change impacts clearly have the potential to increase flooding risks and should be considered in any future planning decisions. The planning regulations will be central to managing future proofing or limited uses of floodplain areas. Designating environmentally-sensitive areas is also recommended to prevent future development in water storage and undeveloped floodplain areas.

The following list of factors have contributed to the recommendations presented in this report:

- Risks associated with climate change;
- Increased interest in sustainability;
- Increased awareness of liability;
- Increasing costs of maintenance, and
- Limited funding for infrastructure projects.

Recommendations beyond adopting the flood lines presented in this report, have been oriented towards more sustainable, low-maintenance, more nature-oriented approaches, which provide not only solutions to flooding risks, but also additional advantages in terms of erosion protection, water quality improvements, and community value, consistent with the Halifax Regional Plan, and the Halifax Green Network Plan.

For all future flood mitigation steps, stakeholder consultations and modelling should be carried out to identify the best compromise between protecting vulnerabilities, overall stakeholder needs, ecosystem protection, and costs. The creation of a dedicated floodplain committee with regular meetings could be one way to streamline this process.

Overall, this study has updated the current state of knowledge on rainfall, hydrologic characteristics, lake and channel flow responses, impacts of structures and possible constrictions, mechanisms leading to flooding, potential climate change impacts and potential flood mitigation options. This study has combined datasets of high resolution and quality with state-of-the-art modelling and analysis to inform the results and recommendations presented.

Recommendations to improve this analysis in the future would include conducting further flow gauging in various areas of the watershed, evaluating in more detail ground infiltration and exfiltration characteristics, updating the climate change projections as research progresses, and trying to collect as much calibration data (water levels) as possible in the waterways during flooding events. Another area of improvement will be to use new Lidar data when it becomes available, as the only available data used in some areas of this study dates from 2007.

In terms of the recommended next steps for HRM, the first goal of this study is to provide information to support and update to planning regulations. An essential step, as noted by HRM, is to make every effort to communicate results and implications of this study, and planning regulations to the public and all affected stakeholders. Communication of flooding risks and emergency procedures, as well as flood proofing techniques, is also very valuable to help residents understand and deal with flooding risks. Warning systems, including flood forecasting and warning, can be very valuable tools to increase public safety. In terms of flood mitigation options, next steps will need to include conducting more detailed analyses and modelling of potential options. This can be done in parallel with an assessment of vulnerabilities along the lake system, conducted through consultation with each of the relevant stakeholders. Together with the management of emergency procedures, these vulnerabilities can be ranked by priority to define flood protection goals. How well each flood mitigation measures addresses each vulnerability can then be used to evaluate the efficiency of each flood protection measure.

Contents

Appendices

Chapter 1 Introduction

1.1 Purpose of Study

Figure 1.1 Shubenacadie Lakes System

In 2018, the Halifax Regional Municipality (HRM) completed a Flood Risk Assessment Study that identified the Shubenacadie Lakes System as a high-priority area for flooding mitigation (WSP, 2018). HRM subsequently moved to analyze the system under Stream 2 of the National Disaster Mitigation Program (NDMP), and issued a request for hydrologic and hydraulic models of the Shubenacadie Watershed and resulting flood inundation maps for a range of current and projected rainfall return periods between Lock 5 at the inlet of Shubenacadie Grand Lake, and Lock 2 at the northern outlet of Lake Charles.

This report presents the work completed by CBCL for the Shubenacadie Lakes System, including comprehensive hydrologic and hydraulic modelling, and flood inundation maps for a range of watershed and storm scenarios. The resulting flood line delineation will provide HRM with information identifying flood risks along the system for current and future climate change scenarios, to support plans for future development and flood mitigation.

1.2 Background

Previous studies in the region include The Shubenacadie-Stewiacke River Basin Study (Bailey, 1981), The Shubenacadie Lakes Subwatershed Study (AECOM, 2013), Sullivan's Pond Storm

Sewer Replacement Phase 1 (Halifax Water & CBCL, 2017), and the National Disaster Mitigation Program (NDMP) Site No. A6 – Shubenacadie Lakes System (WSP, 2018).

The Shubenacadie Lakes System as defined in this study is composed of Shubenacadie Grand Lake, Fletchers Lake, Thomas Lake, Lake William, and Lake Charles. The lakes are connected by both natural waterways, historically used by the Mi'kmaq for travel, and a man-made waterway known as the Shubenacadie Canal. The Shubenacadie Canal is a channel constructed in the 19th century to reconnect and widen the historic waterway joining the Halifax harbour with the Bay of Fundy through Lake Banook, Lake Micmac, Lake William, Thomas Lake, Fletchers Lake, and finally Shubenacadie Grand Lake. Regular operation of the nine locks along the canal stopped before the turn of the 20th century, with the advent of the railroad, though Locks 2 and 3 still remain closed, acting as water level control structures for the system today.

The Shubenacadie Lakes Watershed consists of large swaths of forest interspersed with small communities including Wellington, Fletchers Lake, Fall River, Waverley, and Port Wallace, as well as dense urbanization in Burnside, located at its southern tip. It drains mostly northwards out of the Shubenacadie River, with the exception of Lake Charles, which discharges both north and south. The Shubenacadie Sub-Watershed Study (AECOM, 2013) presented that historically it was believed that about 40% of discharge from Lake Charles flowed towards its south outlet, though the present study found that when modelled, approximately 90% of the flow discharged north. This discrepancy and the findings of CBCL in this study are discussed further in **Section 4.3.**

1.3 Study Approach

This study was carried out in the following phases:

1) **Analysis of existing data and collection of additional field data**
   - Collection of existing Lidar topographic mapping, lake bathymetry, soil characterization, rainfall data, historical flow data, historical flood information and watershed land use;
   - Collection of field data including infrastructure surveying, channel bathymetry, water levels and flows;

2) **Development and calibration of a hydrologic and hydraulic model using PCSWMM**
   - Delineation of watershed and sub-watersheds, soil mapping, land-use mapping, compilation of flow and water level measurements, and development of database of surveyed infrastructure;
   - Calibration and validation of the PCSWMM model to measured rainfall and flow events;

3) **Modelling flooding scenarios and creation of flood inundation maps**
   - Assembly of expected rainfall events based on existing and future climate change conditions;
   - Flood scenario modelling for the chosen design scenarios;
   - Delineation of flood lines for modelled scenarios;
   - Analysis of results to determine areas at high flood risk;
   - Overview of potential flood mitigation efforts;
   - Reporting.

Chapter 2 Data Collection and Analysis

2.1 Data Collection

This section presents an overview of the existing data that was obtained and the field data that was collected for this study.

2.1.1 Existing Data Obenation

The following existing data summarised in **Table 2.1** was obtained and reviewed for the study.

Table 2.1 Summary of Existing Data Collection

Data	Details	Source
Lidar Data	HRM Digital Elevation Model (DEM), 1m resolution	HRM
	Nova Scotia DEM, 20m resolution	Government of Nova Scotia
GIS Shapefiles	Watercourses, waterbodies, watersheds	Government of Nova Scotia
	Halifax County Soils	Agriculture and Agri-Food Canada
	Forestry Inventory and Land Cover	Nova Scotia Department of Natural Resources
Lake Bathymetry Contours	Shubenacadie Grand Lake bathymetry	Nova Scotia Fisheries and Aquaculture
	Fletchers Lake bathymetry	
	Lake Thomas bathymetry	
	Lake William bathymetry	
	Lake Charles bathymetry	
Intensity-Duration-Frequency (IDF) Curves	Halifax Airport IDF Curves (1977-2017)	Environment Canada
Historical Precipitation Data	Halifax-Stanfield International Airport precipitation data (1953-2020)	Environment Canada
Historical River Flow and Water Level Data	Shubenacadie River at Enfield hydrometric station (01DG006) data (1974-1995)	Environment Canada

2.1.2 Field Data Collection

Water Level Measurements

Water level data was collected using Solinst LTC Leveloggers at two sites along the Shubenacadie Lakes System between September 6th, 2019 and October 6th, 2019, to be used as calibration and validation data for the hydraulic model. Levelogger 1 was placed at the inlet of Grand Shubenacadie Lake, just north of Kings Road (44.861065°, -63.619563°), and Levelogger 2 was placed at the outlet of Lake William, just south of Rocky Lake Drive (44.785259°, -63.598029°). Leveloggers use piezoresistive silicon with Hastelloy sensors to measure pressure, which can then be converted into water levels by adjusting for barometric pressure measurements. Hourly barometric pressure form the Environment Canada Halifax-Stanfield Airport station was therefore used to adjust measured water level data.

Hydraulic Structure Surveys

Measurements and photos were collected for 16 structures along the study area. The locations and names of these structures can be found in **Figure 2.1.** A complete summary of drawings, field measurements, and survey data for these structures can be found in **Appendix A** (Hydraulic Structure Data Sheets).

Additional Bathymetric Surveying

To supplement existing bathymetric information obtained from Nova Scotia Fisheries and Aquaculture, additional surveying was completed in the connecting reaches of the lake system. Extents of the bathymetric survey are shown in **Figure 2.2**.

2.1.3 Stakeholder Input

To identify known areas of flooding and infrastructure at increased risk, a meeting was conducted with HRM and representatives from local municipal departments on October 24th, 2019. In addition to flooding extent information to be used for validation, the meeting resulted in the identification of the bridge at Waverley Road/Meadow Walk as a high-risk area for flooding.

2.1.4 Data Analysis

The collected data was analyzed and used to develop the following datasets and maps:

- Combined Digital Elevation Model;
- Watershed Delineation;
- Land Cover Mapping;
- Soil Mapping;
- Flow and Water Level Gauging Data Compilation;
- Rain Gauging Data Compilation; and
- Hydraulic Structure Data Sheets.

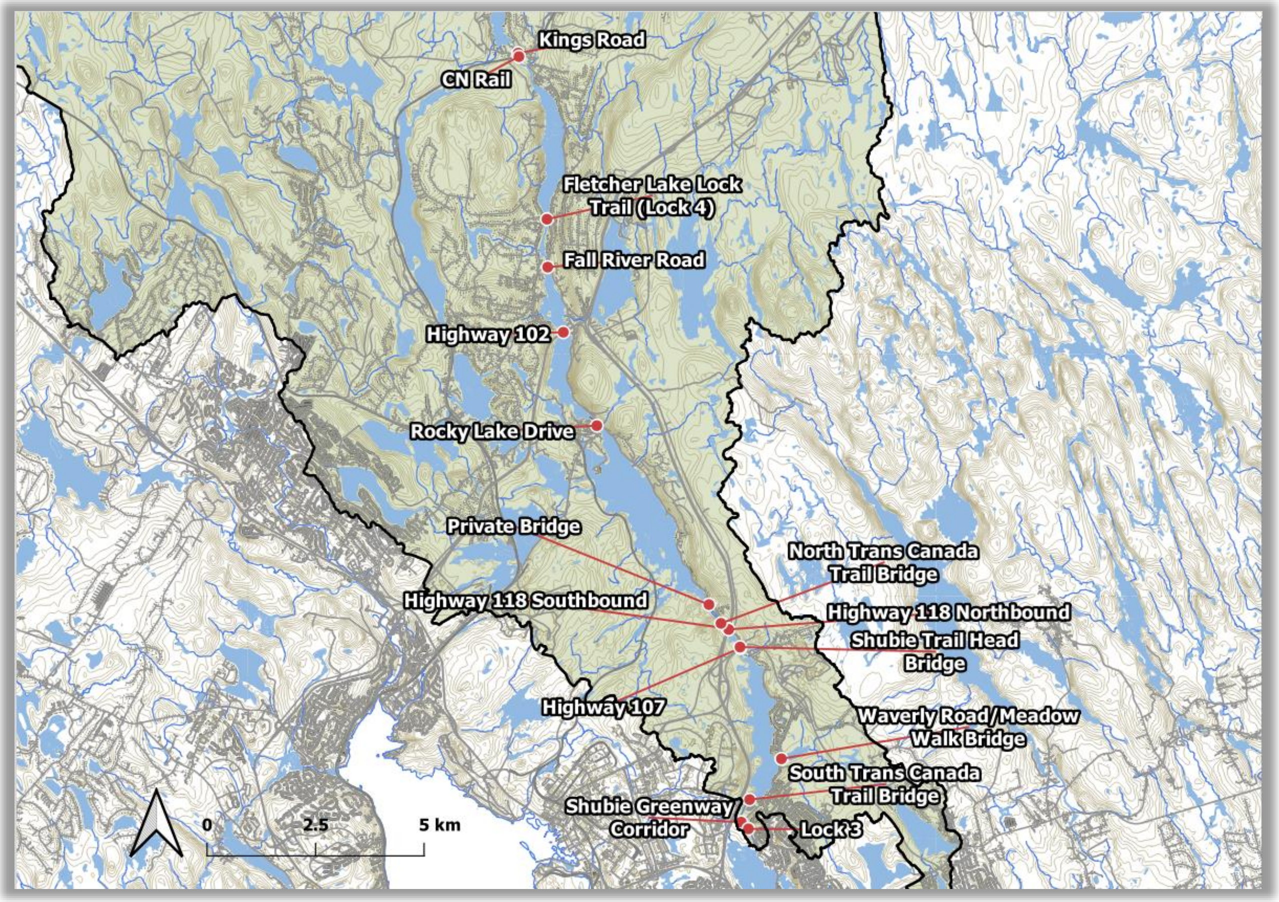

Figure 2.1 Hydraulic Structures Surveyed

Combined Digital Elevation Model

A combined DEM was created from the most up-to-date 1m and 20m resolution Lidar DEMs available, captured in sections across the study area in 2007 and 2011. Though no more up-to-date Lidar was available for the study area, development in the area is not expected to have a large impact on the quality of the hydraulic model along the flowpath. Lidar data was verified with survey information, as discussed in **Section 3.3.1.** This DEM was merged with available lake bathymetry and survey bathymetry to create a representative model of the watershed.

The extents of the available data are shown in **Figure 2.2**, and the resulting combined elevation surface is shown in **Figure 2.3.**

Watershed Delineation

The Shubenacadie watershed was delineated using the combined DEM. It has a total drainage area of ~415 km^2. From the watershed, sub-watersheds were delineated to each bridge or structure along the system such that flows could be estimated immediately upstream of each structure. Then, sub-watersheds were further divided into smaller sub-areas as needed for the hydrologic model such that watershed flows would be accurately distributed throughout the system. This included dividing sub-watersheds in locations where there were long distances between hydraulic structures, or where tributary watercourses intersected with the main channel. The resulting sub-watersheds are shown in **Figure 2.4.**

Land Cover Mapping

Land cover areas for existing development conditions were delineated within the watershed based on satellite imagery and the Nova Scotia Department of Natural Resources Forest Inventory GIS database for the following seven land cover types: Barren, Brush, Dense Forest, Light Forest, Urban, and Water/Wetland. The resulting land cover map as shown in **Figure 2.5** was used to assign values of imperviousness to sub-watersheds. Within the designated urban areas, land cover was classified into Low, Medium, and High Densities, to which imperviousness values were applied: Low Density – 0-30% impervious, Medium Density – 31-70% impervious, High Density – 71 – 100% impervious.

As shown in the land cover map, the watershed contains large swaths of dense and light forest, with pockets of dense and light urbanization in areas such as Burnside, Fall River, and Waverley. Future development maps were provided by HRM, and added to the Land Cover map for models which required it. The level of density/imperviousness assigned to future development areas was selected based on the average of the existing development densities in the watershed.

Soil Mapping

The soil survey data obtained from Agriculture and Agri-Foods Canada was used to develop a soil map of the watersheds by grouping soil layers into 15 layers, as shown in **Figure 2.6.**

Flow and Rain Gauging Data Compilation

Historical daily and peak flow data was obtained from Environment Canada from the flow monitoring station at Enfield (1974-1995). Though flow data was only available from the one location within the watershed and only spans 22 years, the available data was of good quality and adequate for calibration purposes. Historical rainfall data was obtained from Environment Canada at the Halifax-Stanfield International Airport (1953-2020), located within the watershed.

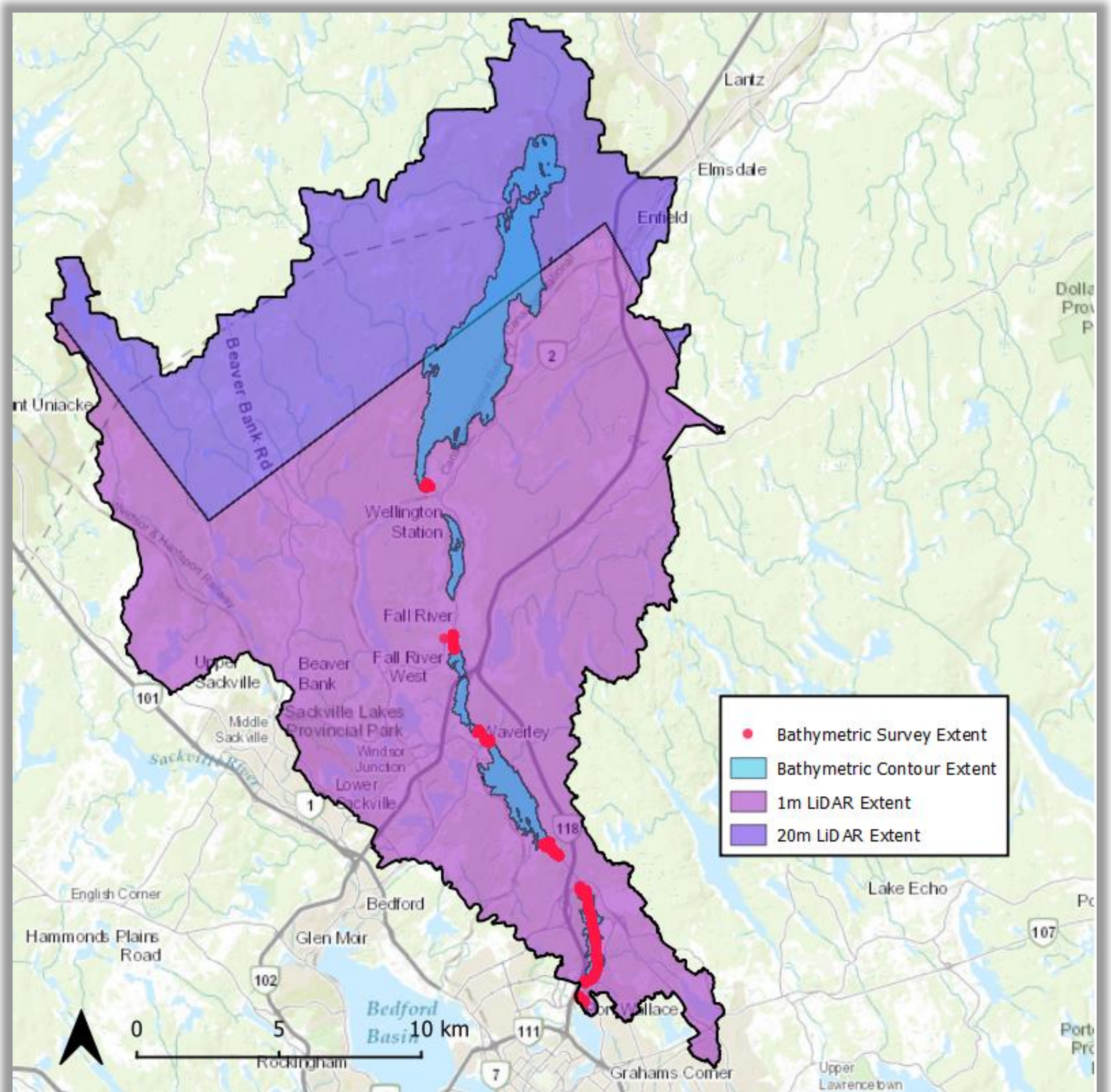

Figure 2.2 Data Extents **(Background map source: Esri World Topographic Map)**

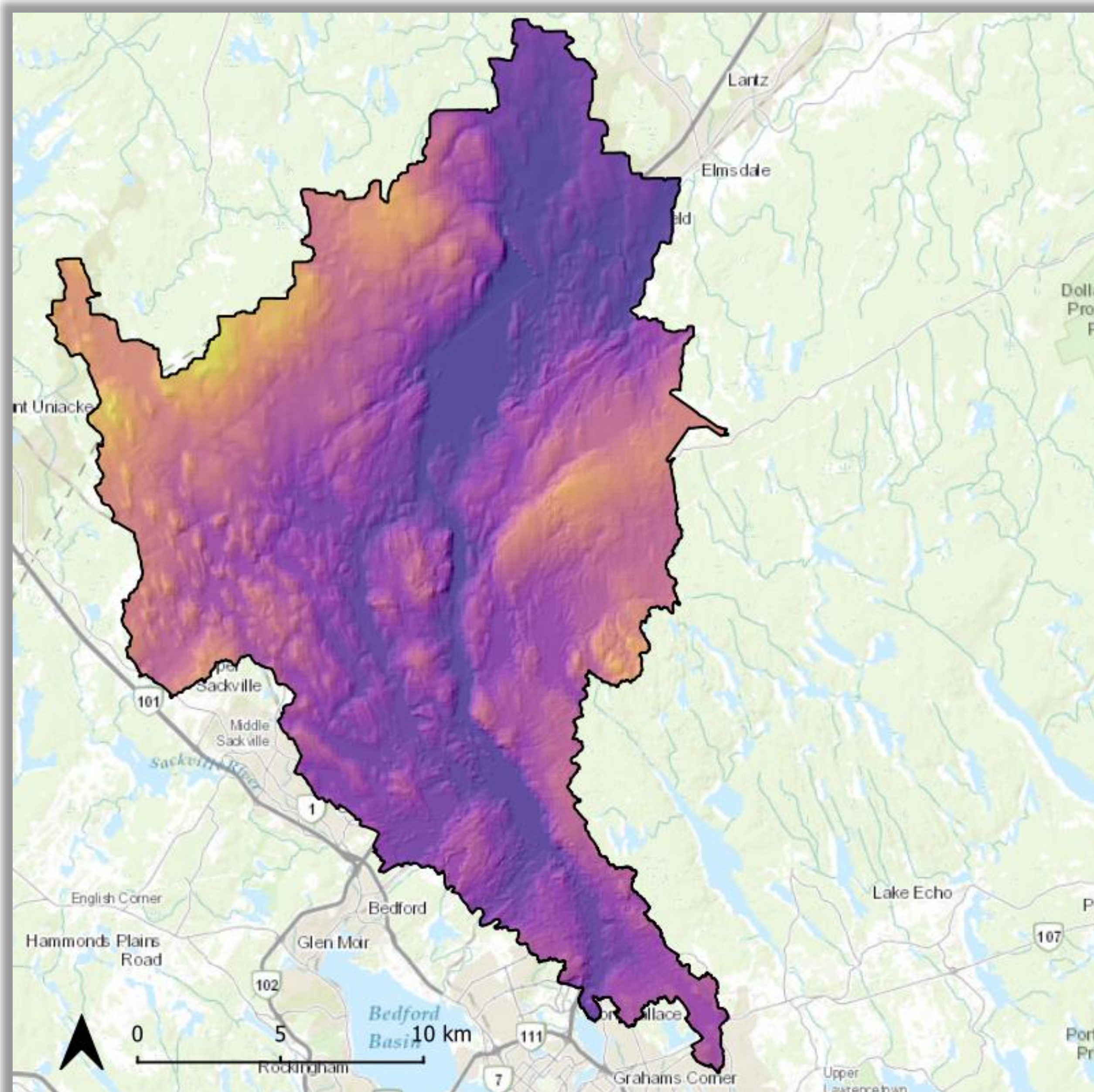

Figure 2.3 Combined DEM Surface **(Background map source: Esri World Topographic Map)**

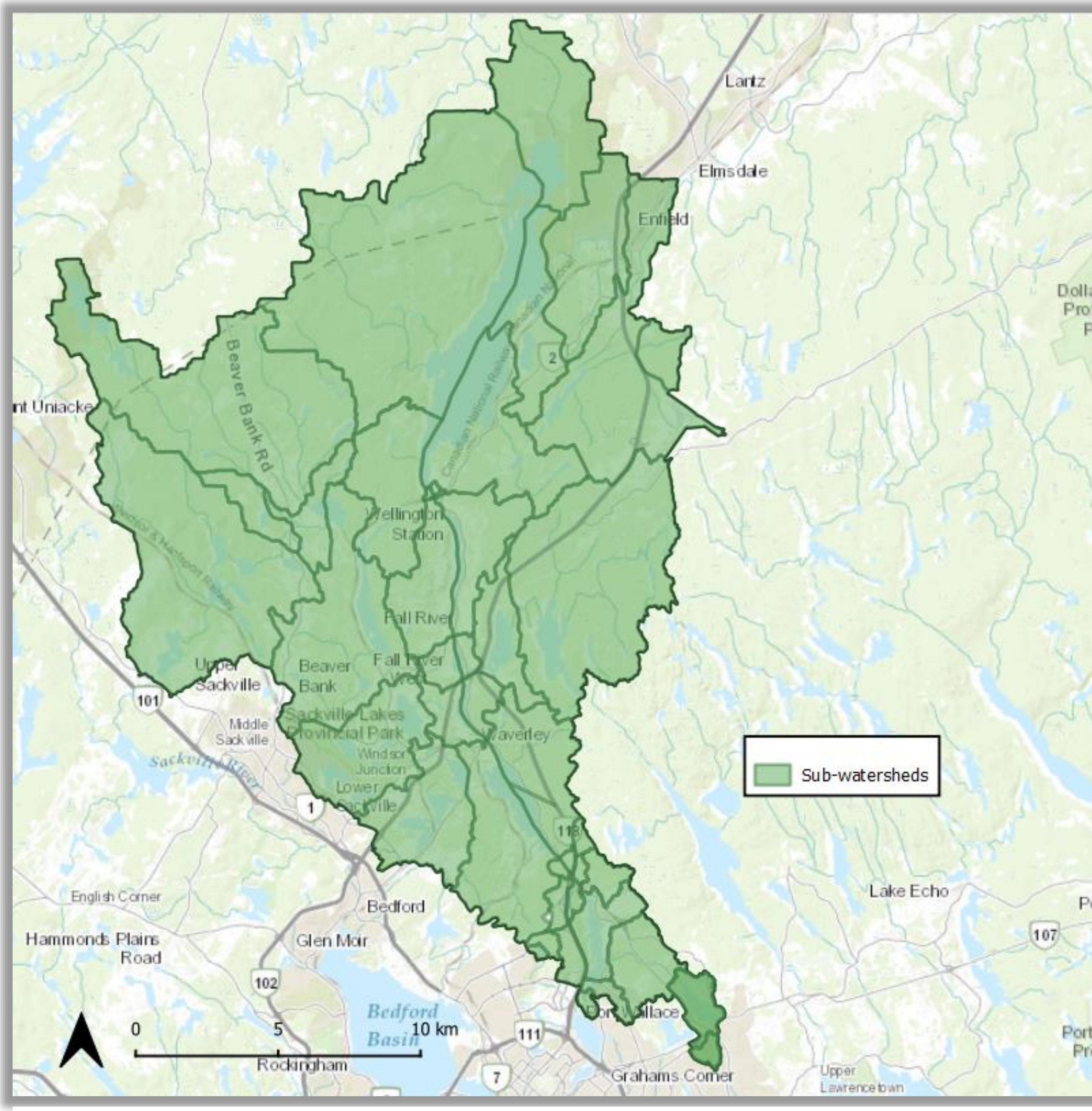

Figure 2.4 Sub-watershed Delineation **(Background map source: Esri World Topographic Map)**

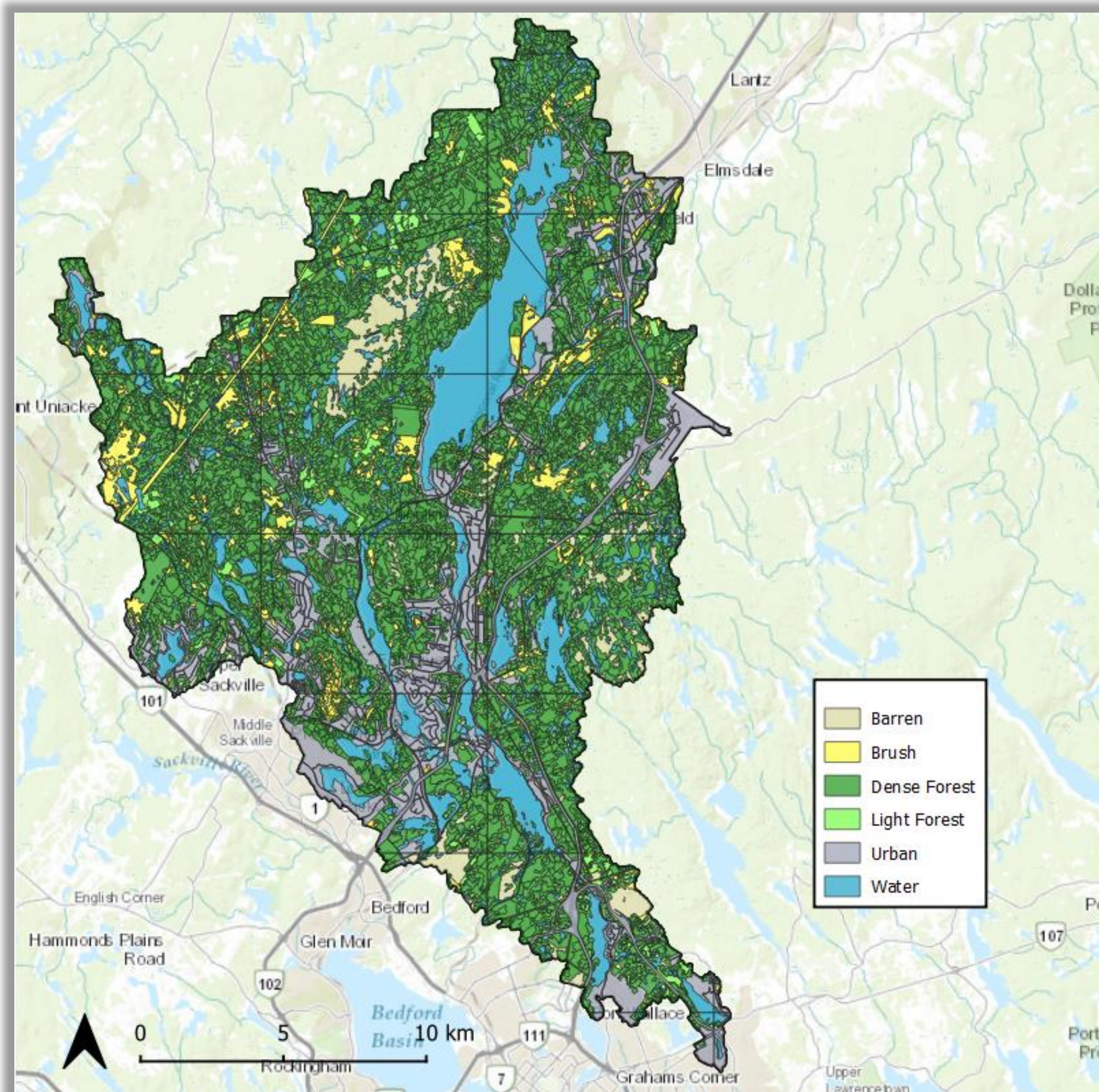

Figure 2.5 Land Cover (Background map source: Esri World Topographic Map)

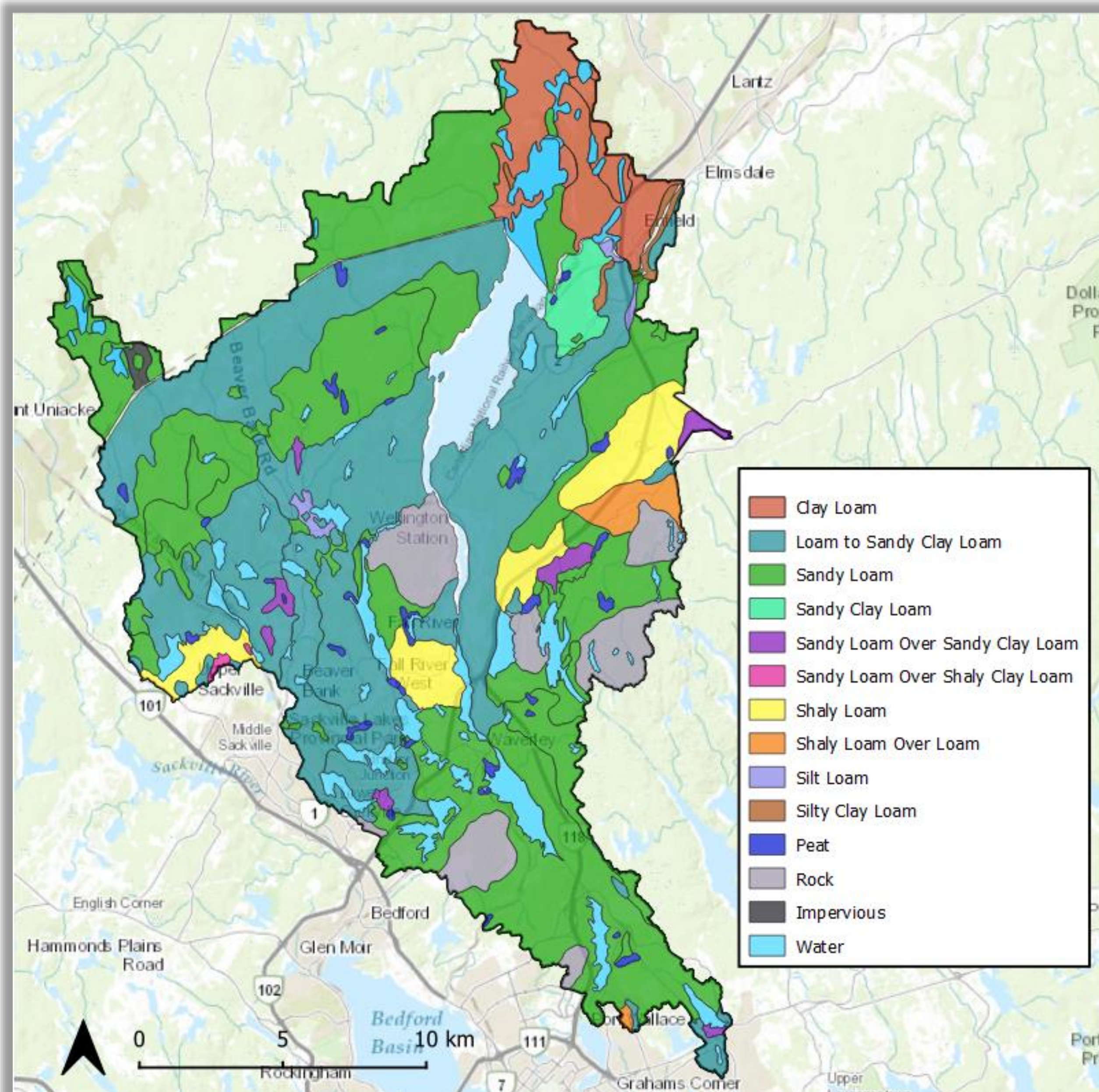

Figure 2.6 Soil Types (Background map source: Esri World Topographic Map)

Chapter 3 Hydrologic & Hydraulic Assessment

The Shubenacadie watershed drains predominantly northwards, out of the Shubenacadie River. A small percentage of additional drainage occurs from Lake Charles southwards along the Shubenacadie Canal towards Lake Micmac (discussed further in **Section 4.3**). The watershed is characterised by its large lake storage capacity, forest cover and pockets of development, hills, and its loam, sandy clay loam, and sandy loam soils. The watershed is moderately developed in small areas including Fletchers Lake, Fall River, and Waverley, and densely developed at its southern tip in Burnside. This is contrasted by large swaths of undeveloped land covered largely in dense forest elsewhere.

3.1 Modelling Software

Both hydrologic and hydraulic modelling was carried out for this study to quantify a range of flooding conditions along the Shubenacadie Lakes system and delineate flood lines. All hydrologic and hydraulic calculations were performed using PCSWMM.

3.1.1 PCSWMM

PCSWMM is a modelling program developed by Computational Hydraulics International (CHI) that integrates Version 5 of the Storm Water Management Model (SWMM) with a GIS engine. SWMM is a hydrologic and one-dimensional hydraulic model produced by the United States Environmental Protection Agency to study urban drainage systems and is capable of performing unsteady flow calculations to simulate water backup, pooling and culvert hydraulics by dynamically solving the continuity and momentum equations with a finite difference scheme.

A SWMM model was selected over HEC-RAS because it is a dynamic model (allows flows and water levels to change in time), it integrates hydrologic and hydraulic calculations (the runoff flows are gradually input over time into the system that constantly responds to it), it is more numerically stable (therefore a higher level of confidence in the results), and most importantly, it calculates the impacts of water storage and flow restrictions on the overall flows and water levels in the entire system, for each time step. This is critical in a system that includes a number of lakes and flow constrictions, such as the Shubenacadie Lakes System.

3.2 Hydrologic Model Development

A hydrologic model of the Shubenacadie watershed was developed using PCSWMM to estimate runoff flows from each sub-watershed for input into the hydraulic model. Imperviousness and roughness coefficients were estimated for each land cover type and applied to the watersheds using area-weighted averages. The imperviousness percentages were estimated by measuring and averaging impervious areas for each land cover type, and roughness coefficients were estimated based on values suggested by McCuen *et al*. (1996). The capillary suction head and saturated hydraulic conductivity of the soils were estimated or each soil class from the established soil map based on values suggested by Rawls *et al.* (1983) and then applied to the watersheds using area-weighted averages. Maximum overland flow lengths were estimated by manually measuring the flow path from the highest point of each sub-watershed to the outlet. Average surface slopes were calculated primarily using GIS tools, and checked and adjusted manually by measuring the slope between two points at every 20m throughout the sub-watersheds and weighing the slopes by drainage area. The percentage of runoff routed from the impervious area to the pervious area was estimated manually for each sub-watershed. The resulting watershed characteristics estimated for each sub-watershed under existing conditions and future development conditions are presented in **Appendix B**.

Groundwater was not independently modelled in the hydrologic model since it only represents a small fraction of peak flow, and PCSWMM is not currently able to model aquifers which cross watershed boundaries or the transfer of water from one aquifer to another. It was, however, simulated in the model by modifying the impervious percentage and pervious surface roughness, which approximates the shallow sub-surface flow which re-emerges in the watercourse and affects peak flows. Additionally, initial flow conditions for both calibration and design storm modelling included flows which are representative of inputs from precipitation and groundwater.

Since both the hydrologic model and hydraulic model are integrated into a single SWMM model, calibration of the hydrologic model was performed simultaneously with the hydraulic model, as discussed in **Section 3.4**. Hydrologic characteristics following model calibration are also presented in **Appendix B.**

3.3 Hydraulic Model Development

A hydraulic model of the Shubenacadie Lakes System was developed using PCSWMM to estimate the flows and water levels throughout the central drainage system. It includes the canals, lakes, bridges, weirs, roadway overflows and locks.

3.3.1 Floodplain Cross Sections

The combined DEM as described in **Section 2.1.2** was used to generate 311 cross sections between the hydraulic structures to input into the model, shown in **Figure 3.1**.

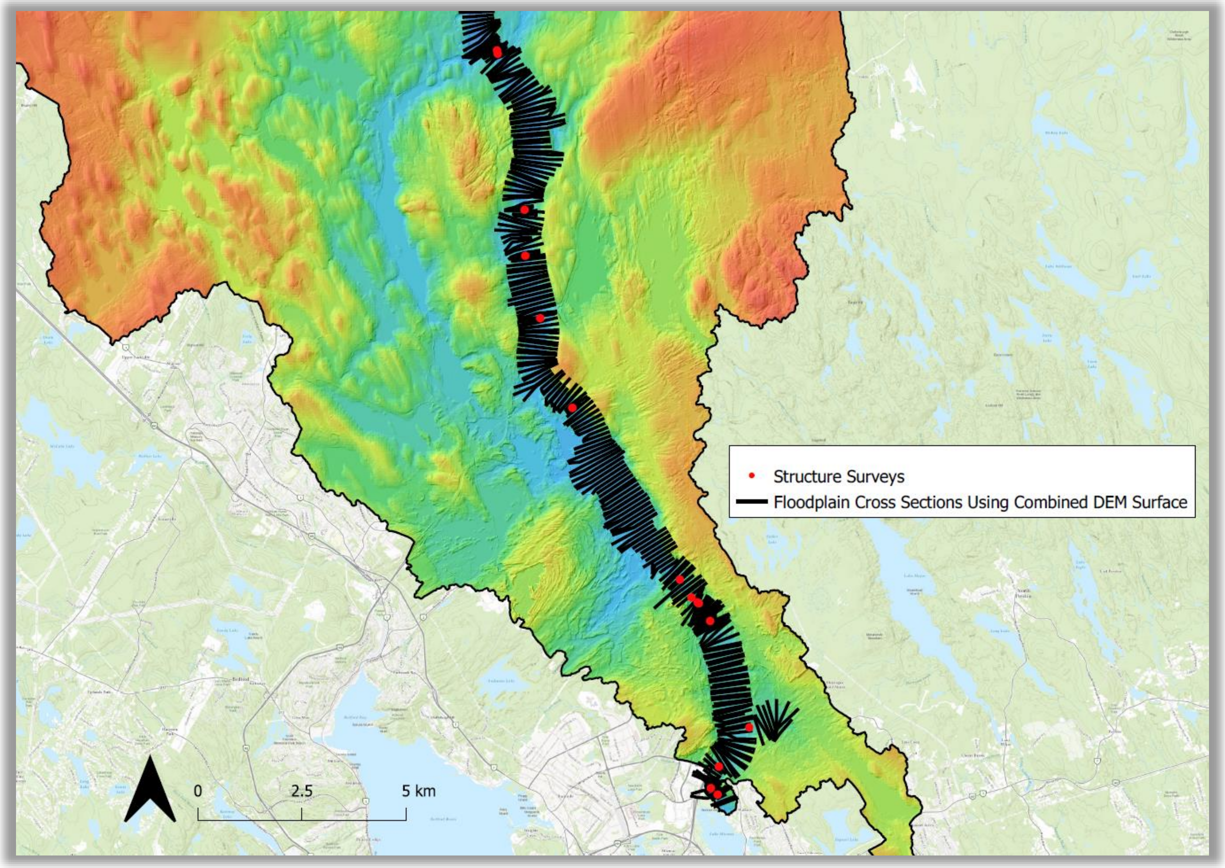

Figure 3.1 Cross Sections and Survey Points Used to Develop Hydraulic Model
(Background map source: Esri World Topographic Map)

Survey and bathymetric data was a crucial addition to the existing Lidar for validation, and because standard Lidar measurements are unable to penetrate the water surface, and thus do not include channel or lake bottom geometry. An example of the survey and Lidar comparison taken from just north of Lock 3 is shown in **Figure 3.2**.

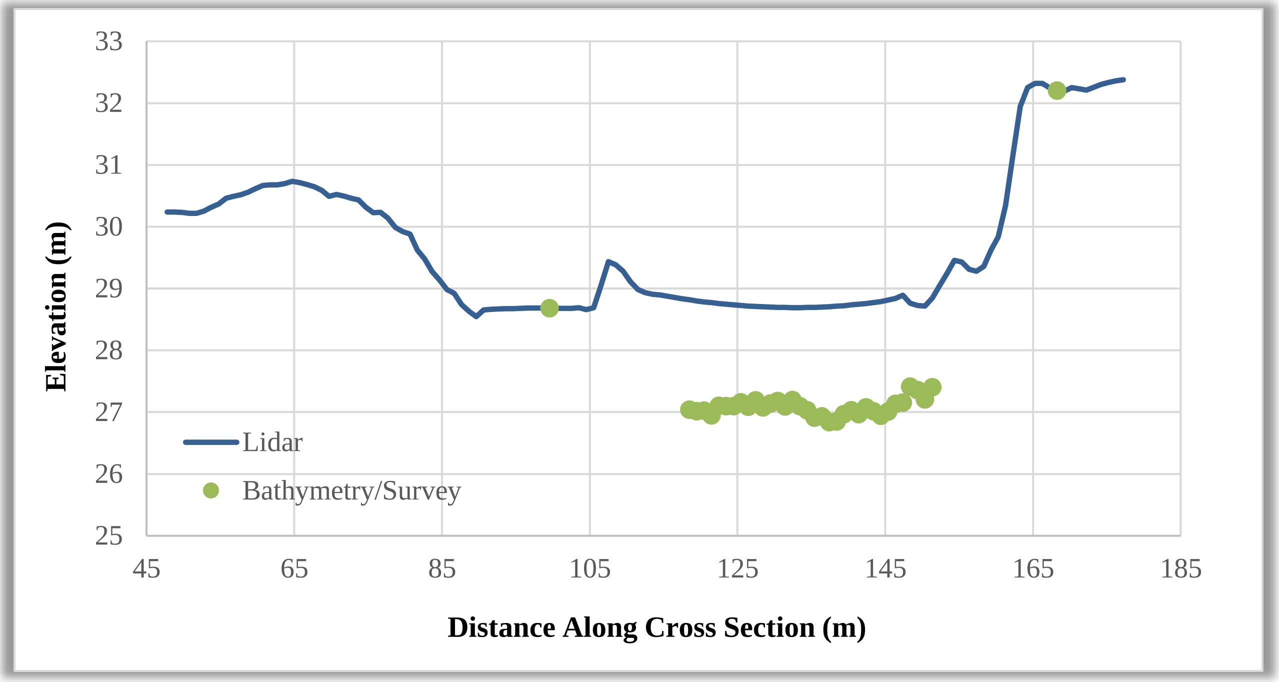

Figure 3.2 Example Comparison of Lidar data and Survey/Bathymetric data north of Lock 3

3.3.2 Hydraulic Structures

Hydraulic structures were input using the survey information for the 16 structures surveyed as described in **Section 2.1**. Initial estimates of roughness coefficients and loss coefficients were selected based on available photos, and inlet/outlet configurations. Lidar data as described in **Section 2.1.1** was used to generate cross sections for the overflow path of each structure. An example hydraulic structure input is shown in **Figure 3.3.**

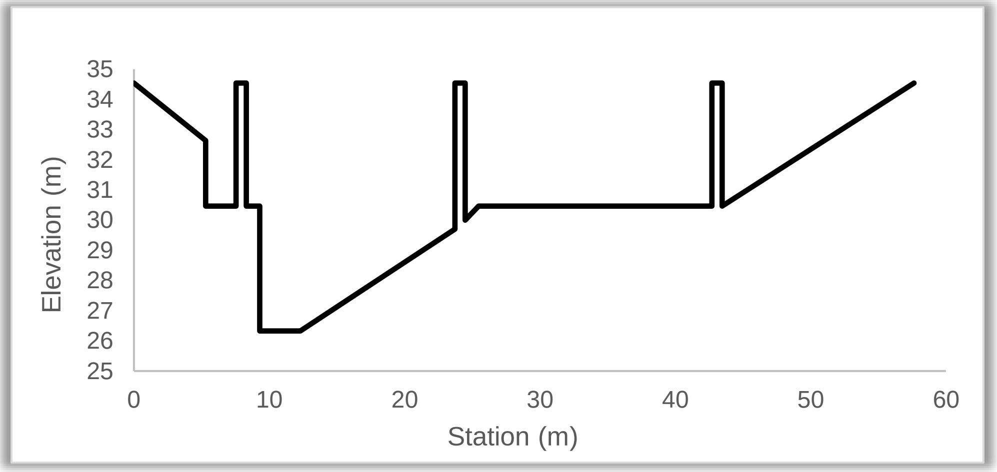

Figure 3.3 Cross Section of Highway 118 Southbound Bridge

3.4 Hydrologic & Hydraulic Model Calibration

Hydrologic and hydraulic model calibration was carried out by inputting historical rainfall data and representative initial flow conditions for selected flood events into the PCSWMM model and then modifying the initial estimated inputs of watershed characteristics and channel roughness coefficients until the flows and water levels simulated by the model were representative of historical values.

3.4.1 Calibration Event

A historical precipitation and flow event was selected for calibration over the measured water level data described in **Section 2.1.2**. The measured water levels for the period of September 6th, 2019 to October 6th, 2019 were used for reference rather than calibration because of the unseasonably dry watershed conditions preceding the window of measurement. A model calibrated on the measured period would overestimate the infiltration and storage capacity of the watershed during flooding events, leading to an underestimation of water levels and the extent of the floodplain, which poses a risk to public safety.

An event more representative of watershed conditions during a flooding event was selected from available historical data: November 17th-22nd, 1990. For this event, daily flow data was taken from Environment Canada's Shubenacadie River at Enfield flow station (01DG006), and accompanying daily rainfall data was taken from Halifax-Stanfield International Airport (8202250). The location of these stations and calibration event data can be found in **Figure 3.4** and **Figure 3.5**, respectively. As can be seen in results presented in **Section 4,** it is noted that the peak flow of the calibration event is smaller than the large storm events modelled. This is simply because the rainfall event associated with the calibration flow is smaller than those which are modelled for flooding scenarios.

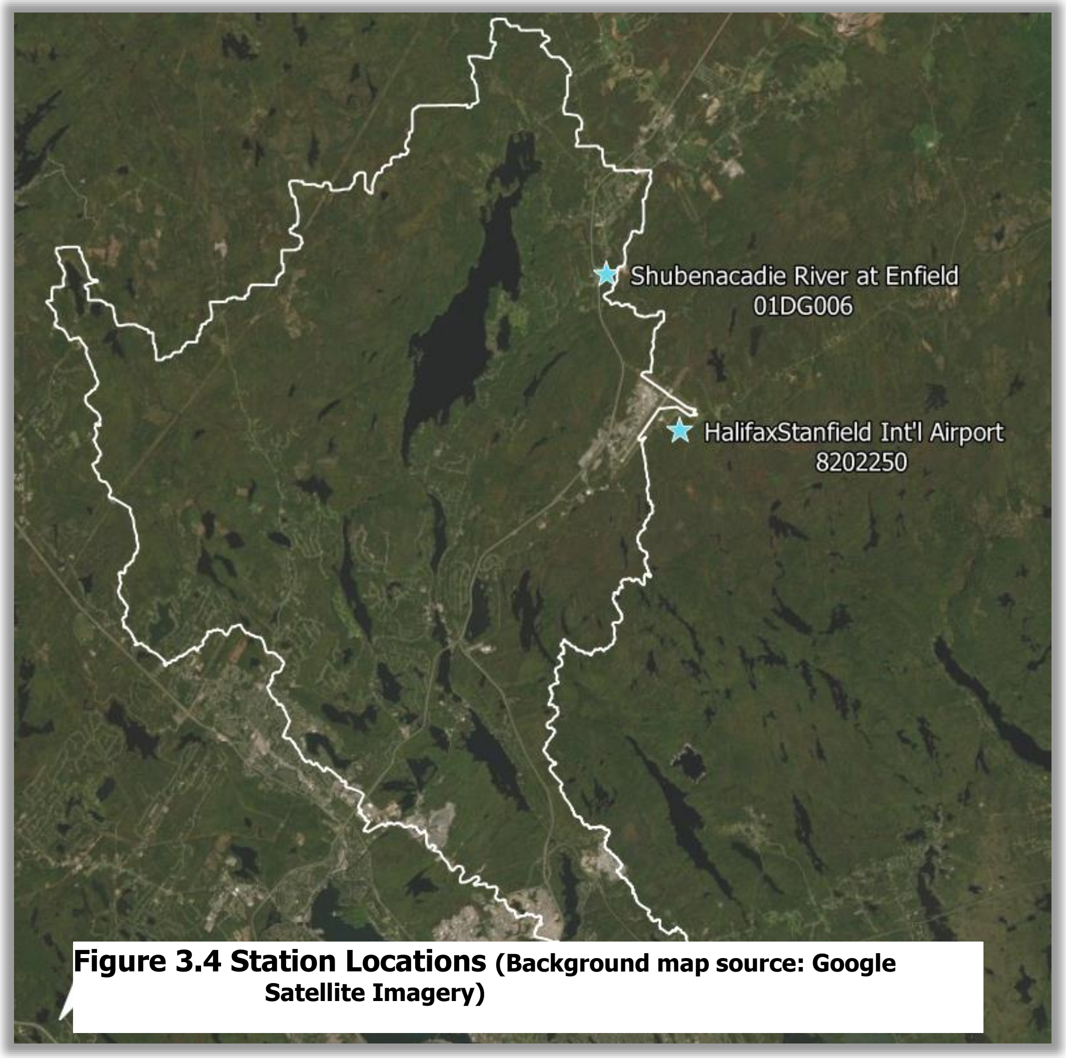

Figure 3.4 Station Locations **(Background map source: Google Satellite Imagery)**

3.4.2 Calibration Initial Conditions

Because the calibration event and subsequent scenarios begin with existing flows in the Shubenacadie Lakes System, initial flow conditions were represented by first introducing base flows to lakes and channels, allowing the system to fill. The model was then run for a few days, allowing excess water to flow out until conditions matched the initial conditions recorded before the November 1990 event at the location of the available flow gage (Enfield). This process allows the lakes to fill to the levels consistent with the recorded flow, it allows the watershed to be in a stable and dynamic state at the beginning of each model run, and is more reflective of real-world conditions rather than prorating calculated flows along the system.

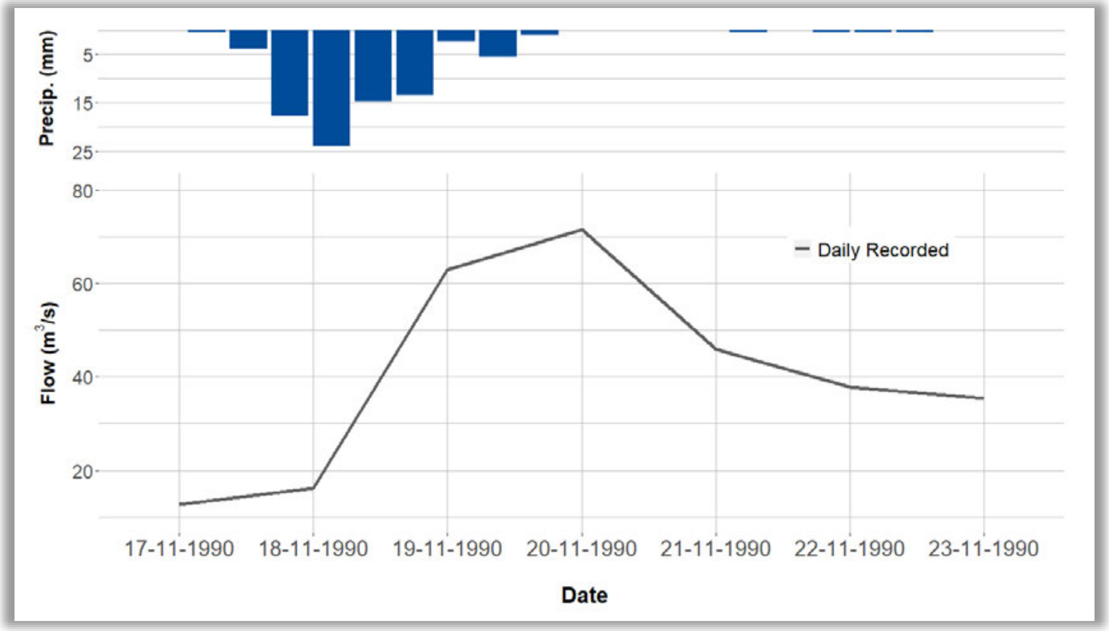

Figure 3.5 November 1990 Calibration Event

3.4.3 Model Parameter Adjustments

To calibrate the model in order to sufficiently reproduce the flows of the calibration event, adjustments were made to model parameters. These parameters included maximum overland flow length, percent imperviousness, conductivity, and channel/channel overbank roughness coefficients. Adjustments to maximum overland flow length and conductivity were significant, showing the fast response time and low infiltration rates of the watershed under calibration conditions, even when non-frozen. These adjustments are presented in **Table 3.1**. Other parameters tested but ultimately unchanged were capillary suction head, depression storage, percent routed (towards pervious or impervious areas) and hydraulic loss coefficients.

Table 3.1 Parameter Adjustments from Model Calibration

Event	Parameter Adjustment (Factor)				
	Maximum Overland Flow Length	% Impervious	Channel Overbank Roughness	Channel Roughness	Conductivity
Nov 1990	0.025	1.2	2.67	1.14	0.103

3.4.4 Calibration Results

To ensure peak flows were properly represented in the calibrated model, the daily flow measurements taken at the flow monitoring station at Enfield were interpolated to hourly flows which peaked at the measured peak flow of 83 m^3/s. The results of the interpolation and the results of the calibrated model at the station location are shown in **Figure 3.6**

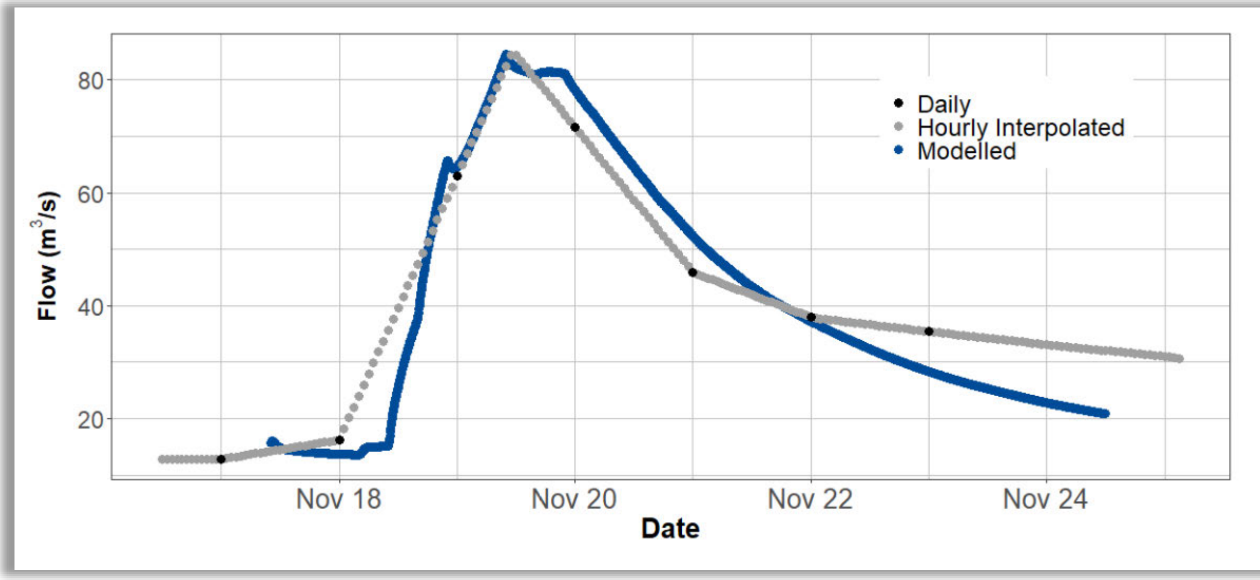

Figure 3.6 Calibration Results

As shown, the model was able to satisfactorily reproduce the measured water level and flow data. Peak flow of the calibrated model was 83.99 m^3/s, representing a 1.2% error, which is considered small in hydrologic and modelling analysis.

3.5 Selection of Design Model Parameters

Two sets of seasonally-representative models were built to analyze a range of flooding condition scenarios. These models included an unsaturated model, allowing for infiltration based on calibration conditions, and a wet/frozen model disallowing infiltration and with additional snowmelt to reflect winter/spring conditions as described further in this section.

3.5.1 Unsaturated Conditions

Initial flow conditions for the unsaturated model were developed by inputting a base flows into the model and then running the model until flows reached the average measured flow rates from the available data at Enfield (01DG006). The corresponding flows and water levels, now matching the average recorded value, were then used as initial flow conditions for the unsaturated model prior to simulating the design storm events.

3.5.2 Wet/Frozen and Snowmelt Conditions

For models including snowmelt contributions, initial snow depth conditions were input into the model based on the average winter and spring snow depths from climate normal values published by Environment Canada for the Halifax-Stanfield Airport climate station. These values are presented in **Table 3.2**. Average values for snowpack were selected over extreme values so as not to affect the expected return periods of the selected design storms.

Snowmelt calculations were performed in the model by inputting climate normal wind speeds, daily maximum temperatures and daily minimum temperature averages, taken from the

Environment Canada station at the Halifax-Stanfield International Airport. Temperature time series were input such that the minimum temperature occurred at the beginning of the storm and maximum temperature occurs at the peak of the storm, allowing for a maximum snowmelt rate to coincide with the peak of the storm. The initial conditions for winter and spring are presented in **Table 3.2**.

Table 3.2 Initial Conditions and Design Climate Inputs for spring and winter

Season	Months	Initial Snow Depth (cm)	Daily Max. Temperature (°C)	Daily Min Temperature (°C)	Wind Speed (km/hr)	01DG006 Average Flow (m^3/s)
Spring	Mar/Apr/May	2.33	9.167	-0.467	17.77	19.36
Winter	Dec/Jan/Feb	9.33	-0.067	-8.83	17.83	16.99

The maximum flow rates modelled at the location of station 01DG006 for a 1 in 100 year event under spring and winter conditions were 383.292 m^3/s and 319.603 m^3/s, respectively. For this reason, the model containing spring conditions was chosen to represent wet/frozen antecedent conditions with snowmelt.

3.6 Design Events

3.6.1 Design Rainfall Events for Existing Climate Conditions

Design rainfall hyetographs that follow the Chicago Distribution with 5-minute discretization intervals were developed for 24-hour duration storm events. The design hyetographs used for flood scenarios included the 1 in 5, 1 in 20, 1 in 100, and 1 in 500 year storms for current climate conditions, which were based on Intensity-Duration-Frequency (IDF) curves developed for this study following the same procedures used by Environment Canada.

A Gumbel statistical distribution was fit to the forty years of available annual maximum rainfall data for the Halifax-Stanfield International Airport, and then an exponential curve was fit to each return period. The resulting IDF curves are presented in **Figure 3.7**. It is noted that official IDF curves published by Environment Canada do not include the 1 in 20 year return period or 1 in 500 year return period, but that there is a high level of confidence in the calculated curves presented in this report, as the published values matched those developed for this study for all other return periods.

Chicago Distribution design rainfall hyetographs were then produced from the IDF curves for 24-hour duration storm events at 5 minute time steps, and are presented in **Figure 3.8**. The Chicago Distribution is a widely-used method for design storms, as it corresponds directly to the intensity/duration relationship of the IDF curve, and thus is representative of the characteristics of historical events.

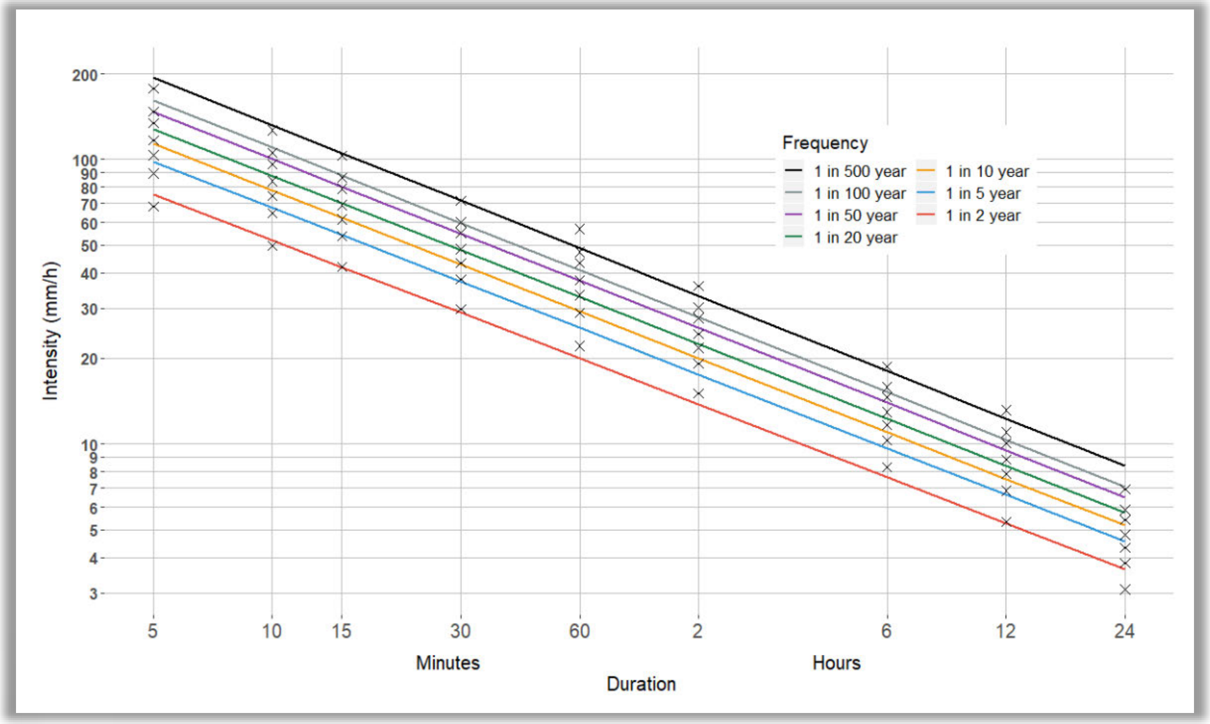

Figure 3.7 IDF Curves for Halifax-Stanfield Int'l Airport

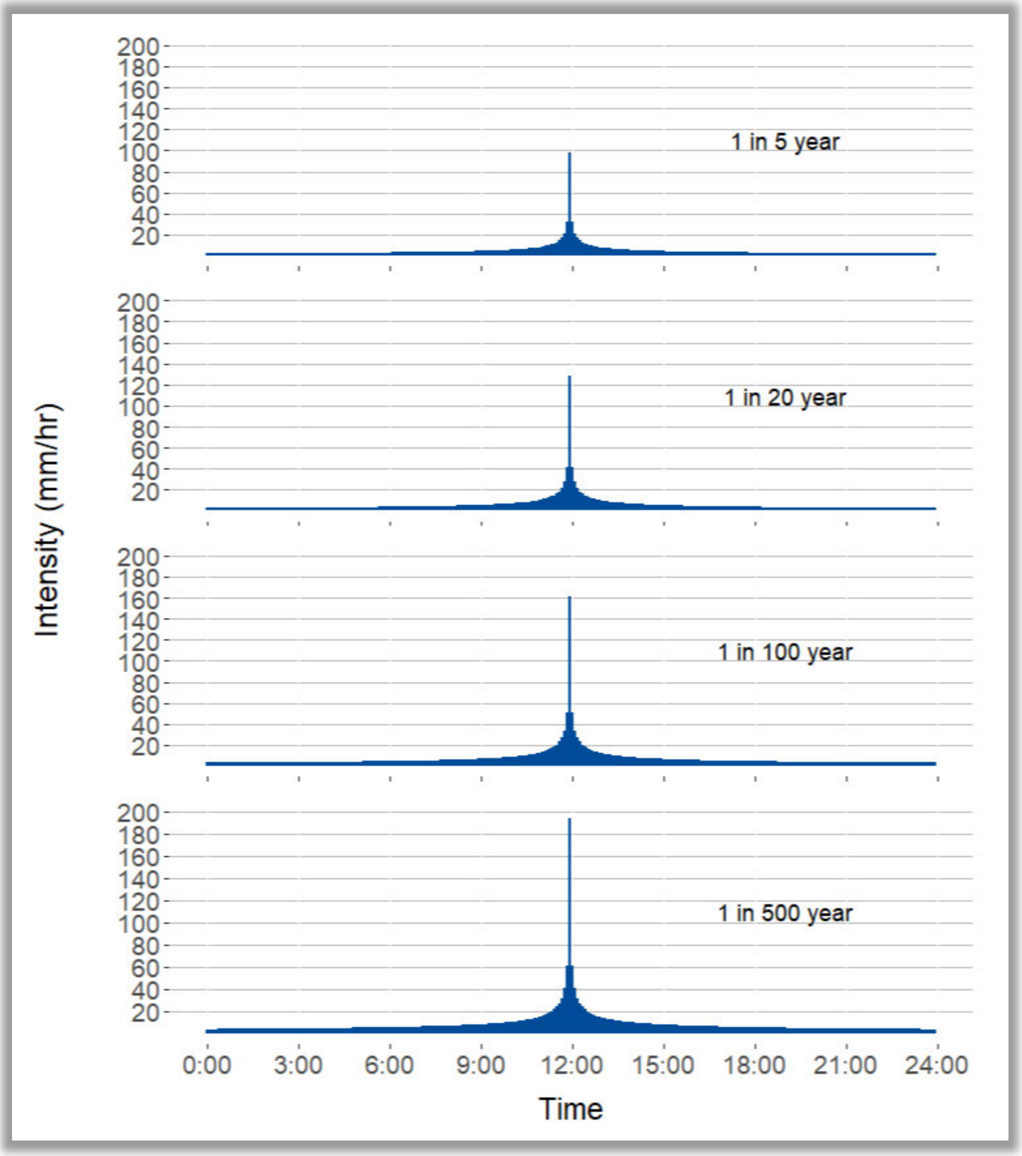

Figure 3.8 1 in 5 Year, 1 in 20 Year, 1 in 100 Year, and 1 in 500 Year Design Storms for Current Climate Conditions

3.6.2 Design Storm Event for the Probable Maximum Precipitation (PMP)

The PMP is the theoretical maximum precipitation for a given duration under modern meteorological conditions (Hogg and Carr, 1985). It is the worst-case storm modelling scenario to be used for an understanding of the sensitivity of the system response and provide additional information used for safety and planning services. Several in-depth theoretical approaches are available for estimating the PMP; however, there is still a wide disparity between theoretically estimated amounts and actual observations, despite considerable investigation into the mechanisms of rainfall production over the last few decades (WMO, 2009). Procedures for estimating PMP cannot be standardized. They vary with the amount and quality of data available, basin size and location, basin and regional topography, storm types producing extreme precipitation, and climate. It should be noted that due to the physical complexity of the phenomena and limitations in data and the meteorological and hydrological sciences, only approximations are currently available for the upper limits of storms and their associated floods. The accuracy of PMP/PMF estimation rests on the quantity and quality of data on extraordinary storms and floods and the depth of analysis and study. Nonetheless, it is impossible to give precise values for PMP and PMF. As yet, there are no methods to quantitatively assess the accuracy of PMP and PMF. Statistical procedures for the PMP are considered the most appropriate method for small basins (1000 m^2), although they have also been used for much larger areas (Hogg and Carr 1985). Statistical approaches are particularly useful where other meteorological data, such as dew point and wind records, are lacking (WMO, 2009).

The approach used for estimating the PMP for this study used the empirical relationships developed by Hershfield (1965), which are based on several hundred thousand station-years of data from many countries. While the Hershfield procedure is not the only statistical approach available, it is the process that has received the widest acceptance (WMO, 2009). However, it is noted that this approach assumes that the PMP has been historically observed at the station located at Halifax-Stanfield International Airport, and that it only estimates point values. The PMP was therefore calculated using the following equation provided by Hershfield (1965):

$$PMP = \overline{X_n} + K_{M24}S_n$$

Where:

$\overline{X_n} = mean\ \ annual\ \ maximum\ 24\ hour\ rainfall\ amount = 77.3\ mm$
$S_n = standard\ \ deviation\ of\ annual\ maximum\ 24\ hour\ rainfall\ amounts = 20.2\ mm$
$K_{M24} = 19(10)^{-0.000965\ \overline{X_n}}$

Using the annual maximum rainfall amounts published by Environment Canada for the Halifax-Stanfield International Airport climate station, the mean and standard deviation were found to be 77.3 mm and 20.2 mm respectively. The PMP was estimated to be **400.53 mm** using the above equation, and a design hyetograph was developed for the 24-hour duration following the Chicago distribution.

3.6.3 Design Storm Events for Climate Change Conditions

Climate change, and its impacts on precipitation intensity, is one of several uncertain factors (such as development, population growth, infrastructure performance, etc.) expected to affect future flooding risks. There are several approaches to estimating the impacts of climate change on precipitation intensity. For this study, climate change scenarios and their impacts were analyzed following the Canadian Federal Hydrologic and Hydraulic Procedure for Flood Hazard Delineation, which outlines practices for the consideration and selection of various scenarios (NRCan, 2019). For this project, projections were obtained using the following two methods (see **Appendix C** for details):

1. Statistical downscaling of precipitation projections from Global Climate Models (GCMs) using the Western University Intensity Duration Frequency Climate Change tool version 4 (IDF-CC Tool) and,
2. Scaling from temperature projections from Global Climate Models (GCMs) using on the Clausius-Clapeyron equation.

A range of projections was obtained for each method based on different GCMs and emission scenarios ("high" and "medium" emissions are referred to as RCP 8.5 and RCP 4.5 respectively). In this study, the IDF-CC Tool results were higher and is thus used for the future design storm scenarios (further information can be found in **Appendix C**). Three scenarios were selected for sensitivity analysis and are presented in **Table 3.3**.

Table 3.3 Climate Change Scenarios for 2100

Scenario	Emission Scenario	Method	Percentile	% increase from baseline
				1 in 100 year 24-hr
Scenario A	RCP 8.5	IDF-CC	95th	116%
Scenario B	RCP 4.5	IDF-CC	95th	78%
Scenario C	RCP 8.5	IDF-CC	50th	40%

The three scenarios selected were analyzed individually rather than the use of an ensemble average, which ignores the uncertainty in the spread of model results. Best practice for selection of a climate change scenario includes an analysis of best and worst case scenarios for a better understanding of system response. A comparison of the flooding impact of the range of the three scenarios used in this study can be found in **Appendix D** and **Appendix E**.

Using only a single scenario has some drawbacks:

1. **Applies a daily scaling factor to sub-daily intensities.** Since the percent change of the scenario is applied uniformly to the design storm hyetograph, this assumes that the projected change for the 24-hour storm is the same as for other durations. This is likely to be an invalid assumption for sub-daily durations. There is emerging evidence that sub-daily (i.e. < 24 hour) precipitation may increase more rapidly than daily precipitation, because storms of different durations are controlled by different atmospheric mechanisms (PCIP, 2015). Therefore this scenario likely underestimates future sub-daily precipitation intensities.
2. **Ignores context from other climate projections.** Projecting future changes in precipitation intensity is challenging (see **Appendix C** for details). Different schools of thought advocate for different methods, but no approach is more reliable and defendable in all situations. The best practice is that no single climate change projection be used in isolation as it belies the inherent uncertainty in projections. A single selection ignores how different projections from the two methods and the multiple scenarios/models compare. It is important to note if the projections obtained from the two methods are significantly different in the floodplain.
3. **Cannot be used in risk assessments.** The agreement or disagreement between climate change projections provides a measure of uncertainty (even though projections should not be interpreted in a probabilistic way). In some locations (i.e., some climates, geographies, or parts of a watershed), flood lines derived from multiple climate projections may be similar, whereas in other locations, flood lines may differ greatly (i.e., the floodline can be more or less sensitive to climate change assumptions). This has a bearing, for example, on the management of assets within the floodplain, which should be based on risk tolerance for

different assets. Therefore, the use of a single scenario does not allow for risk-based decision making.

Of the three scenarios analyzed and compared, the future design storm for flooding was selected in conjunction with HRM to be Scenario C: the IDF-CC result for RCP 8.5 95th percentile. The effects of this projection on rainfall are summarized in **Table 3.4**.

Table 3.4 IDF-CC Results for RCP 8.5 95th percentile

Scenario	% increase from baseline		
	1 in 5 year 24-hr	**1 in 20 year 24-hr**	**1 in 100 year 24-hr**
Scenario A	33%	63%	116%

Although this document focuses on the findings and results from the single scenario discussed above, a full range of climate projections obtained with the IDF-CC Tool and Clausius-Clapeyron equation are provided in **Appendix C**. A comparison of flow profiles and flood lines produced for the three projection scenarios are presented in **Appendix D** and **Appendix E,** respectively.

3.7 Uncertainty

Although the model was successfully calibrated to the November 1990 event, there exists some associated uncertainty, typical of all hydrologic models. The sources of uncertainty include:

- Measurements of hydrologic parameter inputs (soil infiltration, surface roughness, effective impervious area);
- Hydraulic loss parameters (channel roughness, energy losses at structures);
- Computational uncertainty (computational/iteration schemes used to resolve finite difference hydrodynamic equations);
- Calibration data uncertainty (flow data, water level data, amount and location of precipitation, groundwater contribution);
- Natural seasonal changes (most hydrological parameters change throughout the year);
- Climate change uncertainty (discussed further in **Appendix C**).

Each of the above sources of uncertainty will compound the overall uncertainty of the model results. The exact uncertainty cannot be determined due to the wide variation of each of these sources. Hydrologic and hydraulic model assumptions and limitations are generally noted throughout the hydrologic and hydraulic model sections in this report.

Chapter 4 Flood Modelling, Flood Line Delineation, & Mitigation

4.1 Flood Modelling and Results

The calibrated hydrologic and hydraulic models were used to simulate the flood scenarios presented in **Table 4.1** on the following page**.** Model simulation results from the scenarios were then used to produce water elevation profiles that show estimated water levels along the Shubenacadie Lakes System to delineate flood lines which show estimated flooding extents.

Table 4.1 Summary of Scenarios, Water Surface Profiles, and Flood Maps

Scenario Description	Model Parameters and Initial Conditions	Design Rainfall Event	Peak Flow (m^3/s) (01DG006)	Water Surface Profiles	Flood Maps
Historical Design Storm	November 1990	November 1990	84.5	• November 1990 Rainfall	• Map 1: November 1990 Event
Antecedent Conditions Comparison	Unsaturated, no snowmelt, existing development	1 in 100 Year	303.3	• Existing IDF, Unsaturated Conditions & Existing Development • Existing IDF, Wet/Frozen , with Snowmelt & Existing Development	• Map 2: Comparison of Antecedent Conditions
	Wet/Frozen, snowmelt, existing development		383.3		
Existing IDF, Existing Development	Unsaturated, no snowmelt, existing development	1 in 5 Year	156.0	• Existing IDF, Unsaturated Conditions & Existing Development	• Map 3: 1 in 5 Year, 1 in 20 Year, and 1 in 100 Year Flood Lines, Existing Conditions • Map 4: 1 in 100 Year, 1 in 500 Year, and PMP Flood Lines, Existing Conditions
		1 in 20 Year	219.5		
		1 in 100 Year	303.3		
		1 in 500 Year	357.7		
		PMP	655.3		
Climate Change Scenario Comparison	Unsaturated, no snowmelt, existing development	1 in 100 Year	303.3	• Climate Change Scenarios: Future IDFs, Unsaturated Conditions & Existing Development	• Map 5: Climate Change Scenario Comparison
		1 in 100 Year - RCP 8.5: Median (IDF-CC Tool)	443.1		
		1 in 100 Year - RCP 4.5: 95th Percentile (IDF-CC Tool)	550.2		
		1 in 100 Year - RCP 8.5: 95th Percentile (IDF-CC Tool)	630.9		
Existing IDF, Future Development	Spring Conditions - Wet/Frozen with Snowmelt , Future Development	1 in 5 Year	244.9	• Existing IDF, Wet/Frozen with Snowmelt & Future Development	• Map 6: 1 in 5 Year, 1 in 20 Year, and 1 in 100 Year Flood Lines, Current IDFs, Future Development
		1 in 20 Year	307.7		
		1 in 100 Year	383.7		
Future IDF, Future Development	Spring Conditions - Wet/Frozen with Snowmelt, Future Development	1 in 5 Year: RCP 8.5: 95th Percentile (IDF-CC Tool)	324.2	• Future IDF, Wet/Frozen with Snowmelt & Future Development	• Map 7: 1 in 5 Year, 1 in 20 Year, and 1 in 100 Year Flood Lines, Future IDFs, Future Development
		1 in 20 Year: RCP 8.5: 95th Percentile (IDF-CC Tool)	475.1		
		1 in 100 Year: RCP 8.5: 95th Percentile (IDF-CC Tool)	672.5		
Hydraulic Structure Jam	Spring Conditions - Wet/Frozen with Snowmelt, Future Development, and Structure Jams	1 in 100 Year	355.6	• Hydraulic Structure Jam: Existing & Future IDF, Wet/Frozen with Snowmelt & Future Development	• Map 8: Hydraulic Structure Jam
		1 in 100 Year: RCP 8.5: 95th Percentile (IDF-CC Tool)	657.0		
Comparison of Existing and Future IDF and Future Development	Spring Conditions - Wet/Frozen with Snowmelt, Future Development	1 in 20 Year	307.7	• Comparison: Existing & Future IDF, Wet/Frozen with Snowmelt & Future Development	• Map 9: 1 in 20 Year Flood Lines, Existing and Future IDFs, Future Development • Map 10: 1 in 100 Year Flood Lines, Existing and Future IDFs, Future Development
		1 in 20 Year: RCP 8.5: 95th Percentile (IDF-CC Tool)	475.1		
		1 in 100 Year	383.7		
		1 in 100 Year: RCP 8.5: 95th Percentile (IDF-CC Tool)	672.5		
Recommended Base Flow	Spring Conditions - Wet/Frozen with Snowmelt, Future Development	1 in 20 Year: RCP 8.5: 95th Percentile (IDF-CC Tool)	475.1	• Base Flood: Future IDFs, Wet/Frozen with Snowmelt & Future Development	• Map 11: Base Flow Flood Lines
		1 in 100 Year: RCP 8.5: 95th Percentile (IDF-CC Tool)	672.5		

4.2 Hydraulic Structure Head Losses

Head losses and surcharging occurring at the hydraulic structures were analysed for the 1 in 100 year rainfall event to identify structures that could potentially cause flow restrictions during flood events. Head losses were defined as the difference between the peak water levels upstream and downstream of the respective structures. The estimated head losses for the 1 in 100 year rainfall event using unsaturated, existing IDF and existing development conditions are presented in **Table 4.2.**

Table 4.2 Head Losses at Hydraulic Structures between Lock 2 and Lock 5 for 1 in 100 Year Rainfall Event (Existing IDF, Existing Development, Unsaturated, No Snowmelt)

Structure Name	Head Loss (m)	Surcharging?
Lock 3	2.47	-
Shubie Greenway Corridor South	0.69	no
South Trans Canada Trail	0.69[1]	no
Highway 107	0.06	no
Shubie Trail Head	0.28	no
Highway 118 Northbound	0.16	no
Highway 118 Southbound	0.24	no
North Trans Canada Trail	0.34	yes
Private Bridge	0.05	no
Rocky Lake Drive	0.67	yes
Highway 102	0	yes
Fall River Road	0.18	yes
Fletchers Lake Lock Trail (Lock 4)	1.68[1]	yes
CN Rail	0.02	no
King's Road	0.03	yes
Waverley Road/Meadow Walk	2.12[1]	yes

[1]Drastic head loss largely caused by elevation drop at structure outlet

Structures with the highest effects on flow were Lock 3 and the bridges at the Shubie Greenway Corridor South, Rocky Lake Drive, Fletchers Lake Lock Trail (Lock 4), and Waverley Road at Meadow Walk. Additional structures experiencing surcharging and at higher risk for causing flow impediments in the event of ice jams or debris blockage were the bridges at the north Trans Canada Trail crossing, Fall River Road, Highway 102, and King's Road.

4.3 Hydrologic and Hydraulic Model Findings

Findings from this analysis include identification of factors leading to flooding extents generated by the models. Analysis of structure constrictions above identified Lock 3 and the bridges at Shubie Greenway Corridor South, Rocky Lake Drive, Fletchers Lake Lock Trail (Lock 4), and Waverley Road at Meadow Walk as causing notable impediment to flow, while additional bridges such as the North Trans Canada Trail, Highway 102, Fall River Road, and King's Road were identified as being at an increased risk for detrimental effects from ice jams and debris blockage.

Another interesting finding of this study includes the flow dynamics of Lake Charles. The Shubenacadie Sub-Watershed Study (AECOM, 2013) presented that Lake Charles discharges approximately 90% southwards, towards Lake Micmac. This is in contrast to the historical belief that only 40% of Lake Charles discharge passes through this outlet. After the inclusion of surveyed outlet flow control structures, bathymetry, and thorough hydraulic analysis, this study finds that during flooding events, approximately only 10% of discharge from Lake Charles passes southwards, while as much as 90% discharges north towards Lake William. This finding suggests that there is room for improvement on previous water quality studies in the region with the addition of the more detailed survey and bathymetric data presented in this study. An updated water quality model with the improved survey may improve the accuracy of the modelled distribution of sediments and pollutants in the system.

Though in the 19th century the Shubenacadie Canal was excavated out by people rather than natural geologic and hydrodynamic processes, the canal served to widen and re-open a historic waterway which connected Shubenacadie Grand Lake with the Halifax harbor about 14,500 years ago. The natural waterway, carved by glaciers, served as drainage for the Shubenacadie Grand Lake for about 3,000 years (Belt, 1865; Fergusson, 1971; Shubenacadie Canal Commission, 2019). Over millennia, this etched a natural waterway and carved a floodplain in the topography that still largely influences the flooding extents presented in this report. This natural process is an important consideration, because it demonstrates that flooding outside of the canal and lake system (in the floodplain) is a largely natural phenomenon.

The model shows that the current 1 in 100 year peak flood extents occupy a large portion of this natural floodplain. Notably, the model results also indicate that events of a greater magnitude, such as the 1 in 500 year event, the PMP, or future events influenced by climate change, lead to in increased floodplain width, but only by a small relative amount. This means that high flows will regularly fill the floodplain, but that extremely high flows will stay within this main floodplain. It is important to note because this also means that the floodplain is necessary for the conveyance of high flows. Development within the floodplain will unavoidably be at risk of flooding, and any restriction of this floodplain will lead to higher upstream water levels.

4.4 Flood Line Delineation

As shown in **Table 4.1,** each flood line presented in **Appendix E** was delineated based on a combination of the design rainfall and antecedent conditions. For a given return period, the maximum water level of each of the scenarios at each location along the system was selected to delineate the respective floodlines. Thus, each flood line delineation consists of the maximum of the extreme rainfall flood event. The resulting flood lines therefore do not represent the flood extents for a single time stamp, but rather represent the extent of the flood plain at its maximum at each point along the system.

All flood lines were delineated by interpolating the water levels output by the model and then intersecting them with the 1m resolution Lidar using GIS tools.

4.4.1 Flood Line Verification

The historical design storm event (November 1990) flood line was compared with anecdotal data acquired at the October 10th 2019 meeting between CBCL, HRM, and representatives from municipal departments.

4.5 Encroachment Analysis

Encroachment analyses are used by the Federal Emergency Management Agency (FEMA) to show how activities such as infilling and development in the regulatory floodway will produce an increase in flood levels, based on by hydraulic modelling (FEMA 37, 1993). The goal of the encroachment analysis is to therefore determine the reduction in floodplain width at every location along the system that will cause a specified increase in water level. For this study, a 5% increase in water level was used to define the encroachment, and the analysis was carried out for the 1 in 100 year rainfall event using the PCSWMM model.

Normally, the base flood is the one-percent chance event, and the designated height is one foot, unless the state has designated a more stringent regulation for maximum rise (Brummer, 2016). In order to be consistent with this, a 5% rise was selected, which on average corresponds to approximately 1 foot. A percentage value was selected in order to generate results that show the relative sensitivity of flooding over the whole system as a result of floodplain development, rather than an absolute value that does not support comparative analyses.

A typical land use planning policy allows development to still occur between the 1 in 20 and 1 in 100 year floodplain extents, provided that the development is flood proofed. This analysis is made to identify specific locations where such a policy would result in increased flooding risks. The resulting 1 in 100 year encroachment floodplain width was therefore compared to the existing 1 in 20 year floodplain width to determine locations where development between the 1 in 20 year and 1 in 100 year flood lines would create increased upstream flooding risk. This comparison is presented graphically in for the Shubenacadie Lakes System in **Figure 4.1.**

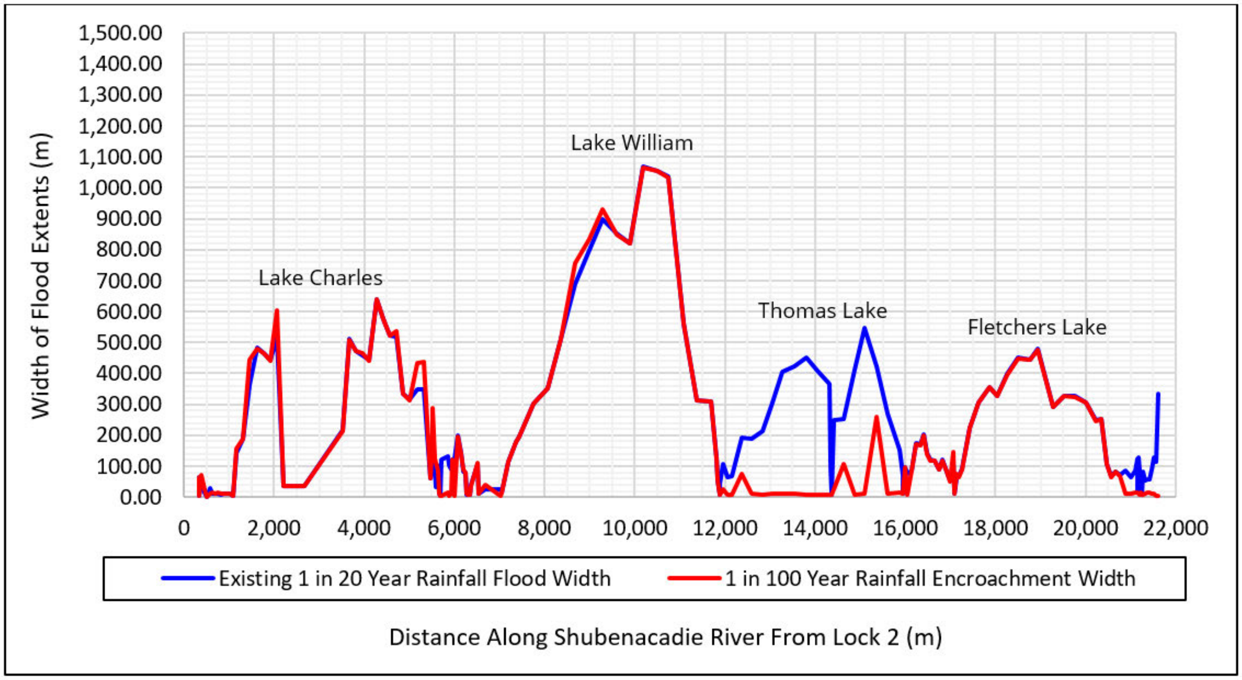

Figure 4.1 Encroachment Analysis

As shown, if the water levels are allowed to increase by 5%, some areas allow some floodplain encroachment through development, while other areas allow very little. In terms of impacts of higher water levels, allowing for a 5% increase in water level was created by mostly very small reductions in the 1 in 100 year encroachment floodplain width when compared to the existing 1 in 20 year floodplain width. Areas identified as seeing the largest potential decrease in floodplain width as a result of development within the regulatory floodway are the areas around of Lake Charles and the north tip of Fletchers Lake. Overall, it is recognized that any increase in water levels as a result of development is not considered acceptable (at it would increase flooding risks), and since it is a complex system, it is recommended that development that restricts the floodplain width be discouraged within the 1 in 100 year floodplain boundaries.

4.6 Selection of Base Flood

The Request for Proposals from HRM included a requirement for a recommendation of the "Base Flood". This was defined by HRM as a pair of flood lines, for the flood way (1 in 20 year) and the floodway fringe (1 in 100 year), for planning and regulatory purposes. Since the scope of this study does not include any stakeholder consultation, assessment of vulnerability of floodplain land uses, infrastructure and services, nor any review of existing and future planning challenges and opportunities, the current recommendation is strictly related to hydrodynamics and the current state of climate change science.

In this respect, CBCL agrees with following HRM's proposition to select the most conservative model result to ensure that known risks to public safety are not being ignored.

This means that the future 1 in 20 year and 1 in 100 year flood lines in worst case conditions is recommended, which, in this instance, includes the following characteristics:

- Wet/frozen with snowmelt conditions (Spring);
- Future development conditions;

- Future IDFs (climate change conditions) based on the selection of **Scenario A** (IDF-CC result for RCP 8.5 95th percentile) in conjunction with HRM.

4.7 Analysis of Flood Mitigation Options

A high level flood mitigation review was carried out to discuss potential flood mitigation options throughout the community. In general, the goal of flood mitigation is to protect vulnerable areas from flood damage. While this can be achieved by increasing the capacity of the system by widening the floodplain where room is available, this is not a recommended approach in the Shubenacadie Lakes System. Because the flow path of the system rests within the Shubenacadie Canal, the required intervention to the canal would be adverse to historical, environmental, community, and economic interests. Instead, separating the water from the vulnerable areas can be achieved by taking some of the following approaches, summarized in order of priority in **Table 4.3** Summary of Flood Mitigation Options and discussed in detail below.

Table 4.3 Summary of Flood Mitigation Options

Priority	Mitigation Option	Summary
1	**Planning Measures: Zoning and By-Laws**	Preventing future development in flood-prone areas through zoning and by-laws is the most effective and lowest-cost strategy to avoid placing future services, land uses, and infrastructure at risk.
2	**Reducing Peak Flows Through Infiltration**	Preventing excess water in vulnerable areas from being generated in the first place is best achieved through measures such as Low Impact Development and Stormwater Best Management Practices (LID and BMPs). In-stream controls and detention ponds are only moderately effective.
3	**Retreating or Displacing Vulnerable Services, Land Uses, and Infrastructure**	Retreating options including purchasing impacted properties is the most effective long-term measure, but can come at a high cost and is a sensitive issue for homeowners.
4	**Structure Upgrades**	Perhaps the simplest approach, but must be done only after thorough assessment of the downstream flooding effects of improved conveyance.

5	**Structural Flood Protection/Raising Ground and Properties**	Protecting vulnerable areas by construction of walls and berms is only recommended if the approaches above are not successful. This can include raising the ground level as was done in the Ellenvale Run area of Dartmouth. This means, however, narrowing the natural floodplain and increasing upstream flooding risks, flow velocities, risks of erosion, and increased risk to public safety if berms fail.

4.7.1 Planning Measures such as Zoning and By-Laws

This is typically the first recommendation in flood mitigation studies: minimising potential future flood risks to vulnerable areas by controlling development within the floodplain. A common practice is to prevent any development within the "High Risk" zone, or 1 in 20 year floodplain, and allow only non-permanent uses that do not infringe on the floodplain in the "Moderate Risk" zone, or 1 in 100 year floodplain. It is worthwhile to note that any construction in the floodplain that somehow restricts the flow of water will increase flooding risks to the upstream areas. It is therefore fundamental that before the Municipality considers allowing any form of development within the 1 in 100 year floodplain, impacts of this action be studied, understood and accepted. Since planning is oriented towards controlling future development, the flood lines should consider future climatic conditions and therefore take into account climate change.

4.7.2 Reducing Peak Flows through Infiltration

Reducing peak flows can be achieved by either storing water upstream, or infiltrating the rainfall before it becomes runoff. Direct storage of water may not be effective in this case since the major watersheds are relatively large and would therefore require a significant amount of excavation and land area to make an impact on the flows. Infiltration of stormwater, however, may have good potential. This is a natural process, and one that has been tampered with through development of the watershed. Low Impact Development and Stormwater Best Management Practices (LID and BMPs) can restore the natural (pre-development) hydrologic balance of infiltration vs. rainfall, by constructing infiltration areas, permeable surfaces, perforated pipes, rain gardens, bioswales, etc.

This can start very simply, by implementing a program of roof downspout disconnection, to be redirected to a green space. If implemented in its entirety immediately, its cost would be prohibitive. However, if implemented as part of planning and building permit approval regulations, each time a modification is made or new construction begins, the incremental cost can be minimal, with significant improvements.

This approach is therefore a crucial recommendation, to be implemented wherever possible, whenever the opportunity presents itself. Since LID and BMPs can take many shapes and forms, it is recommended that a study be conducted to identify the best opportunities currently available, and optimise their implementation with planned capital works programs. Similarly, any future development should require such measures to maintain peak flows, runoff volumes, flows, water quality and increase biodiversity.

4.7.3 Purchasing the Impacted Properties

This approach, which is currently being pursued in Sydney, Nova Scotia, has clear benefits: the impacted individuals are now permanently safe, properties at risk can be restored to the natural floodplain, upstream flooding risks can be reduced, there is no further maintenance cost or residual risk, and the lakefront area can now be enhanced for public enjoyment.

It is the only permanent option that needs no further maintenance to be effective, and it can still be used for non-permanent uses such as park or recreational space. The main challenges to this option are therefore its cost and resistance from property owners who may not wish to sell and move.

4.7.4 Structure Upgrades

This has historically been the most common first step taken to reduce flooding risks. Flooding can be caused by a multitude of factors, including not only high flows and insufficient bridge capacity, but also high surface and channel roughness, low channel slope or insufficient room in the floodplain. Perhaps the simplest approach, if not the most cost-effective, is to assess whether bridge structures have an impact on the overall flood levels and whether or not upgrading these structures will address the flood risks.

For the Shubenacadie Lakes System, there are only a few structures which seem to give evidence of flows being restricted enough to cause a higher water level upstream (See flood profiles in **Appendix D**). These include Lock 3, and the bridges at Rocky Lake Drive, Fall River Road, and Fletchers Lake Lock Trail (Lock 4). Upgrading the structures that create some level of obstruction to the flow, however, will be costly, and though it would reduce water levels and risks of flooding on their upstream side, it would also increase risks of flooding on their downstream side. The decision to upgrade them will therefore need to be supported by an assessment of the balance between current risks of flooding of upstream areas, the potential increased risks of flooding of downstream areas, and the risk of bridges or locks being washed out.

The conclusion of this discussion is that upgrading structures is not a recommended option for the Shubenacadie Lake System, unless options presented above are pursued first. If upgrading a structure is necessary for structural reasons, a detailed, system-wide modelling exercise should be carried out to ensure that no increased risks of flooding are created for upstream or downstream landowners.

4.7.5 Structural Flood Protection

Structural flood protection is a means of constructing berms to protect areas at risk. The mechanism is that berms will protect vulnerable areas by reducing the floodplain width. This reduction can lead to increased water levels upstream, and should therefore be considered only with careful thought and analysis. Berms also create a residual risk, in which the protected areas could still get flooded by an event greater than the design event, or by failure of the structure (leading to larger damage). It is very important to understand the concept of residual risk since it will have to be accepted by both the HRM and those who are protected. Constructing flood protection measures therefore means that not only capital costs will have to be incurred, but also operation and maintenance costs, as well as costs of the potential flood damage which might be of an even greater magnitude than if a flood mitigation structure had not been there.

Constructing flood protection berms would also require locally raising some of the roads to prevent water from going around the berms, and possibly require pumping stations. It is estimated that in most cases, relatively small areas would be draining towards the watercourses behind the new berms, and therefore culverts with check valves may be sufficient to convey local drainage into the watercourses and pumping may not be required.

While some areas may benefit from flood protection berms (wherever unwanted flooding is occurring), the berms would not be feasible in locations where they could increase upstream water levels. This risk would need to be identified by individual hydraulic modelling and analysis studies of the entire system prior to the consideration of any such measure.

4.7.6 Property Raising

Raising the ground level of individual properties above the peak water levels is an alternative method of flood protection that has similar impacts on the floodplain hydraulics as constructing protective berms. In this manner, the flood waters from the waterway would stay in front of the properties and the surface drainage from the affected areas will flow by gravity naturally towards the lake system. An example of a raised property in Dartmouth, Nova Scotia is shown in **Figure 4.2** Example of Raised Property along Ellenvale Run in Dartmouth

However, several difficulties are involved with grading land on private properties. As a first step, a survey should be conducted to determine the extents of the necessary land grading. Land grading may not be possible if homes are located on land which is too low. If determined possible, all features of the original property should be reinstated as close to the original conditions as possible, including sheds, fences, but also trees and shrubs. Landowners may offer resistance, and it is therefore necessary to take early steps to discuss and obtain buy-in from every affected land owner before proceeding with this option.

Figure 4.2 Example of Raised Property along Ellenvale Run in Dartmouth

4.7.7 House Raising

An alternative option to raising the entire property that is gaining popularity, especially after the recent wave of floods in the US and the UK, is to just raise the home itself. Jacking companies have been developing products that can raise homes for an estimated average cost of $50,000 per house. This would be accompanied with infill to adjust the surrounding land to the level of the house and make it accessible. As with raising the property, close coordination with the homeowners will be needed.

As noted for the option of constructing berms, raising the level of the home or the land is not recommended unless more recommended options have been exhausted.

4.8 Flood Scenario Modelling, Flood Mapping, and Flood Mitigation Analysis Findings

Results of flood scenario modelling and mapping are presented in **Appendix D** and **Appendix E.** Climate change scenario comparison mapping and 1 in 100 year/1 in 500 year/PMP comparison mapping showed that while water levels can vary largely in the system depending on storm event, flood plain widths were only largely affected in a few areas, primarily: Along Lockview Road near Lockview High School in Fall River, between Rocky Lake Dive and Highway 102 in Waverley, and the Highway 102 ramp at Waverley Road. This is mostly a result of the existing floodplain topography in which the floodplain edges have higher slopes, resulting in a small change of width when water levels increase.

A discussion of potential flood mitigation options is presented in **Section 4.7.** It reviews the benefits and challenges associated with each potential measure. Although this study did not investigate in detail, nor model, any flood mitigation option, certain insights can be drawn from the results. The flood line delineation showed that climate change impacts clearly have the potential to increase flooding risks and should be considered in any future planning decision.

While the northern reaches of the watershed are largely undeveloped, there are pockets of development which are urbanised, including sections of Burnside which are densely developed, and Fall River, Waverley, and Fletchers Lake which are less densely developed. These developments limit infiltration and increase flows, but they also create additional vulnerabilities. The least intrusive and most cost-effective flood mitigation option is to implement stormwater infiltration measures (LID and BMPs). Such measures, if implemented in future development and existing development during repairs or resurfacing, can have a very low direct cost but make a large impact in flood reduction.

Other options discussed include conducting channel restoration and protecting wetlands, as well as purchasing properties at risk. The planning regulations will be crucial to managing future development, and it is recommended that they include language on runoff control, flood proofing or limited uses in floodplain areas. Options such as upgrading bridges, building berms, or raising the level of the land/homes, should only be used after the above options have been exhausted.

The Shubenacadie Canal has a rich history, and there have been large efforts in recent years to preserve the historic and community value. Public safety, as well as the value the canal holds to the community must be taken into consideration before the preparation of any mitigation options. Stakeholder consultations and further modelling should be carried out to identify the best compromise between protecting vulnerabilities, overall stakeholder needs, ecosystem protection, and costs.

Chapter 5 Summary and Conclusions

A need for thorough hydrologic and hydraulic analysis of the Shubenacadie Lakes System was identified by the HRM following a NDMP study (WSP, 2018). This study has assessed the hydrology and hydraulic regime of the Shubenacadie Lakes System and its watershed, in order to produce floodplain maps for various flood scenarios. Flood risks were evaluated based on a calibrated hydrologic and hydraulic model using PCSWMM, for which model calibration was carried out. Design flood scenarios included variations in saturation and snowmelt conditions, rainfall conditions under climate change, and development conditions. The resulting flood lines delineated for this study are presented in **Appendix E. Table 4.1** lists each map produced for this study, including saturation and snowmelt changes, historical design storm, climate change comparisons, existing and future climate scenarios, existing and future development scenarios.

The analysis presented in this report was carried out to support the flood extents produced by the hydrologic and hydraulic models. The flood extents may be incorporated into future planning documents, which warrants this thorough analysis. Included in this assessment was also an in-depth analysis of climate change impacts on rainfall. Since climate change is to be considered in planning documents, it was essential to use the best science and tools available to evaluate those effects. This analysis is presented in **Section 3.6** and discussed further in **Appendix C.**

The RFP required a recommendation for the selection of a Base Flood. This was defined by HRM as a pair of flood lines, for the floodway (1 in 20 year) and the floodway fringe (1 in 100 year), for planning and regulatory purposes. Since the scope of this study did not include stakeholder consultation, assessment of vulnerability of infrastructure, floodplain land uses and services, nor any review of existing and future planning challenges and opportunities, the current recommendation is strictly related to hydrodynamics and the current state of climate change science.

In this respect, CBCL agrees with following HRM's proposition to select the most conservative model result to ensure that known risks to public safety are not being ignored. This means that the future 1 in 20 and 1 in 100 year flood lines in worst case climate conditions is recommended, which in this case includes the following characteristics:

- Wet/Frozen with Snowmelt conditions (Spring);
- Future development conditions;
- Future IDFs (climate change conditions) based on the selection of **Scenario A** (IDF-CC result for RCP 8.5 95th percentile) in conjunction with HRM.

In addition to the selection of a base flood, findings from this study include the identification of factors that lead to the flooding extents generated by the models. The analysis of structure constrictions identified five structures that create notable impediments to the passage of water: Lock 3, and the bridges at Shubie Greenway Corridor South, Rocky Lake Drive, Fletchers Lake Lock Trail (Lock 4), and Waverley Road at Meadow Walk.

Other than these structures, there are few anthropogenic impacts to the natural shape of the floodplain that was created about 14,500 years ago, as discussed in **Section 4.3.** This is an important finding, because it demonstrates that flooding outside of the waterway (in the floodplain) is a natural phenomenon. Notably, the model results indicate that events of a greater magnitude, including a 1 in 500 year rainfall event, the PMP, or future rainfall as influenced by climate change, increase the floodplain width (as expected), but only by a small amount relative to the increase in flow. This means that high flows will regularly fill the floodplain, but that extremely high flows will also stay mostly within this main floodplain. It is important to note because it means that the floodplain is necessary for the conveyance of high flows. Development within this floodplain will unavoidably be at risk of flooding, and any restriction of this floodplain will lead to higher upstream water levels.

It was found that antecedent condition variation had little effect on floodplain width, as the 1 in 100 year rainfall event flood extents for the watershed under unsaturated conditions with no snowmelt was only marginally smaller than the same event under spring conditions that accounted for saturated/frozen soils with snowmelt. Similarly, future development in the region showed little effect on the floodline width.

Climate change scenarios were presented in **Section 3.6.3** and discussed further in **Appendix C.** Three climate change scenarios were tested from a range of emission scenarios and projection ranges. Scenario A (RCP 8.5, IDF-CC 95th percentile) projected a 116% change from the 1 in 100 year event, Scenario B (RCP 4.5, IDF-CC 95th percentile) projected a 78% change from the 1 in 100 year event, and Scenario C (RCP 8.5, IDF-CC Median) projected a 40% change form the 1 in 100 year event. Comparison of the three climate change scenarios presented showed that while flow depths differed greatly, floodlines extents only saw a small effect. As a result of this analysis, Scenario A was chosen as the designated climate change scenario. While this selection provides a safe projection for climate change impacts, it is noted that it does not drastically widen the floodlines when compared to the other climate change scenarios, which is the result of the existing floodplain topography in which the floodplain edges have higher slopes, resulting in only a small change of width when water levels increase. This provides additional support for selection of this scenario over the others.

A discussion of flood mitigation options is presented in **Section 4.7.** This section reviews the benefits and challenges associated with each potential measure. Although this assessment did not investigate in detail, nor model, any flood mitigation option, certain high level aspects can be drawn from the results. The flood line delineation showed that climate change impacts clearly have the potential to increase flooding risks and should be considered in any future planning decision. The planning regulations will be central to managing future development and it is recommended that they include language on setback limits, runoff control, flood proofing, or limited uses in floodplain areas.
Designating environmentally sensitive areas (e.g. Watercourse Greenbelt zoning in East Hants) is also recommended to prevent future development in water storage and undeveloped

floodplain areas. The following list of factors have contributed to the prioritized recommendations noted below:

- Risks associated with climate change;
- Increased interest in sustainability;
- Increased awareness of liability;
- Increasing costs of maintenance, and
- General reduction in funding for infrastructure projects

Recommendations have been generally oriented towards more sustainable, low maintenance, more nature-oriented approaches, which provide not only solutions to flooding risks, but also additional advantages in terms of erosion protection, water quality improvements and overall aesthetics, protection/restoration of the natural character of the waterways, and community value. This is consistent with the Halifax Regional Plan and the Halifax Green Network Plan (Greenbelting and Open Space Plan).

A summary of recommendation options for flood mitigation is as follows:

1) **Planning Measures: Zoning and By-Laws.** Preventing future development in flood-prone areas through zoning and by-laws is the most effective and lowest-cost strategy to avoid placing future services, land uses, and infrastructure at risk.

2) **Reducing Peak Flows through Infiltration.** Preventing excess water in vulnerable areas from being generated in the first place is best achieved through measures such as Low Impact Development and Stormwater Best Management Practices (LID and BMPs). In-stream controls and detention ponds are only moderately effective.

3) **Retreating or Displacing Vulnerable Services, Land Uses, and Infrastructure.** Retreating options including purchasing impacted properties is the most effective long-term measure, but can come at a high cost and is a sensitive issue for homeowners.

4) **Structure Upgrades.** Perhaps the simplest approach, but must be done only after thorough assessment of the downstream flooding effects of improved conveyance.

5) **Structural Flood Protection/Raising Ground and Properties.** Protecting vulnerable areas by construction of walls and berms is only recommended if the approaches above are not successful. This can include raising the ground level as was done in the Ellenvale Run area of Dartmouth. This means, however, narrowing the natural floodplain and increasing upstream flooding risks, flow velocities, risks of erosion, and increased risk to public safety if berms fail.

The Shubenacadie Lakes System has strong community and historic value. In all cases, stakeholder consultations and modelling should be carried out to identify the best compromise between protecting vulnerabilities, overall stakeholder needs, ecosystem protection and costs. The creation of a dedicated floodplain committee with regular meetings can streamline this process.

Overall, this study has updated the current state of knowledge on rainfall, hydrologic characteristics, flow responses, impacts of structures, mechanisms leading to flooding, potential climate change impacts and potential flood mitigation options. This study has brought very detailed data sets of high resolution and quality, combined with state-of-the-art modelling and analysis to inform the results and recommendations presented.

Recommendations to improve this analysis in the future would include conducting further flow gauging in various areas of the watershed, evaluating in more detail ground infiltration and exfiltration characteristics, being cognizant of the latest climate change research as it progresses, and trying to collect as much calibration and validation data (water levels) as possible in the system during flood events.

In terms of recommended next steps for the HRM, the first goal of this study is to provide information to support an update to the planning regulations. An essential step, as noted by the HRM, is to make every effort to communicate the results and implications of this study and planning regulation to the public and all affected stakeholders, which is best achieved by using a wide range of approaches.

Communication of flooding risks and emergency procedures, as well as flood proofing techniques, is also very valuable to help residents understand and deal with flooding risks. Warning systems, including flood forecasting and warning, can be very valuable tools to increase public safety. In terms of flood mitigation options, next steps will need to include conducting more detailed analyses and modelling of potential options. This can be done in parallel with an assessment of vulnerabilities along the system, conducted through consultation with each of the relevant stakeholders. Vulnerabilities for land use, infrastructure and services can be obtained from stakeholders. Together with vulnerabilities in the management of emergency procedures (e.g. ensuring reliable communications or access to emergency services), these can be ranked by priority to define flood protection goals. How well each flood mitigation measures addresses each vulnerability can then be used to evaluate the efficiency of each flood protection measure.

Should you have any questions about this analysis, please do not hesitate to contact the undersigned. We thank you again for the opportunity to conduct this very interesting analysis.

Yours very truly,

Prepared by: Reviewed by:

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APPENDIX A

Hydraulic Structure Data Sheets

Bridge / Drainage Structure Data Sheet

Street Name / Close to Civic Address #: Locks Rd
Structure Number/Name: Lock 3
Shape: Rectangluar
Height: 2.13 m
Width: 8.6 m
Length: 1.65 m
Material: Wooden Deck
Watercourse Name: Shubenacadie Canal
Coordinates of Structure centre (N,E): (4949996N, 456065)
Coordinate System UTM Zone 20 NAD83 (26920)

Provide elevations and photos as follows:

Upstream

Structure Inlet:	
Invert Elevation:	26.91 m
Road Elevation at Edge of Asphalt :	29.32 m

Picture of Structure:

Upstream Channel

Picture of Channel:

Downstream

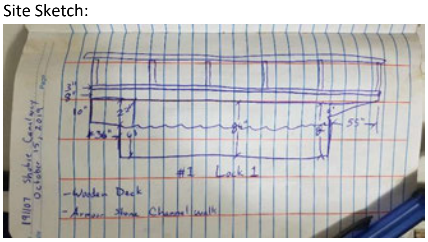
Structure Outlet

Picture of Structure:

Downstream Channel

Picture of Channel:

Site Sketch:



0.5588	0.2794	0.8382	this is the distance in m from bridge deck surface to water surface
		29.415	elevation of bridge deck
		28.5768	this is the water surface elevation
		28.6276	this is the weir elevation
		26.142	this is the elevation of the lake in front of the weir
		2.4856	this is the weir offset height

Other Comments:
Wooden Deck
Armour Stone Channel Walls

Bridge / Drainage Structure Data Sheet

Street Name / Close to Civic Address #:	Locks Rd
Structure Number/Name:	Shubie Greenway Corridor
Shape:	Bridge
Height:	4.32 m
Width:	12.18 m
Length:	2.9 m
Material:	Steel
Watercourse Name:	Shubenacadie Canal
Coordinates of Structure centre (N,E):	(4950151N, 455901)
Coordinate System	UTM Zone 20 NAD83 (26920)

Provide elevations and photos as follows:

Upstream

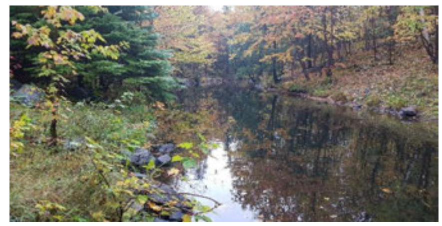
Structure Inlet:

Invert Elevation:	27.31 m
Road Elevation at Edge of Asphalt :	31.81 m

Picture of Structure:

Upstream Channel

Picture of Channel:



Downstream

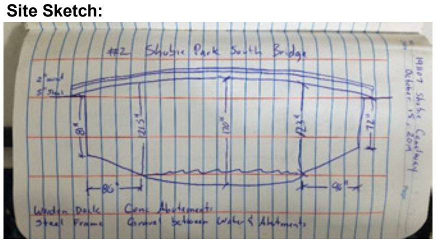
Structure Outlet

Picture of Structure:

Downstream Channel

Picture of Channel:

Site Sketch:



Other Comments:

Wooden Deck
Steel Frame
Concrete Abutments
Gravel between water and abutments

Bridge / Drainage Structure Data Sheet

Street Name / Close to Civic Address #:	John Brenton Drive
Structure Number/Name:	South Trans Canada Trail Bridge
Shape:	Bridge
Height:	4.57 m
Width:	18.86 m
Length:	1.7 m
Material:	Steel
Watercourse Name:	Shubenacadie Canal
Coordinates of Structure centre (N,E):	(4950668N, 456098)
Coordinate System	UTM Zone 20 NAD83 (26920)

Provide elevations and photos as follows:

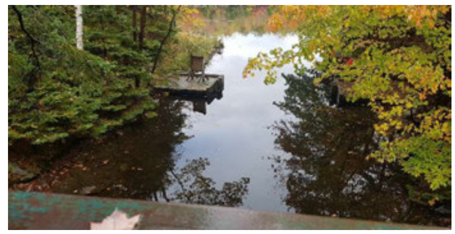
Upstream

Structure Inlet:	
Invert Elevation:	27.5 m
Road Elevation at Edge of Asphalt :	32.07 m

Picture of Structure:

Upstream Channel

Picture of Channel:



Downstream

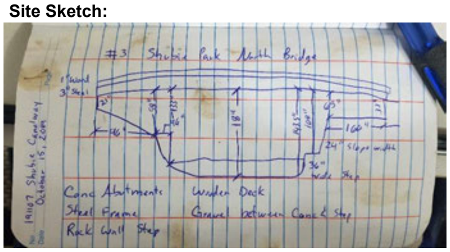
Structure Outlet

Picture of Structure:

Downstream Channel

Picture of Channel:

Site Sketch:



Other Comments:

Wooden Deck
Concrete Abutments
Steel Frame
Rock Wall Step
Gravel Between Conc and Step

Bridge / Drainage Structure Data Sheet

Street Name / Close to Civic Address #:	Highway 107/Waverley Road
Structure Number/Name:	Highway 107 Bridge
Shape:	Overpass
Height:	9.71 m
Width:	140 m
Length:	16 m
Material:	Concrete
Watercourse Name:	Shubenacadie Canal
Coordinates of Structure centre (N,E):	(4954148N, 455912)
Coordinate System	UTM Zone 20 NAD83 (26920)

Provide elevations and photos as follows:

Upstream

Structure Inlet:

Invert Elevation:	26.87 m
Road Elevation at Edge of Asphalt :	39.49 m

Picture of Structure:

Upstream Channel

Picture of Channel:

Downstream

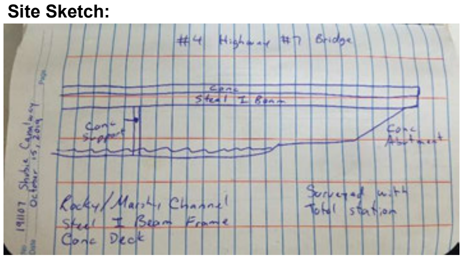
Structure Outlet

Picture of Structure:

Downstream Channel

Picture of Channel:

Site Sketch:



Other Comments:

Concrete Deck
Steel I Beam Frame
Rocky/Marshy Channel

Bridge / Drainage Structure Data Sheet

Street Name / Close to Civic Address #: Waverley Rd/Highway 107
Structure Number/Name: Shubie Trail Head Bridge
Shape: Bridge
Height: 3.15 m
Width: 7.26 m
Length: 4.3 m
Material: Steel
Watercourse Name: Shubenacadie Canal
Coordinates of Structure centre (N,E): (4950668N, 456098)
Coordinate System UTM Zone 20 NAD83 (26920)

Provide elevations and photos as follows:

Upstream

Structure Inlet:

Invert Elevation:	27.24 m
Road Elevation at Edge of Asphalt :	30.92 m

Picture of Structure:

Upstream Channel

Picture of Channel:

Downstream

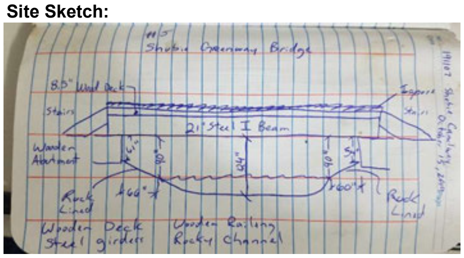
Structure Outlet

Picture of Structure:

Downstream Channel

Picture of Channel:

Site Sketch:



Other Comments:
Wooden Deck
Steel Frame
Wooden Railing
Rocky Channel

Bridge / Drainage Structure Data Sheet

Street Name / Close to Civic Address #:	Highway 118/Waverley Road
Structure Number/Name:	Highway 118 NB Bridge
Shape:	Bridge
Height:	9.28 m
Width:	5.16 m
Length:	14 m
Material:	Concrete
Watercourse Name:	Shubenacadie Canal
Coordinates of Structure centre (N,E):	(4954572N, 455643)
Coordinate System	UTM Zone 20 NAD83 (26920)

Provide elevations and photos as follows:

Upstream

Structure Inlet:	
Invert Elevation:	26.3 m
Road Elevation at Edge of Asphalt :	m

Picture of Structure:

Upstream Channel

Picture of Channel:

Downstream

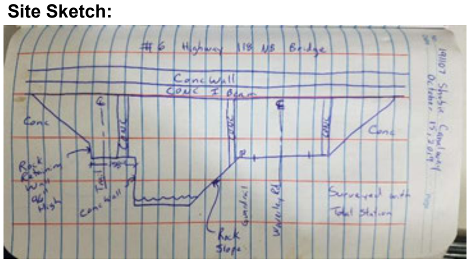
Structure Outlet

Picture of Structure:

Downstream Channel

Picture of Channel:

Site Sketch:



Other Comments:

Concrete Structure
Concrete Sidewall
Rock Retaining wall near trail
Gravel/Rock Side slope towards Waverley Road

Bridge / Drainage Structure Data Sheet

Street Name / Close to Civic Address #:	Highway 118/Waverley Road	
Structure Number/Name:	Highway 118 SB Bridge	
Shape:	Bridge	
Height:	9.34	m
Width:	6.33	m
Length:	14	m
Material:	Concrete	
Watercourse Name:	Shubenacadie Canal	
Coordinates of culvert centre (N,E):	(4954595N, 455614)	
Coordinate System	UTM Zone 20 NAD83 (26920)	

Provide elevations and photos as follows:

Upstream

Culvert Inlet:		
Invert Elevation:	26.2	m
Road Elevation at Edge of Asphalt :		m

Picture of Culvert:

Upstream Channel

Picture of Channel:

Downstream

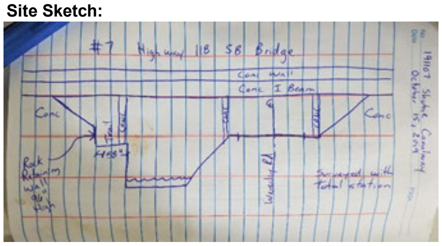
Culvert Outlet

Picture of Structure:

Downstream Channel

Picture of Channel:

Site Sketch:



Other Comments:

Concrete Structure
Concrete Sidewall
Rock Retaining wall near trail
Gravel/Rock Side slope towards Waverley Road

Bridge / Drainage Structure Data Sheet

Street Name / Close to Civic Address #: Waverley Road
Structure Number/Name: North Trans Canada Trail Bridge
Shape: Bridge
Height: 1.42 m
Width: 10 m
Length: 0.9 m
Material: Wood
Watercourse Name: Shubenacadie Canal
Coordinates of Structure centre (N,E): (4954714N, 455467)
Coordinate System UTM Zone 20 NAD83 (26920)

Provide elevations and photos as follows:

Upstream

Structure Inlet:	
Invert Elevation:	26.18 m
Road Elevation at Edge of Asphalt :	27.6 m

Picture of Structure:

Upstream Channel

Picture of Channel:

Downstream

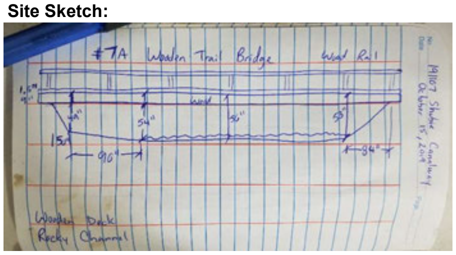
Structure Outlet

Picture of Structure:

Downstream Channel

Picture of Channel:

Site Sketch:



Other Comments:
Wooden Deck
Wooden Railing
Rocky Channel
Steel Frame

Bridge / Drainage Structure Data Sheet

Street Name / Close to Civic Address #:	Waverley Road
Structure Number/Name:	Private Bridge
Shape:	Bridge
Height:	2.92 m
Width:	17 m
Length:	3.7 m
Material:	Steel/Wood
Watercourse Name:	Shubenacadie Canal
Coordinates of Structure centre (N,E):	(4955146N, 455192)
Coordinate System	UTM Zone 20 NAD83 (26920)

Provide elevations and photos as follows:

Upstream

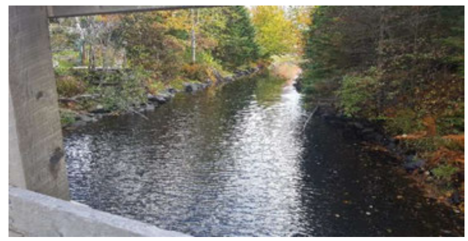
Structure Inlet:

Invert Elevation:	18 m
Road Elevation at Edge of Asphalt :	21.2 m

Picture of Structure:

Upstream Channel

Picture of Channel:



Downstream

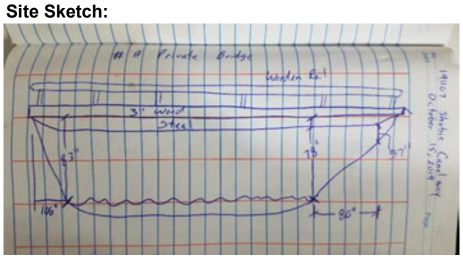
Structure Outlet

Picture of Structure:

Downstream Channel

Picture of Channel:

Site Sketch:



Other Comments:

Steel Frame

Wooden Deck

Bridge / Drainage Structure Data Sheet

Street Name / Close to Civic Address #:	Rocky Lake Drive
Structure Number/Name:	Rocky Lake Drive Bridge
Shape:	Bridge
Height:	2.44 m
Width:	4.9 m
Length:	18 m
Material:	Concrete
Watercourse Name:	Shubenacadie Canal
Coordinates of Structure centre (N,E):	(4959266N, 452644)
Coordinate System	UTM Zone 20 NAD83 (26920)

Provide elevations and photos as follows:

Upstream

Structure Inlet:

Invert Elevation:	18.3 m
Road Elevation at Edge of Asphalt :	21.43 m

Picture of Structure:

Upstream Channel

Picture of Channel:

Downstream

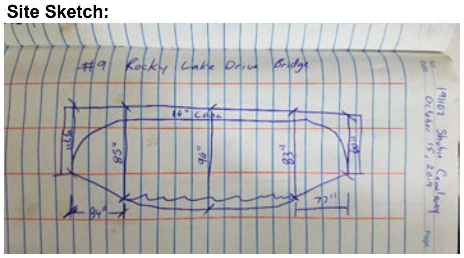
Structure Outlet

Picture of Structure:

Downstream Channel

Picture of Channel:

Site Sketch:



Other Comments:

Concrete Strucutre

Gravel/Rocky Channel

Bridge / Drainage Structure Data Sheet

Street Name / Close to Civic Address #:	Highway 102/Waverley Road
Structure Number/Name:	Highway 102 Bridge
Shape:	Bridge
Height:	4.42 m
Width:	9.3 m
Length:	24 m
Material:	Concrete
Watercourse Name:	Shubenacadie Canal
Coordinates of Structure centre (N,E):	(4961411N, 451890)
Coordinate System	UTM Zone 20 NAD83 (26920)

Provide elevations and photos as follows:

Upstream

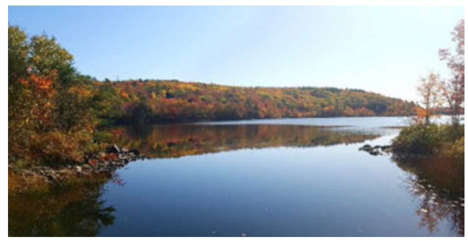
Structure Inlet:

Invert Elevation:	17.13 m
Road Elevation at Edge of Asphalt :	22.27 m

Picture of Structure:

Upstream Channel

Picture of Channel:



Downstream

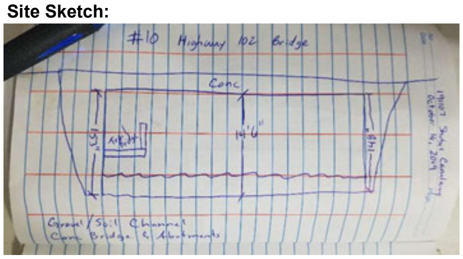
Structure Outlet

Picture of Structure:

Downstream Channel

Picture of Channel:

Site Sketch:



Other Comments:

Gravel/Soil Channel
Concrete Bridge
Concrete Abutment
Steel Framed Pedestrian Bridge

Bridge / Drainage Structure Data Sheet

Street Name / Close to Civic Address #: Fall River Rd/Waverley Rd
Structure Number/Name: Fall River Road Bridge
Shape: Bridge
Height: 2.95 m
Width: 11.5 m
Length: 16 m
Material: Concrete
Watercourse Name: Shubenacadie Canal
Coordinates of Structure centre (N,E): (4962905N, 451542)
Coordinate System UTM Zone 20 NAD83 (26920)

Provide elevations and photos as follows:

Upstream

Structure Inlet:

Invert Elevation: 17.92 m
Road Elevation at Edge of Asphalt : 21.04 m

Picture of Structure:

Upstream Channel

Picture of Channel:

Downstream

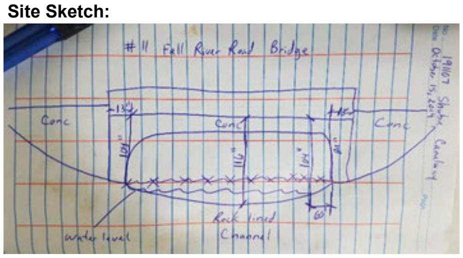
Structure Outlet

Picture of Structure:

Downstream Channel

Picture of Channel:

Site Sketch:



Other Comments:
Concrete Structure
Concrrete Abutment
Rock Lined Channel

Bridge / Drainage Structure Data Sheet

Street Name / Close to Civic Address #:	Fletcher Drive
Structure Number/Name:	Fletcher Lake Lock Trail Bridge
Shape:	Bridge
Height:	2.13 m
Width:	12.6 m
Length:	1.4 m
Material:	Steel Frame
Watercourse Name:	Shubenacadie Canal
Coordinates of Structure centre (N,E):	(4964002N, 451534)
Coordinate System	UTM Zone 20 NAD83 (26920)

Provide elevations and photos as follows:

Upstream

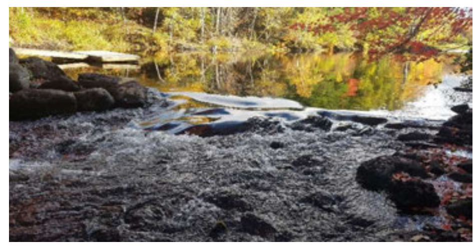
Structure Inlet:

Invert Elevation:	17.11 m
Road Elevation at Edge of Asphalt :	19.6 m

Picture of Structure:

Upstream Channel

Picture of Channel:



Downstream

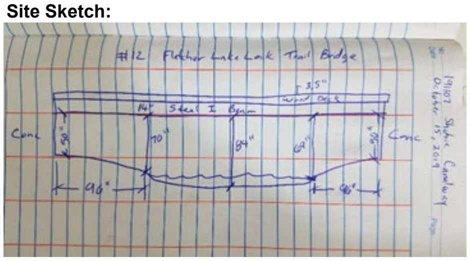
Structure Outlet

Picture of Structure:

Downstream Channel

Picture of Channel:

Site Sketch:



Other Comments:

Steel Frame
Wooden Deck
Rocky Channel

Bridge / Drainage Structure Data Sheet

Street Name / Close to Civic Address #:	Kings Road
Structure Number/Name:	CN Rail Bridge
Shape:	Bridge
Height:	6.7 m
Width:	28 m
Length:	6 m
Material:	Steel
Watercourse Name:	Shubenacadie Canal
Coordinates of Structure centre (N,E):	(4967729N, 450918)
Coordinate System	UTM Zone 20 NAD83 (26920)

Provide elevations and photos as follows:

Upstream

Structure Inlet:

Invert Elevation:	13.85 m
Road Elevation at Edge of Asphalt :	23.6 m

Picture of Structure:

Upstream Channel

Picture of Channel:

Downstream

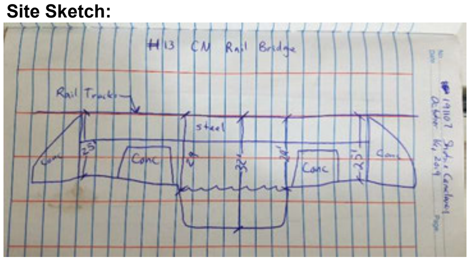
Structure Outlet

Picture of Structure:

Downstream Channel

Picture of Channel:

Site Sketch:



Other Comments:

Steel Frame

Railroad track on deck

Bridge / Drainage Structure Data Sheet

Street Name / Close to Civic Address #: Kings Road/Sunnylea Rd
Structure Number/Name: Kings Road Bridge
Shape: Bridge
Height: 3.3 m
Width: 9 m
Length: 12 m
Material: concrete
Watercourse Name: Shubenacadie Canal
Coordinates of Structure centre (N,E): (4967809N, 450902)
Coordinate System UTM Zone 20 NAD83 (26920)

Provide elevations and photos as follows:

Upstream

Structure Inlet:	
Invert Elevation:	14.04 m
Road Elevation at Edge of Asphalt :	18.02 m

Picture of Structure:

Upstream Channel

Picture of Channel:

Downstream

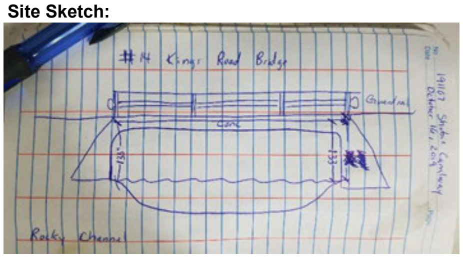
Structure Outlet

Picture of Structure:

Downstream Channel

Picture of Channel:

Site Sketch:



Other Comments:
Concrete Structure
Rocky Channel
Fast Current

Bridge / Drainage Structure Data Sheet

Street Name / Close to Civic Address #:	Wavereley Rd / Meadow Walk
Structure Number/Name:	#15 Waverley Rd Bridge
Shape:	Bridge
Height:	1.95 m
Width:	4.7 m
Length:	10.9 m
Material:	concrete
Watercourse Name:	Barry's Run
Coordinates of Structure centre (N,E):	456830.8N,4951598.8
Coordinate System	UTM Zone 20 NAD83 (26920)

Road Crown Elevation: 33.942 m

Headwall	none
Width:	m
Height:	m
Material:	
Wingwall	
Length:	2 m
Height:	2 m
Angle to Flow:	0 Degrees
Material:	Gabion Walls

Provide elevations and photos as follows:

Upstream

Structure Inlet:

Invert Elevation:	31.992 m
Road Elevation at Edge of Asphalt :	33.942 m

Picture of Structure:

Upstream Channel

Picture of Channel:

Downstream

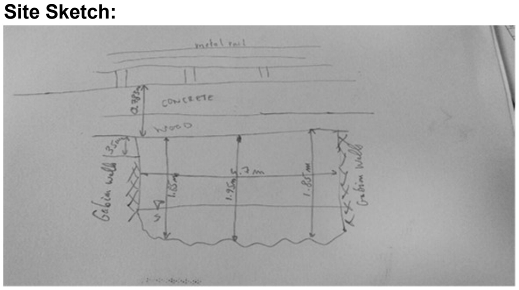
Structure Outlet

Picture of Structure:

Downstream Channel

Picture of Channel:

Site Sketch:



Other Comments:

Wood structure
Rocky Channel
Fast Current

APPENDIX B

Watershed Characteristics Tables

Table B-1 Estimated Watershed Characteristics for the Shubenacadie Lakes System (Pre-Calibration) (Existing Development Conditions, Unsaturated, No Snowmelt)

Sub-Watershed Name	Area (ha)	Slope (%)	Maximum Overland Flow Length (m)	Imperv. (%)	Impervious Area Roughness	Pervious Area Roughness	Percent of Area Routed to Pervious Area (%)	Capillary Suction Head (mm)	Conductivity (mm/hr)
Charles_1	365.3454	1.33	1315	51.328	0.038	0.3	100	241.721	4.449
Charles000	191.8732	4	1995	27.2	0.025	0.207	67.6	121.6	10
Charles010	109.4865	3.4	2080	25.7	0.025	0.219	74.3	110.1	10.9
Charles020S	38.0665	8.4	912	14.7	0.027	0.23	83.8	117.9	10.3
Charles030	445.8953	4.8	2278	59.4	0.02	0.136	37	113.5	10.8
Charles040	111.5416	4.5	2049	42.8	0.021	0.167	42.3	124.7	6.8
Charles050	54.9944	4.8	850	35.1	0.024	0.209	64.6	110.1	10.9
Charles060	577.2256	1.8	3664	14.6	0.027	0.239	83.5	130.8	10.1
CranSouth000	76.1665	4.9	784	46.1	0.021	0.17	40.8	218.5	1.5
Fletchers_1	850.9054	2.06	1803	21.295	0.033	0.43	100	209.398	2.228
Fletchers_2	811.2651	1.91	2769	29.994	0.026	0.507	100	210.576	2.105
Fletchers_Outlet_1	5.198	1.94	434	80	0.014	0.55	100	219.964	1.524
Fletchers_Outlet_2	0.9701	2.85	137	60	0.027	0.5	100	210.32	1.21
Juniper001	24.1805	4.2	276	30.9	0.025	0.188	69.7	110.1	10.9
Juniper002	155.2521	5.6	897	67.5	0.019	0.169	33.7	213.2	5.6
Loon000	278.0316	3.6	1250	47.4	0.022	0.153	47.2	155.4	3.5
MicMac004	48.4799	5.5	589	27.2	0.024	0.188	63.4	110.1	10.9
S1	62.3947	1.85	2400	10.2	0.027	0.23	86.5	89	12.7
S2	66.4512	1.76	3934	73	0.02	0.18	100	220	12.7
Shub__Outlet_2	2481.492	1.39	10543	19.135	0.032	0.6	100	164.421	4.428
Shub__Outlet_3	1360.461	1.31	4056	23.533	0.047	0.33	100	232.842	2.325
Shub__Outlet_4	959.9558	1.31	4056	23.533	0.047	0.33	100	232.842	2.325
Shub_10	2297.319	1.63	4111	29.793	0.038	0.35	100	245.019	2.328
Shub_11	1383.643	1.63	4111	29.793	0.038	0.35	100	245.019	2.328
Shub_2	350.2267	1.3	2462	7.85	0.04	0.6	100	208.217	3.616
Shub_3	454.0305	1.57	2312	19.266	0.044	0.35	100	213.541	2.679
Shub_4	4054.38	1.62	7609	13.817	0.047	0.5	100	198.495	4.35
Shub_5	4106.067	1.6	9171	10.773	0.054	0.5	100	182.359	5.769
Shub_6	6211.751	1.53	6914	10.36	0.078	0.61	100	166.222	7.187
Shub_7	1802.256	1.27	2139	25.068	0.067	0.547	100	215.715	2.462
Shub_8	1262.533	1.13	3179	9.734	0.062	0.61	100	223.944	1.52
Shub_9	1627.815	0.95	4376	15.91	0.066	0.31	100	261.449	1.401
Shub_Inlet_1	9.6204	1.13	347	60	0.02	0.61	100	210.11	1.17
Shub_Outlet_2_1	282.2432	1.55	2444	4.309	0.036	0.65	100	108.667	10.447
Shube_Inlet_2	11.5104	1.69	353	60	0.014	0.55	100	219.964	1.524
Thomas_1	301.9779	1.9	1800	46.764	0.036	0.4	100	160.795	7.137
Thomas_2	225.6749	2.83	1258	24.435	0.039	0.4	100	223.935	4.104
Thomas_3	178.5324	1.87	1224	57.209	0.027	0.5	100	153.071	2.772
Thomas_4	97.9425	2.047	769	53.173	0.034	0.35	100	268.548	1.261
Thomas_5	639.7524	1.6	2059	50	0.052	0.4	100	220.217	3.2
Thomas_6	3639.824	1.61	6516	13.225	0.067	0.673	100	171.886	5.13
William_1	1483.713	2.02	2501	13.06	0.07	0.679	100	185.345	7.252
William_2	1255.729	1.92	1042	27.65	0.047	0.45	100	203.342	6.606
William_3	1109.945	1.82	2185	18.725	0.054	0.502	100	158.366	9.473
William_Inlet	32.1729	3.16	677	35	0.012	0.34	100	109.982	10.922
William_Inlet_1	33.4845	3.57	548	2.369	0.048	0.7	100	109.982	10.922

Table B-2 Estimated Watershed Characteristics for the Shubenacadie Lakes System (Post-Calibration) (Existing Development Conditions, Unsaturated, No Snowmelt)

Sub-Watershed Name	Area (ha)	Slope (%)	Maximum Overland Flow Length (m)	Imperv. (%)	Impervious Area Roughness	Pervious Area Roughness	Percent of Area Routed to Pervious Area (%)	Capillary Suction Head (mm)	Conductivity (mm/hr)
Charles_1	365.3454	1.33	32.878	61.594	0.038	0.3	100	241.721	0.458
Charles000	191.8732	4	49.878	32.64	0.025	0.207	67.6	121.6	1.015
Charles010	109.4865	3.4	51.996	30.84	0.025	0.219	74.3	110.1	1.113
Charles020S	38.0665	8.4	22.806	17.64	0.027	0.23	83.8	117.9	1.047
Charles030	445.8953	4.8	56.945	71.28	0.02	0.136	37	113.5	1.113
Charles040	111.5416	4.5	51.218	51.36	0.021	0.167	42.3	124.7	0.687
Charles050	54.9944	4.8	21.258	42.12	0.024	0.209	64.6	110.1	1.113
Charles060	577.2256	1.8	91.611	17.52	0.027	0.239	83.5	130.8	1.031
CranSouth000	76.1665	4.9	19.592	55.32	0.021	0.17	40.8	218.5	0.164
Fletchers_1	850.9054	2.06	45.077	25.554	0.033	0.43	100	209.398	0.229
Fletchers_2	811.2651	1.91	69.23	35.993	0.026	0.507	100	210.576	0.213
Fletchers_Outlet_1	5.198	1.94	10.848	96	0.014	0.55	100	219.964	0.164
Fletchers_Outlet_2	0.9701	2.85	3.419	72	0.027	0.5	100	210.32	0.131
Juniper001	24.1805	4.2	6.901	37.08	0.025	0.188	69.7	110.1	1.113
Juniper002	155.2521	5.6	22.429	81	0.019	0.169	33.7	213.2	0.573
Loon000	278.0316	3.6	31.244	56.88	0.022	0.153	47.2	155.4	0.36
MicMac004	48.4799	5.5	14.728	32.64	0.024	0.188	63.4	110.1	1.113
S1	62.3947	1.85	60	12.24	0.027	0.23	86.5	89	1.309
S2	66.4512	1.76	98.347	87.6	0.02	0.18	100	220	1.309
Shub__Outlet_2	2481.492	1.39	263.579	22.962	0.032	0.6	100	164.421	0.458
Shub__Outlet_3	1360.461	1.31	101.388	28.24	0.047	0.33	100	232.842	0.229
Shub__Outlet_4	959.9558	1.31	101.388	28.24	0.047	0.33	100	232.842	0.229
Shub_10	2297.319	1.63	102.769	35.752	0.038	0.35	100	245.019	0.229
Shub_11	1383.643	1.63	102.769	35.752	0.038	0.35	100	245.019	0.229
Shub_2	350.2267	1.3	61.551	9.42	0.04	0.6	100	208.217	0.36
Shub_3	454.0305	1.57	57.799	23.119	0.044	0.35	100	213.541	0.278
Shub_4	4054.38	1.62	190.232	16.58	0.047	0.5	100	198.495	0.442
Shub_5	4106.067	1.6	229.286	12.928	0.054	0.5	100	182.359	0.589
Shub_6	6211.751	1.53	172.861	12.432	0.078	0.61	100	166.222	0.736
Shub_7	1802.256	1.27	53.485	30.082	0.067	0.547	100	215.715	0.262
Shub_8	1262.533	1.13	79.464	11.681	0.062	0.61	100	223.944	0.164
Shub_9	1627.815	0.95	109.405	19.092	0.066	0.31	100	261.449	0.147
Shub_Inlet_1	9.6204	1.13	8.678	72	0.02	0.61	100	210.11	0.115
Shub_Outlet_2_1	282.2432	1.55	61.111	5.171	0.036	0.65	100	108.667	1.064
Shube_Inlet_2	11.5104	1.69	8.816	72	0.014	0.55	100	219.964	0.164
Thomas_1	301.9779	1.9	45.004	56.117	0.036	0.4	100	160.795	0.72
Thomas_2	225.6749	2.83	31.453	29.322	0.039	0.4	100	223.935	0.425
Thomas_3	178.5324	1.87	30.604	68.651	0.027	0.5	100	153.071	0.278
Thomas_4	97.9425	2.047	19.218	63.808	0.034	0.35	100	268.548	0.131
Thomas_5	639.7524	1.6	51.475	60	0.052	0.4	100	220.217	0.327
Thomas_6	3639.824	1.61	162.899	15.87	0.067	0.673	100	171.886	0.524
William_1	1483.713	2.02	62.519	15.672	0.07	0.679	100	185.345	0.736
William_2	1255.729	1.92	26.058	33.18	0.047	0.45	100	203.342	0.671
William_3	1109.945	1.82	54.622	22.47	0.054	0.502	100	158.366	0.965
William_Inlet	32.1729	3.16	16.915	42	0.012	0.34	100	109.982	1.113
William_Inlet_1	33.4845	3.57	13.696	2.843	0.048	0.7	100	109.982	1.113

Table B-3 Estimated Watershed Characteristics for the Shubenacadie Lakes System (Post-Calibration) (Existing Development Conditions, Wet/Frozen, Snowmelt)

Sub-Watershed Name	Area (ha)	Slope (%)	Maximum Overland Flow Length (m)	Imperv. (%)	Impervious Area Roughness	Pervious Area Roughness	Percent of Area Routed to Pervious Area (%)	Capillary Suction Head (mm)	Conductivity (mm/hr)
Charles_1	365.3454	1.33	32.878	61.594	0.038	0.3	100	241.721	0.01
Charles000	191.8732	4	49.878	32.64	0.025	0.207	67.6	121.6	0.01
Charles010	109.4865	3.4	51.996	30.84	0.025	0.219	74.3	110.1	0.01
Charles020S	38.0665	8.4	22.806	17.64	0.027	0.23	83.8	117.9	0.01
Charles030	445.8953	4.8	56.945	71.28	0.02	0.136	37	113.5	0.01
Charles040	111.5416	4.5	51.218	51.36	0.021	0.167	42.3	124.7	0.01
Charles050	54.9944	4.8	21.258	42.12	0.024	0.209	64.6	110.1	0.01
Charles060	577.2256	1.8	91.611	17.52	0.027	0.239	83.5	130.8	0.01
CranSouth000	76.1665	4.9	19.592	55.32	0.021	0.17	40.8	218.5	0.01
Fletchers_1	850.9054	2.06	45.077	25.554	0.033	0.43	100	209.398	0.01
Fletchers_2	811.2651	1.91	69.23	35.993	0.026	0.507	100	210.576	0.01
Fletchers_Outlet_1	5.198	1.94	10.848	96	0.014	0.55	100	219.964	0.01
Fletchers_Outlet_2	0.9701	2.85	3.419	72	0.027	0.5	100	210.32	0.01
Juniper001	24.1805	4.2	6.901	37.08	0.025	0.188	69.7	110.1	0.01
Juniper002	155.2521	5.6	22.429	81	0.019	0.169	33.7	213.2	0.01
Loon000	278.0316	3.6	31.244	56.88	0.022	0.153	47.2	155.4	0.01
MicMac004	48.4799	5.5	14.728	32.64	0.024	0.188	63.4	110.1	0.01
S1	62.3947	1.85	60	12.24	0.027	0.23	86.5	89	0.01
S2	66.4512	1.76	98.347	87.6	0.02	0.18	100	220	0.01
Shub__Outlet_2	2481.492	1.39	263.579	22.962	0.032	0.6	100	164.421	0.01
Shub__Outlet_3	1360.461	1.31	101.388	28.24	0.047	0.33	100	232.842	0.01
Shub__Outlet_4	959.9558	1.31	101.388	28.24	0.047	0.33	100	232.842	0.01
Shub_10	2297.319	1.63	102.769	35.752	0.038	0.35	100	245.019	0.01
Shub_11	1383.643	1.63	102.769	35.752	0.038	0.35	100	245.019	0.01
Shub_2	350.2267	1.3	61.551	9.42	0.04	0.6	100	208.217	0.01
Shub_3	454.0305	1.57	57.799	23.119	0.044	0.35	100	213.541	0.01
Shub_4	4054.38	1.62	190.232	16.58	0.047	0.5	100	198.495	0.01
Shub_5	4106.067	1.6	229.286	12.928	0.054	0.5	100	182.359	0.01
Shub_6	6211.751	1.53	172.861	12.432	0.078	0.61	100	166.222	0.01
Shub_7	1802.256	1.27	53.485	30.082	0.067	0.547	100	215.715	0.01
Shub_8	1262.533	1.13	79.464	11.681	0.062	0.61	100	223.944	0.01
Shub_9	1627.815	0.95	109.405	19.092	0.066	0.31	100	261.449	0.01
Shub_Inlet_1	9.6204	1.13	8.678	72	0.02	0.61	100	210.11	0.01
Shub_Outlet_2_1	282.2432	1.55	61.111	5.171	0.036	0.65	100	108.667	0.01
Shube_Inlet_2	11.5104	1.69	8.816	72	0.014	0.55	100	219.964	0.01
Thomas_1	301.9779	1.9	45.004	56.117	0.036	0.4	100	160.795	0.01
Thomas_2	225.6749	2.83	31.453	29.322	0.039	0.4	100	223.935	0.01
Thomas_3	178.5324	1.87	30.604	68.651	0.027	0.5	100	153.071	0.01
Thomas_4	97.9425	2.047	19.218	63.808	0.034	0.35	100	268.548	0.01
Thomas_5	639.7524	1.6	51.475	60	0.052	0.4	100	220.217	0.01
Thomas_6	3639.824	1.61	162.899	15.87	0.067	0.673	100	171.886	0.01
William_1	1483.713	2.02	62.519	15.672	0.07	0.679	100	185.345	0.01
William_2	1255.729	1.92	26.058	33.18	0.047	0.45	100	203.342	0.01
William_3	1109.945	1.82	54.622	22.47	0.054	0.502	100	158.366	0.01
William_Inlet	32.1729	3.16	16.915	42	0.012	0.34	100	109.982	0.01
William_Inlet_1	33.4845	3.57	13.696	2.843	0.048	0.7	100	109.982	0.01

Table B-4 Estimated Watershed Characteristics for the Shubenacadie Lakes System (Post-Calibration) (Future Development Conditions, Unsaturated, No Snowmelt)

Sub-Watershed Name	Area (ha)	Slope (%)	Maximum Overland Flow Length (m)	Imperv. (%)	Impervious Area Roughness	Pervious Area Roughness	Percent of Area Routed to Pervious Area (%)	Capillary Suction Head (mm)	Conductivity (mm/hr)
Charles_1	365.3454	1.33	32.878	61.594	0.038	0.3	100	241.721	0.458
Charles000	191.8732	4	49.878	50.67	0.025	0.207	67.6	121.6	1.015
Charles010	109.4865	3.4	51.996	30.84	0.025	0.219	74.3	110.1	1.113
Charles020S	38.0665	8.4	22.806	17.64	0.027	0.23	83.8	117.9	1.047
Charles030	445.8953	4.8	56.945	85.588	0.02	0.136	37	113.5	1.113
Charles040	111.5416	4.5	51.218	58.54	0.021	0.167	42.3	124.7	0.687
Charles050	54.9944	4.8	21.258	42.12	0.024	0.209	64.6	110.1	1.113
Charles060	577.2256	1.8	91.611	42.37	0.027	0.239	83.5	130.8	1.031
CranSouth000	76.1665	4.9	19.592	55.32	0.021	0.17	40.8	218.5	0.164
Fletchers_1	850.9054	2.06	45.077	31.072	0.033	0.43	100	209.398	0.229
Fletchers_2	811.2651	1.91	69.23	35.993	0.026	0.507	100	210.576	0.213
Fletchers_Outlet_1	5.198	1.94	10.848	96	0.014	0.55	100	219.964	0.164
Fletchers_Outlet_2	0.9701	2.85	3.419	72	0.027	0.5	100	210.32	0.131
Juniper001	24.1805	4.2	6.901	37.08	0.025	0.188	69.7	110.1	1.113
Juniper002	155.2521	5.6	22.429	81	0.019	0.169	33.7	213.2	0.573
Loon000	278.0316	3.6	31.244	56.88	0.022	0.153	47.2	155.4	0.36
MicMac004	48.4799	5.5	14.728	32.64	0.024	0.188	63.4	110.1	1.113
S1	62.3947	1.85	60	12.24	0.027	0.23	86.5	89	1.309
S2	66.4512	1.76	98.347	87.6	0.02	0.18	100	220	1.309
Shub__Outlet_2	2481.492	1.39	263.579	22.962	0.032	0.6	100	164.421	0.458
Shub__Outlet_3	1360.461	1.31	101.388	28.24	0.047	0.33	100	232.842	0.229
Shub__Outlet_4	959.9558	1.31	101.388	28.24	0.047	0.33	100	232.842	0.229
Shub_10	2297.319	1.63	102.769	39.152	0.038	0.35	100	245.019	0.229
Shub_11	1383.643	1.63	102.769	35.752	0.038	0.35	100	245.019	0.229
Shub_2	350.2267	1.3	61.551	9.42	0.04	0.6	100	208.217	0.36
Shub_3	454.0305	1.57	57.799	23.119	0.044	0.35	100	213.541	0.278
Shub_4	4054.38	1.62	190.232	16.58	0.047	0.5	100	198.495	0.442
Shub_5	4106.067	1.6	229.286	12.928	0.054	0.5	100	182.359	0.589
Shub_6	6211.751	1.53	172.861	12.432	0.078	0.61	100	166.222	0.736
Shub_7	1802.256	1.27	53.485	30.082	0.067	0.547	100	215.715	0.262
Shub_8	1262.533	1.13	79.464	24.252	0.062	0.61	100	223.944	0.164
Shub_9	1627.815	0.95	109.405	19.092	0.066	0.31	100	261.449	0.147
Shub_Inlet_1	9.6204	1.13	8.678	72	0.02	0.61	100	210.11	0.115
Shub_Outlet_2_1	282.2432	1.55	61.111	5.171	0.036	0.65	100	108.667	1.064
Shube_Inlet_2	11.5104	1.69	8.816	72	0.014	0.55	100	219.964	0.164
Thomas_1	301.9779	1.9	45.004	62.59	0.036	0.4	100	160.795	0.72
Thomas_2	225.6749	2.83	31.453	29.322	0.039	0.4	100	223.935	0.425
Thomas_3	178.5324	1.87	30.604	85.451	0.027	0.5	100	153.071	0.278
Thomas_4	97.9425	2.047	19.218	63.808	0.034	0.35	100	268.548	0.131
Thomas_5	639.7524	1.6	51.475	60	0.052	0.4	100	220.217	0.327
Thomas_6	3639.824	1.61	162.899	15.87	0.067	0.673	100	171.886	0.524
William_1	1483.713	2.02	62.519	15.672	0.07	0.679	100	185.345	0.736
William_2	1255.729	1.92	26.058	33.18	0.047	0.45	100	203.342	0.671
William_3	1109.945	1.82	54.622	22.47	0.054	0.502	100	158.366	0.965
William_Inlet	32.1729	3.16	16.915	42	0.012	0.34	100	109.982	1.113
William_Inlet_1	33.4845	3.57	13.696	2.843	0.048	0.7	100	109.982	1.113

Table B-5 Estimated Watershed Characteristics for the Shubenacadie Lakes System (Post-Calibration) (Future Development Conditions, Wet/Frozen, Snowmelt)

Sub-Watershed Name	Area (ha)	Slope (%)	Maximum Overland Flow Length (m)	Imperv. (%)	Impervious Area Roughness	Pervious Area Roughness	Percent of Area Routed to Pervious Area (%)	Capillary Suction Head (mm)	Conductivity (mm/hr)
Charles_1	365.3454	1.33	32.878	61.594	0.038	0.3	100	241.721	0.01
Charles000	191.8732	4	49.878	50.67	0.025	0.207	67.6	121.6	0.01
Charles010	109.4865	3.4	51.996	30.84	0.025	0.219	74.3	110.1	0.01
Charles020S	38.0665	8.4	22.806	17.64	0.027	0.23	83.8	117.9	0.01
Charles030	445.8953	4.8	56.945	85.588	0.02	0.136	37	113.5	0.01
Charles040	111.5416	4.5	51.218	58.54	0.021	0.167	42.3	124.7	0.01
Charles050	54.9944	4.8	21.258	42.12	0.024	0.209	64.6	110.1	0.01
Charles060	577.2256	1.8	91.611	42.37	0.027	0.239	83.5	130.8	0.01
CranSouth000	76.1665	4.9	19.592	55.32	0.021	0.17	40.8	218.5	0.01
Fletchers_1	850.9054	2.06	45.077	31.072	0.033	0.43	100	209.398	0.01
Fletchers_2	811.2651	1.91	69.23	35.993	0.026	0.507	100	210.576	0.01
Fletchers_Outlet_1	5.198	1.94	10.848	96	0.014	0.55	100	219.964	0.01
Fletchers_Outlet_2	0.9701	2.85	3.419	72	0.027	0.5	100	210.32	0.01
Juniper001	24.1805	4.2	6.901	37.08	0.025	0.188	69.7	110.1	0.01
Juniper002	155.2521	5.6	22.429	81	0.019	0.169	33.7	213.2	0.01
Loon000	278.0316	3.6	31.244	56.88	0.022	0.153	47.2	155.4	0.01
MicMac004	48.4799	5.5	14.728	32.64	0.024	0.188	63.4	110.1	0.01
S1	62.3947	1.85	60	12.24	0.027	0.23	86.5	89	0.01
S2	66.4512	1.76	98.347	87.6	0.02	0.18	100	220	0.01
Shub__Outlet_2	2481.492	1.39	263.579	22.962	0.032	0.6	100	164.421	0.01
Shub__Outlet_3	1360.461	1.31	101.388	28.24	0.047	0.33	100	232.842	0.01
Shub__Outlet_4	959.9558	1.31	101.388	28.24	0.047	0.33	100	232.842	0.01
Shub_10	2297.319	1.63	102.769	39.152	0.038	0.35	100	245.019	0.01
Shub_11	1383.643	1.63	102.769	35.752	0.038	0.35	100	245.019	0.01
Shub_2	350.2267	1.3	61.551	9.42	0.04	0.6	100	208.217	0.01
Shub_3	454.0305	1.57	57.799	23.119	0.044	0.35	100	213.541	0.01
Shub_4	4054.38	1.62	190.232	16.58	0.047	0.5	100	198.495	0.01
Shub_5	4106.067	1.6	229.286	12.928	0.054	0.5	100	182.359	0.01
Shub_6	6211.751	1.53	172.861	12.432	0.078	0.61	100	166.222	0.01
Shub_7	1802.256	1.27	53.485	30.082	0.067	0.547	100	215.715	0.01
Shub_8	1262.533	1.13	79.464	24.252	0.062	0.61	100	223.944	0.01
Shub_9	1627.815	0.95	109.405	19.092	0.066	0.31	100	261.449	0.01
Shub_Inlet_1	9.6204	1.13	8.678	72	0.02	0.61	100	210.11	0.01
Shub_Outlet_2_1	282.2432	1.55	61.111	5.171	0.036	0.65	100	108.667	0.01
Shube_Inlet_2	11.5104	1.69	8.816	72	0.014	0.55	100	219.964	0.01
Thomas_1	301.9779	1.9	45.004	62.59	0.036	0.4	100	160.795	0.01
Thomas_2	225.6749	2.83	31.453	29.322	0.039	0.4	100	223.935	0.01
Thomas_3	178.5324	1.87	30.604	85.451	0.027	0.5	100	153.071	0.01
Thomas_4	97.9425	2.047	19.218	63.808	0.034	0.35	100	268.548	0.01
Thomas_5	639.7524	1.6	51.475	60	0.052	0.4	100	220.217	0.01
Thomas_6	3639.824	1.61	162.899	15.87	0.067	0.673	100	171.886	0.01
William_1	1483.713	2.02	62.519	15.672	0.07	0.679	100	185.345	0.01
William_2	1255.729	1.92	26.058	33.18	0.047	0.45	100	203.342	0.01
William_3	1109.945	1.82	54.622	22.47	0.054	0.502	100	158.366	0.01
William_Inlet	32.1729	3.16	16.915	42	0.012	0.34	100	109.982	0.01
William_Inlet_1	33.4845	3.57	13.696	2.843	0.048	0.7	100	109.982	0.01

APPENDIX C

Climate Change Scenarios

Climate Change Scenarios

Introduction

The purpose of this climate change discussion is to (1) provide additional background on the challenges of projecting extreme precipitation (Section A.1), (2) to discuss the strengths and limitations on the methods used in this study (Section A.2 and A.3), and (3) to provide additional climate change scenarios and flood lines that can be used in a risk analysis.

C.1 - Precipitation Extremes are Difficult to Project

Precipitation extremes are particularly challenging to project into the future. This is primarily because key precipitation processes occur at small scales, which are difficult to represent in models. For instance, convective updraft cores can be only a few hundred metres to a few kilometers across (Westra *et al*. 2014). However, not only do precipitation extremes depend on small-scale processes, but they are also affected by certain elements of larger-scale circulation. For instance, jet streams that are also important for precipitation extremes and models struggle to resolve the location of jet streams (Trenberth *et al*. 2003, O'Gorman *et al*. 2015).

As a result, projections for precipitation extremes can vary by more than 100%. No method for projecting extreme precipitation is perfect. This is illustrated below with a discussion of the advantages and disadvantages of the methods used in this study.

C.2 - Statistical Downscaling with the IDF-CC Tool

The Western University Intensity Duration Frequency Climate Change tool (IDF-CC tool) uses statistical downscaling with Environment and Climate Change Canada climate station precipitation data. This tool is becoming widely used because of its simplicity. It has been mapped across Canada (Simonovic *et al*. 2017), and has been compared to other approaches (Schardong *et al*. 2018) and tested with both GCMs and RCMs as input (Schardong and Simonivic 2019).

To calculate daily extremes, the IDF-CC tool uses a dataset of 10 km x 10 km downscaled GCMs. The GCMs are downscaled using BCCAQv2, a hybrid method that combines results from BCCA (Maraun *et al*. 2010) and quantile mapping (QMAP; Gudmundsson *et al*. 2012). The tool interpolates the BCCAQv2 dataset to a point location (inverse square distance weighting method), and extreme values are estimated using GEV and L-moments (Srivastav *et al*. 2014).

For sub-daily durations, a quantile scaling method is used to establish a relationship between the annual maximum daily precipitations of the base period with that of the future period. The use of only one value per year has been suggested to be more effective than using the total rainfall distribution (Li *et al*. 2017). A major drawback of this method is that it assumes that the existing relationship between daily and sub-daily precipitation will remain unchanged in the future, and there is evidence to show that this is incorrect (Trenbeth *et al*. 2003, O'orman *et al*. 2015, Westra *et al*. 2014, Cannon and Innocenti 2019). Because this assumption is a significant source of uncertainty, future sub-daily precipitation estimates from the tool should be used with caution, as they are likely to be underestimated (Coulibaly *et al*. 2016).

C.3 - Scaling with the Clausius-Clapeyron Equation

Another approach to estimating future changes in the intensity of extreme rainfall is based on the relationship of rainfall to atmospheric temperature, because warmer air is capable of holding more water than cooler air (Trenberth et al. 2003). The capacity of the atmosphere to hold water is governed by the Clausius-Clapeyron (CC) equation, which can be approximated as an increase in precipitation intensity of 7% per degree Celsius. There is also emerging evidence for a "super-CC" scaling rate, where observational studies of hourly rainfall have shown rates of up to double the CC rate (14% per degree Celsius) for temperatures between 12-22°C (Westra et al. 2014). Results based on the scaling rate have been found to be comparable to the IDF-CC tool, although higher for the prairies (perhaps because they are moisture-limited; Schardong et al. 2018).

The scaling rate is supported by robust thermodynamic understanding, and it has recently been adopted in 2019 by the Canadian Standards Association (CSA PLUS 4013:19) and has been argued to be the only defensible approach based on studies by Zhang *et al*. (2017) and Zwiers (2017). A number of studies have shown a CC-scaling rate based convection-permitting models as well as observations (Westra *et al*. 2014).

However, the use of the theoretical scaling rates assumes that there is sufficient water availability and that there are no changes to the atmospheric circulation patterns that produce rainfall. These factors are known to also affect extreme precipitation, but are not accounted for by the scaling rate (O'Gorman *et al*. 2015, Blenkinsop *et al*. 2018, CSA 2019, Pfahl *et al*., 2017). Hence, the true scaling rates should actually vary with latitude and altitude as well as seasonal temperature (Westra *et al.* 2014), and variations in the scaling rates have been observed in Canada and elsewhere (Li *et al*. 2019, Gaur *et al*. 2018, Panthou *et al*. 2014).

As a result, there are diverging opinions on whether this scaling rate should be used (Prein *et al*. 2017, Schardong *et al*. 2018). One challenge is that we do not have enough research to know precisely how to apply it. For example, the CSA (2019) is not prescriptive about which temperature to use (e.g., mean annual, seasonal, temperature during heavy rainfall, dew point temperatures). In this study, annual average daily temperatures were used.

C.4 - Recommended approach - Using Multiple Climate Change Scenarios as part of Sensitivity Analysis

The sections above share the advantages and disadvantages of the two methods used in this study. Other approaches for estimating the impacts of climate change on precipitation intensity including using statistically downscaled Global Climate Models (GCMs), Regional Climate Models (RCMs), or Convection-Permitting Models. These approaches also have various strengths and limitations in terms of the ensembles of GCMs used, the choice of emission scenarios, as well as process-based assumptions**, therefore no single climate change projection method should be used in isolation**. Instead, best practice is to consider and compare all available tools as well as their assumptions and obtain a range of possible climate change outcomes (Charron 2016, CSA 2019). Other considerations not mentioned here include statistical uncertainty, regional frequency analyses, and nonstationary statistical methods, among others.

A low-hanging fruit for this study is to use multiple scenarios available from the two methods. For this purpose, two additional climate change scenarios have been selected. The scenarios are described below and reported in Table D1. All scenarios are shown for context in Figure D1. Flood levels and floodplain width for those scenarios have been generated and are discussed below.

- **Scenario A** uses the IDF-CC Tool and the 95^{th} percentile of the most conservative emission scenario (RCP 8.5). This is the most conservative projection, which ensures public safety but can result in overestimated floodlines.
- **Scenario B** uses the same method (IDF-CC) and emission scenario (RCP 8.5) as Scenario A, but is for the 50th percentile of models (i.e. median). Comparison with Scenario A provides a measure of the modelling uncertainty. This helps answer the question: “How does our ability to represent the climate with models affect the flood line?”
- **Scenario C** uses the same method (IDF-CC) and percentile (95th) as the primary scenario (Scenario A) but is for emission scenario RCP 4.5 rather than RCP 8.5. Comparison with Scenario A provides a measure of the uncertainty caused by the uncertainty of the emission scenario. This helps answer the question: “How does the flood line change if different assumptions about global emissions (which are based on population, technology, international policy, conflict) are made?”

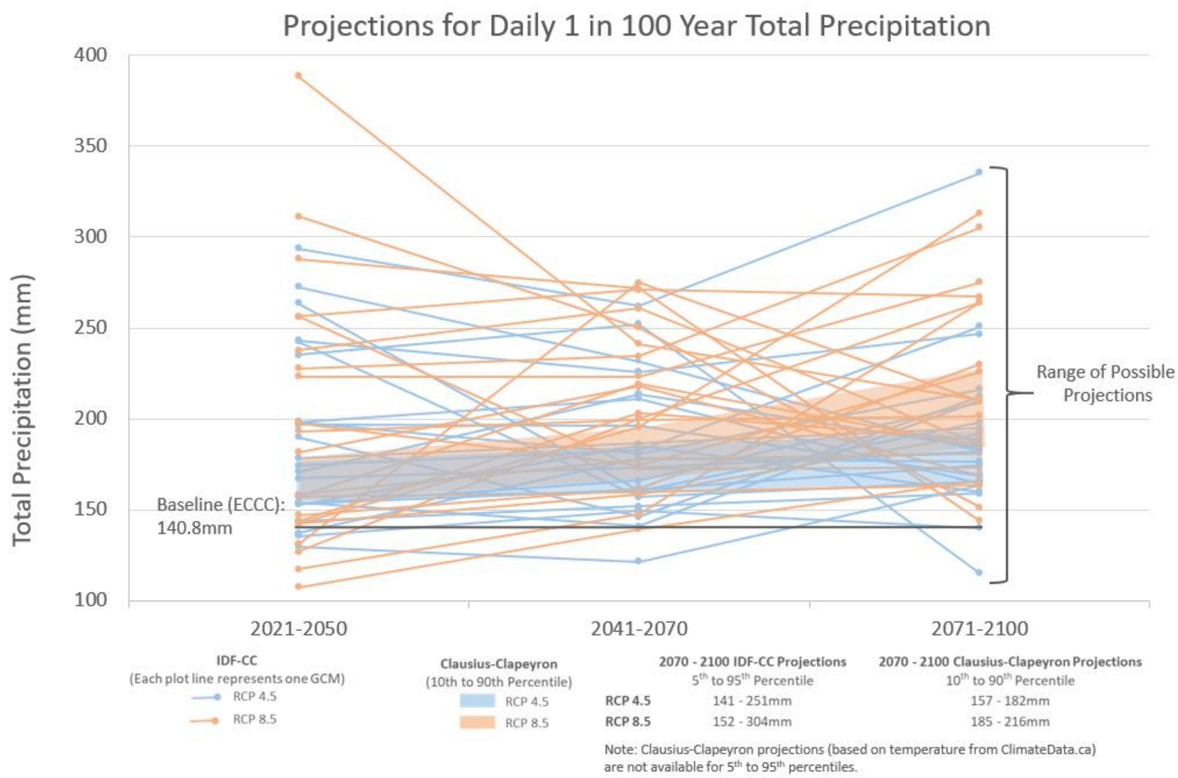


Figure C.1 - Range of Projections at Halifax-Stanfield Int'l Airport for future 1 in 100 year precipitation based on two methods: IDF-CC Tool and Clausius-Clapeyron scaling.

C.5 – Climate Projections Effect on Floods

For the Shubenacadie Lake System, flood flow rates are strongly influenced by the volume of design storm precipitation. Increasing the volume of design storm rainfall increases the peak flow rate and correspondingly the depth of the flood and the width of the floodplain. The uncertainty in future rainfall amounts leads to uncertainty in future flood water levels and floodplain widths.

To help quantify how uncertainty in future rainfall intensities affects projections for future flood water levels and floodplain widths, the 1 in 100 design storms for each of the three scenarios were input to the model.

Figure C.2 shows an example of the increase in **floodplain width** from the current 100 year to future 100 year floods for the three climate scenarios.

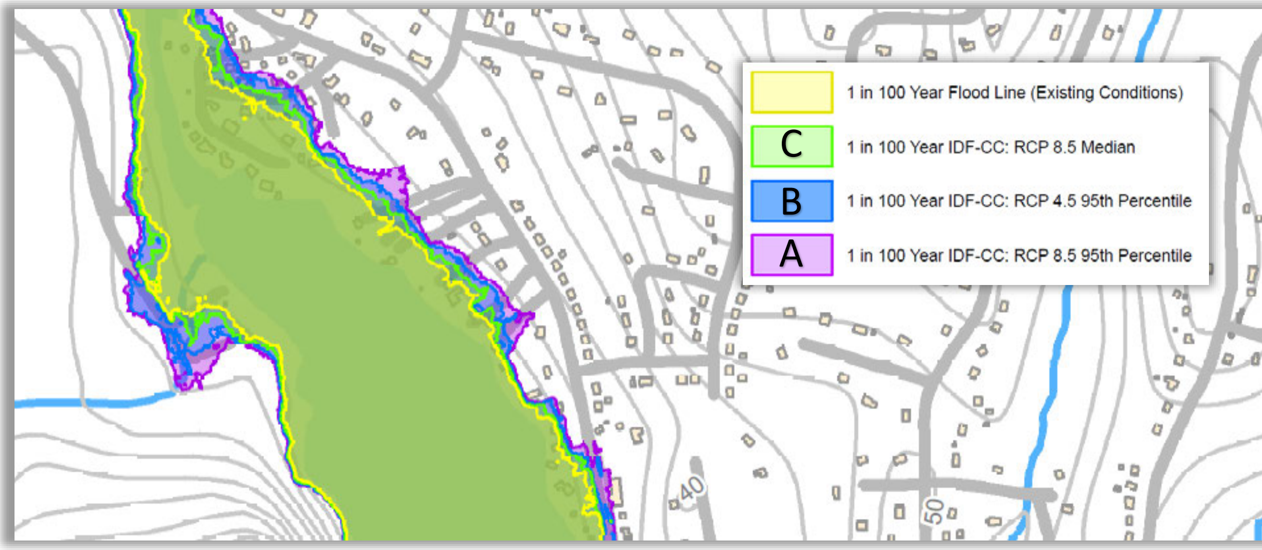


Figure C.2 – Example section of difference in floodplain for the three climate scenarios. A full comparison map can be seen in **Appendix D.**

Comparing the difference in level and width illustrates that some parts of the rivers are more sensitive to the differences between the climate change scenarios (i.e., they are more sensitive to climate change uncertainty). Importantly, while the largest scenario (A) produces higher flow rates and consistently higher water levels, the increase in floodplain width is variable. The higher climate projection does not necessarily lead to a wide scale increase in flooding throughout the study area. The increase in width occurs only at areas already sensitive to flooding due to their river morphology (channel and floodplain slope, width, etc.) As shown in **Figure C.2** (and in the full extent provided in **Appendix D**), the increase in floodplain width is quite dramatic in some locations while nearby it does not changes substantially.

Though there is high uncertainty in how rainfall may change in the future; a key determinant in flooding is river morphology (e.g. channel slope, valley width) and this will change little over time. As such, it is prudent to account for the climate uncertainty by using a conservative climate projection, since it simply adds a greater level of protection to where the river is already prone to flooding.

C.6 – References

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APPENDIX D

Water Elevation Profiles

Current IDFs, Unsaturated Conditions, Existing Development
Land Profile
November 1990
1 in 5 Year Rainfall
1 in 20 Year Rainfall
1 in 100 Year Rainfall
1 in 500 Year Rainfall
PMP
Lake Charles
Lake William
Thomas Lake
Fletchers Lake
Lock 3
Shubie Greenway Corridor
South Trans Canada Trail
Highway 118 NB/SB
Highway 107
Shubie Trail Head
North Trans Canada Trail
Private Bridge
Rocky Lake Drive
Highway 102
Fall River Road
Fletcher Lake Lock Trail
CN Rail
Kings Road
Geodetic Elevation (m)
Distance Along Shubenacadie Lakes System (m)

Current IDFs, Saturated Conditions, Existing Development
Geodetic Elevation (m)
Distance Along Shubenacadie Lakes System (m)
Land Profile
1 in 5 Year Rainfall
1 in 20 Year Rainfall
1 in 100 Year Rainfall
Lake Charles
Lake William
Thomas Lake
Fletchers Lake
Lock 3
Shubie Greenway Corridor
South Trans Canada Trail
Highway 118 NB/SB
Highway 107
Shubie Trail Head
North Trans Canada Trail
Private Bridge
Rocky Lake Drive
Highway 102
Fall River Road
Fletcher Lake Lock Trail
CN Rail
Kings Road
0
1000
2000
3000
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7000
8000
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10000
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Climate Change Comparison, Unsaturated Conditions, Existing Development
Land Profile
1 in 100 Year Rainfall
1 in 100 Year Rainfall: IDF-CC RCP 8.5 Median (40% Increase)
1 in 100 Year Rainfall: IDF-CC RCP 4.5 95th Percentile (78% Increase)
1 in 100 Year Rainfall: IDF-CC RCP 8.5 95th Percentile (116% Increase)
Lake Charles
Lake William
Thomas Lake
Fletchers Lake
Highway 118 NB/SB
Lock 3
Shubie Greenway Corridor
South Trans Canada Trail
Highway 107
Shubie Trail Head
North Trans Canada Trail
Private Bridge
Rocky Lake Drive
Highway 102
Fall River Road
Fletcher Lake Lock Trail
CN Rail
Kings Road
Geodetic Elevation (m)
Distance Along Shubenacadie Lakes System (m)
0
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Current IDFs, Saturated Conditions, Future Development
Land Profile
1 in 5 Year Rainfall
1 in 20 Year Rainfall
1 in 100 Year Rainfall
Lake Charles
Lake William
Thomas Lake
Fletchers Lake
Lock 3
Shubie Greenway Corridor
South Trans Canada Trail
Highway 118 NB/SB
Highway 107
Shubie Trail Head
North Trans Canada Trail
Private Bridge
Rocky Lake Drive
Highway 102
Fall River Road
Fletcher Lake Lock Trail
CN Rail
Kings Road
Geodetic Elevation (m)
Distance Along Shubenacadie Lakes System (m)

Future IDFs, Saturated Conditions, Future Development
Land Profile
1 in 5 Year Rainfall (CC)
1 in 20 Year Rainfall (CC)
1 in 100 Year Rainfall (CC)
Lake Charles
Lake William
Thomas Lake
Fletchers Lake
Lock 3
Shubie Greenway Corridor
South Trans Canada Trail
Highway 118 NB/SB
Highway 107
Shubie Trail Head
North Trans Canada Trail
Private Bridge
Rocky Lake Drive
Highway 102
Fall River Road
Fletcher Lake Lock Trail
CN Rail
Kings Road
Geodetic Elevation (m)
Distance Along Shubenacadie Lakes System (m)
0
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5000
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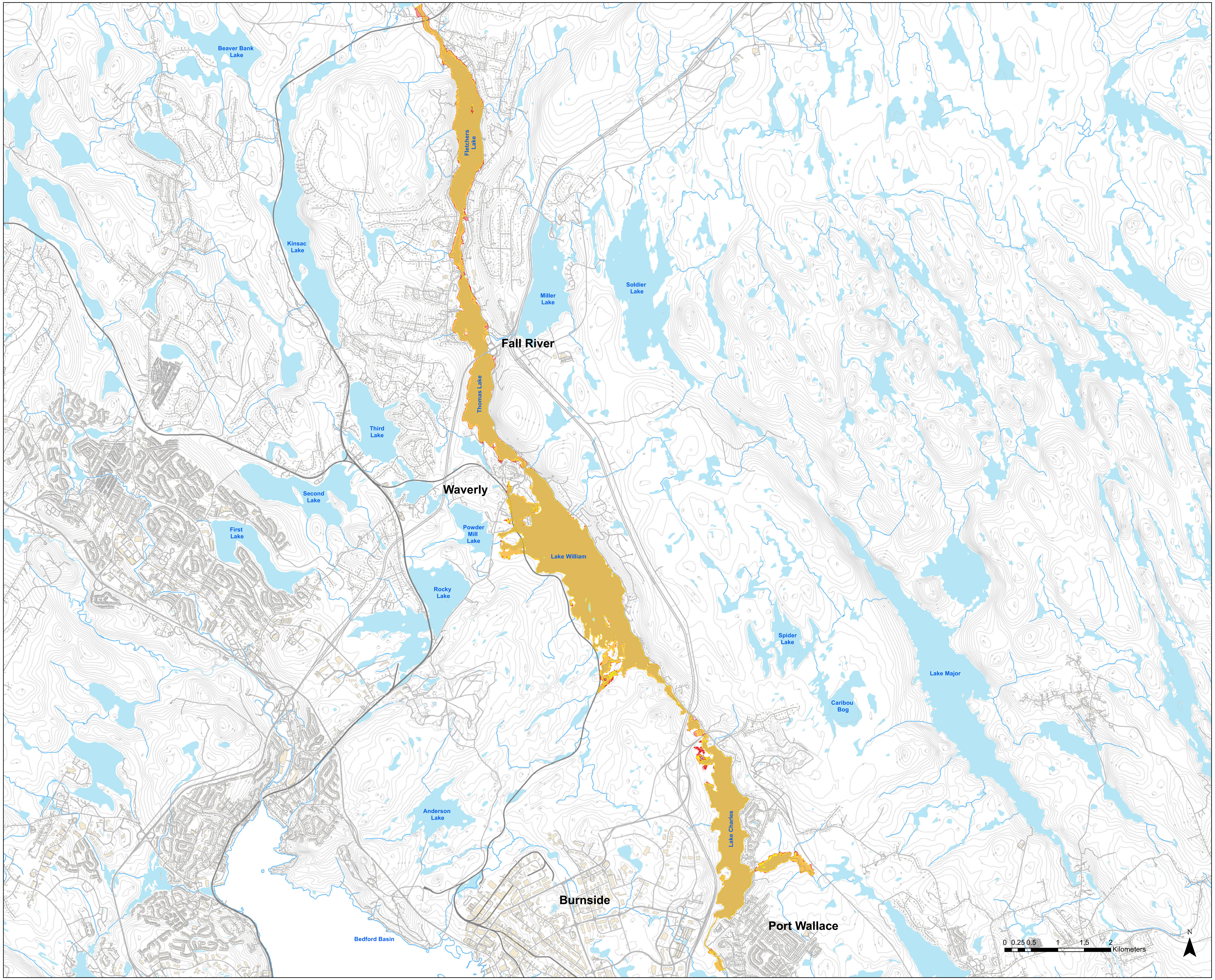
Structure Jams, Saturated Conditions, Future Development
Land Profile
1 in 100 Year Rainfall (No Jams)
1 in 100 Year Rainfall, Structure Jams
1 in 100 Year Rainfall (CC), Structure Jams
Lake Charles
Lake William
Thomas Lake
Fletchers Lake
Highway 118 NB/SB
Lock 3
Shubie Greenway Corridor
South Trans Canada Trail
Highway 107
Shubie Trail Head
North Trans Canada Trail
Private Bridge
Rocky Lake Drive
Highway 102
Fall River Road
Fletcher Lake Lock Trail
CN Rail
Kings Road
Geodetic Elevation (m)
Distance Along Shubenacadie Lakes System (m)

Comparison - Current and Future IDFs, Saturated Conditions, Future Development
Land Profile
1 in 20 Year Rainfall
1 in 20 Year Rainfall (CC)
1 in 100 Year Rainfall
1 in 100 Year Rainfall (CC)
Lake Charles
Lake William
Thomas Lake
Fletchers Lake
Lock 3
Shubie Greenway Corridor
South Trans Canada Trail
Highway 118 NB/SB
Highway 107
Shubie Trail Head
North Trans Canada Trail
Private Bridge
Rocky Lake Drive
Highway 102
Fall River Road
Fletcher Lake Lock Trail
CN Rail
Kings Road
Geodetic Elevation (m)
Distance Along Shubenacadie Lakes System (m)

Base Flood Selections: Saturated Conditions, Future Development, Future IDFs
Land Profile
Floodway (1 in 20 Year Rainfall Event (CC))
Floodway Fringe (1 in 100 Year Rainfall Event (CC))
Lake Charles
Lake William
Thomas Lake
Fletchers Lake
Geodetic Elevation (m)
Distance Along Shubenacadie Lakes System (m)
Lock 3
Shubie Greenway Corridor
South Trans Canada Trail
Highway 118 NB/SB
Highway 107
Shubie Trail Head
North Trans Canada Trail
Private Bridge
Rocky Lake Drive
Highway 102
Fall River Road
Fletcher Lake Lock Trail
CN Rail
Kings Road

APPENDIX E

Flood Line Delineation Maps



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Halifax Regional Municipality

Shubenacadie Lakes System Floodplain Study

Flood Line Delineation

Map 1

Historical Design Storm

Legend

- November 1990 Calibration Event
- 1 in 5 Year Rainfall Event, Existing Conditions
- Buildings
- Roads
- Railroads

SCALE: 1:31,500

Date: May 2020
CBCL Project #: 191107.00

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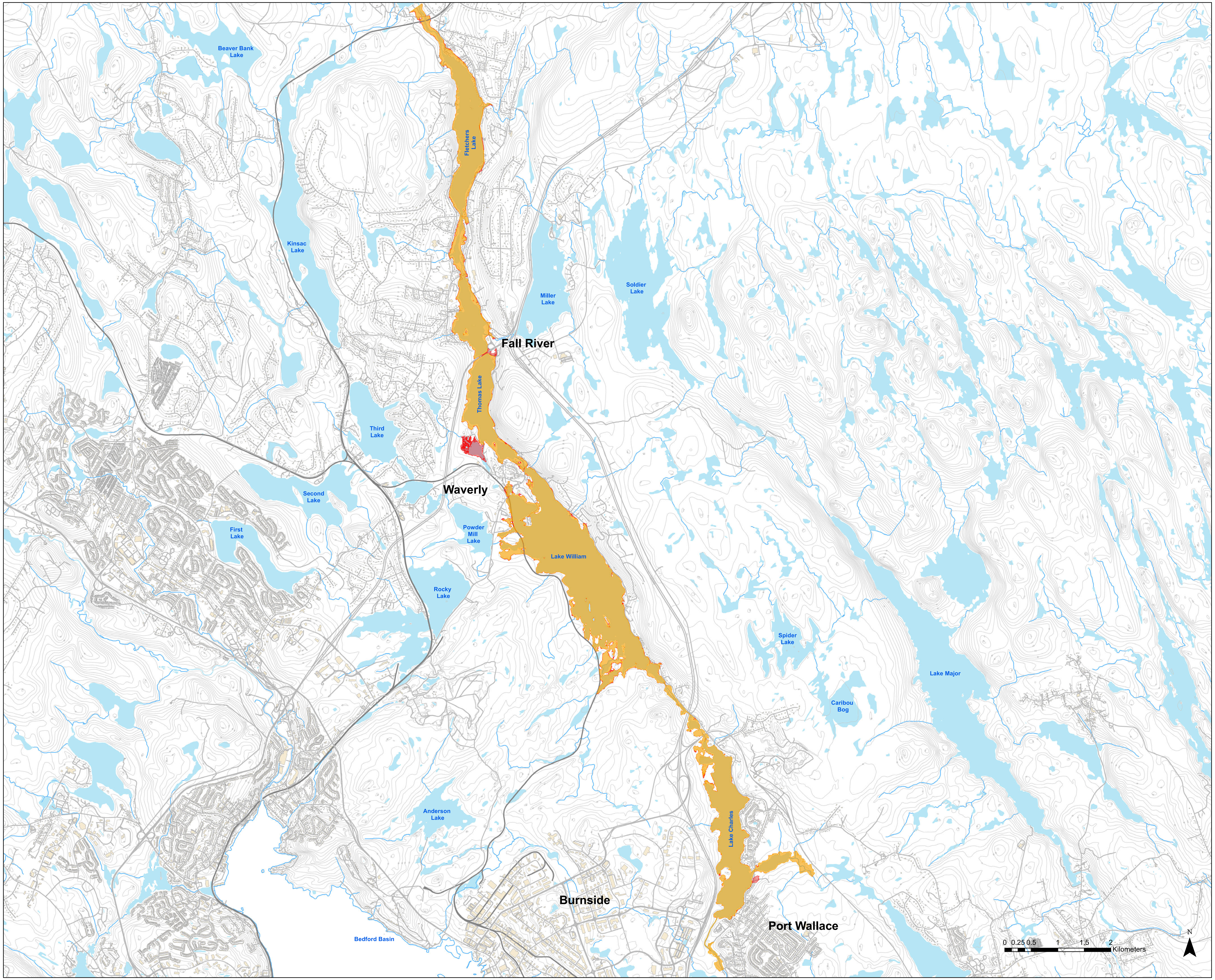

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Shubenacadie Lakes System Floodplain Study

Flood Line Delineation

Map 2

Comparison of Antecedent Conditions

Legend

- 1 in 100 Year Rainfall Event, Unsaturated Conditions
- 1 in 100 Year Rainfall Event, Spring Conditions (Wet/Frozen with Snowmelt)
- Buildings
- Roads
- Railroads

SCALE: 1:31,500

Date: May 2020
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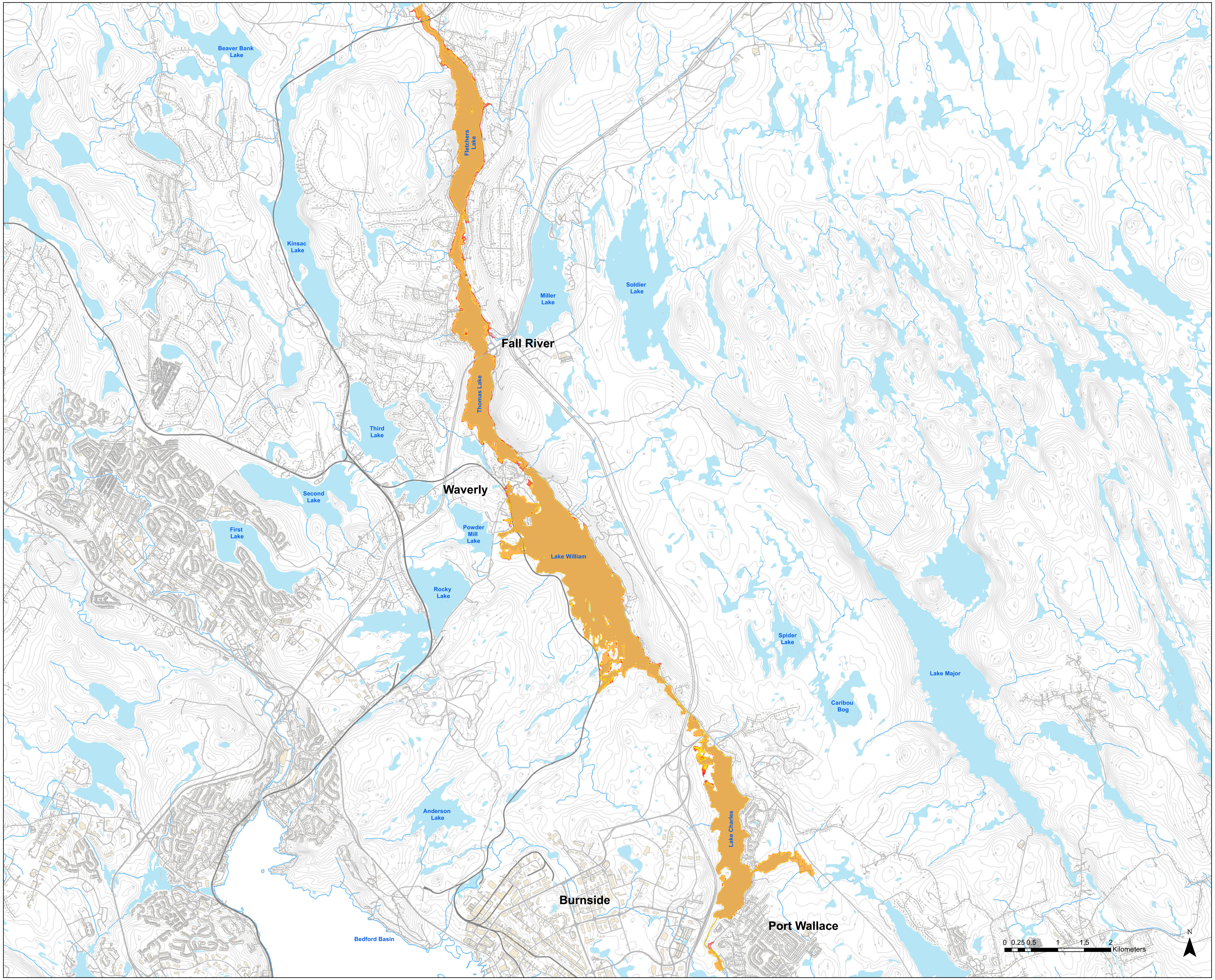

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Shubenacadie Lakes System Floodplain Study

Flood Line Delineation

Map 3

Existing Conditions, Unsaturated
1 in 5 Year, 1 in 20 Year, 1 in 100 Year

Legend

- 1 in 5 Year Rainfall Event, Existing Conditions, Unsaturated
- 1 in 20 Year Rainfall Event, Existing Conditions, Unsaturated
- 1 in 100 Year Rainfall Event, Existing Conditions, Unsaturated
- Buildings
- Roads
- Railroads

SCALE: 1:31,500

Date: May 2020
CBCL Project #: 191107.00

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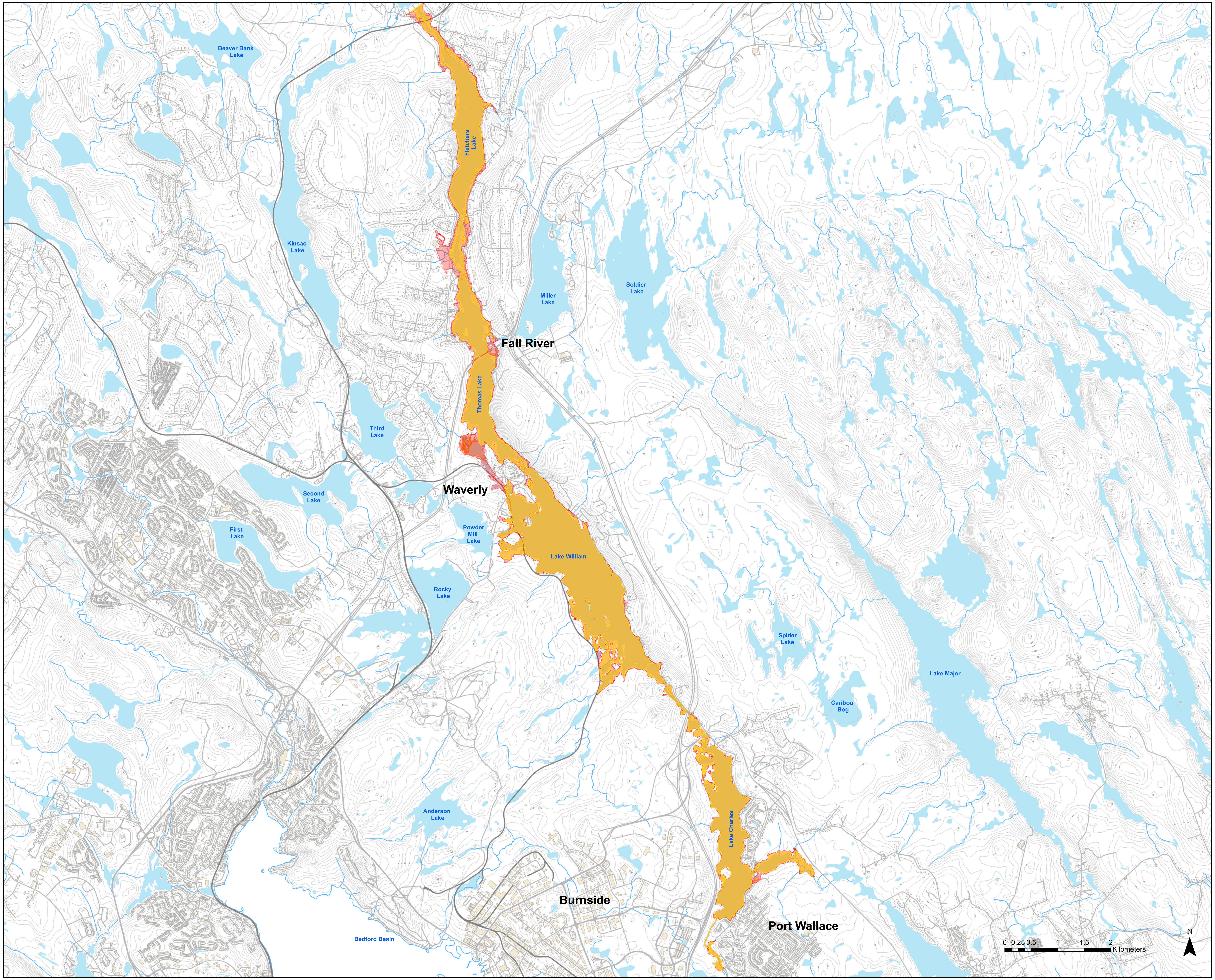

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Shubenacadie Lakes System Floodplain Study

Flood Line Delineation

Map 4
Existing Conditions, Unsaturated
1 in 100 Year, 1 in 500 Year, PMP

Legend

- 1 in 100 Year Rainfall Event, Existing Conditions, Unsaturated
- 1 in 500 Year Rainfall Event, Existing Conditions, Unsaturated
- PMP Rainfall Event, Existing Conditions, Unsaturated
- Buildings
- Roads
- Railroads

SCALE: 1:31,500

Date: May 2020
CBCL Project #: 191107.00

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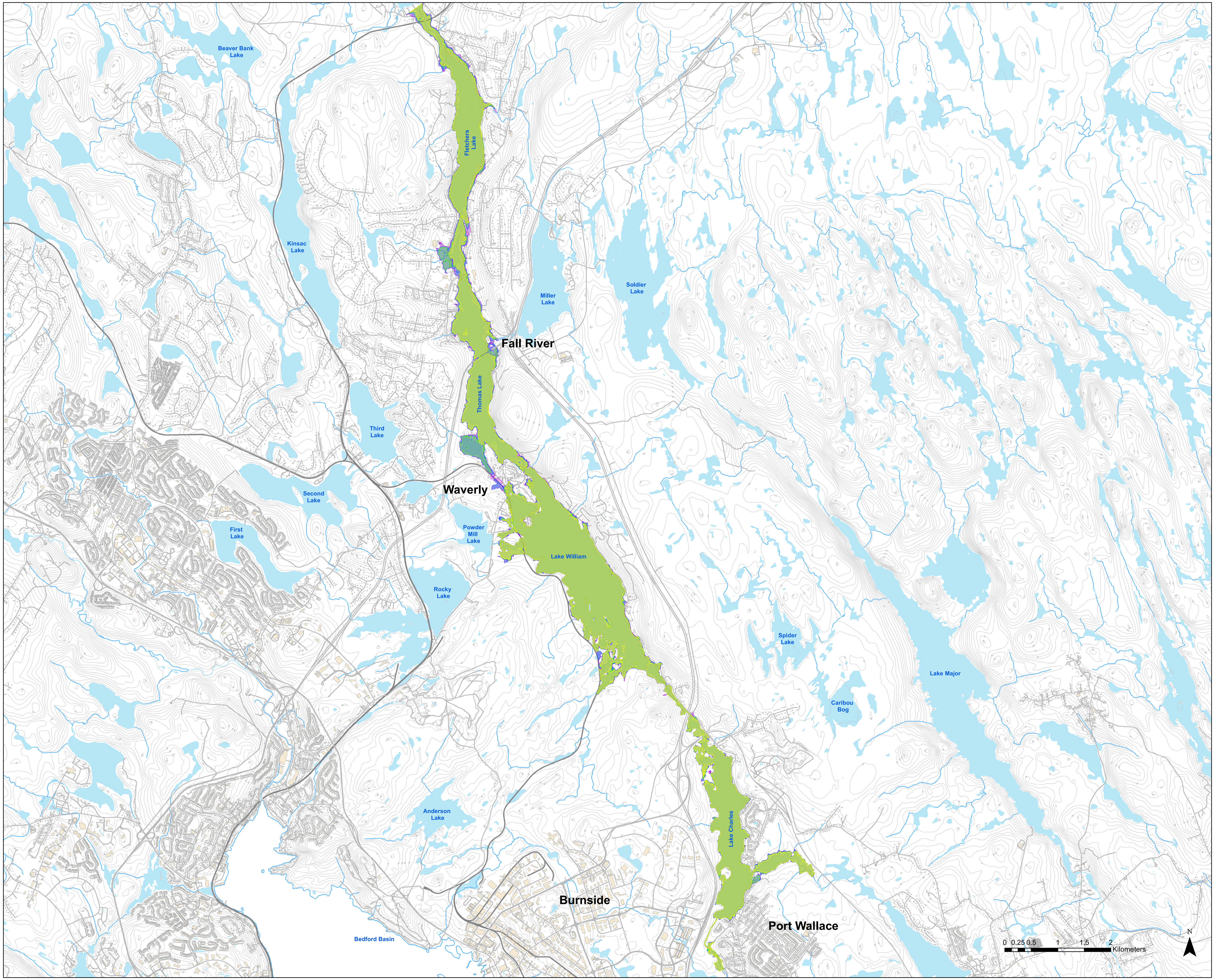

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Shubenacadie Lakes System Floodplain Study

Flood Line Delineation

Map 5

Climate Change Scenarios

Legend

- 1 in 100 Year Rainfall Event, Existing Conditions
- 1 in 100 Year Rainfall Event - IDF-CC: RCP 8.5 Median
- 1 in 100 Year Rainfall Event - IDF-CC: RCP 4.5 95th Percentile
- 1 in 100 Year Rainfall Event - IDF-CC: RCP 8.5 95th Percentile
- Buildings
- Roads
- Railroads

SCALE: 1:31,500

Date: May 2020
CBCL Project #: 191107.00

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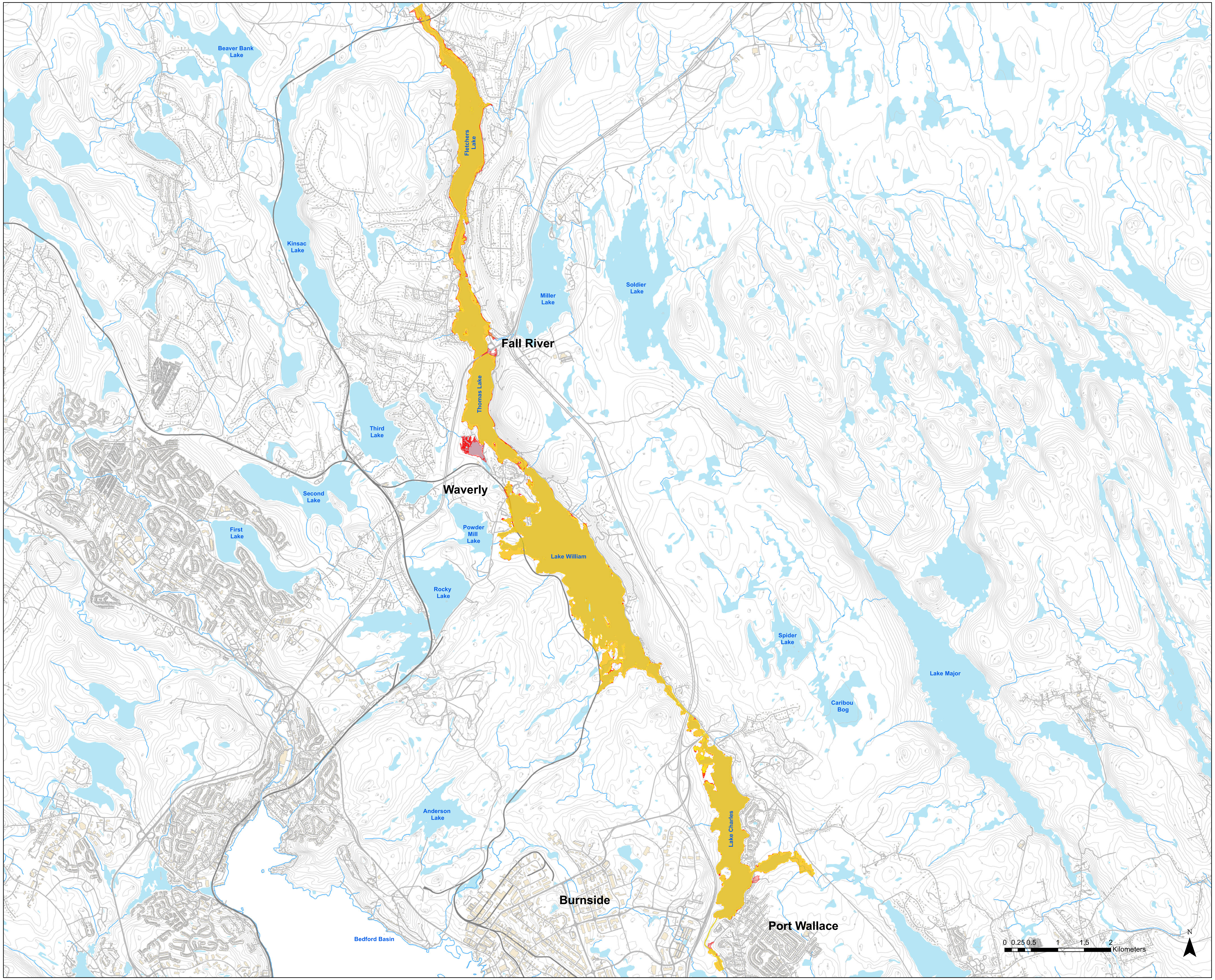

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Shubenacadie Lakes System Floodplain Study

Flood Line Delineation

Map 6

Future Development
Existing IDFs

Legend

- 1 in 5 Year Rainfall Event, Future Development
- 1 in 20 Year Rainfall Event, Future Development
- 1 in 100 Year Rainfall Event, Future Development
- Buildings
- Roads
- Railroads

SCALE: 1:31,500

Date: May 2020
CBCL Project #: 191107.00

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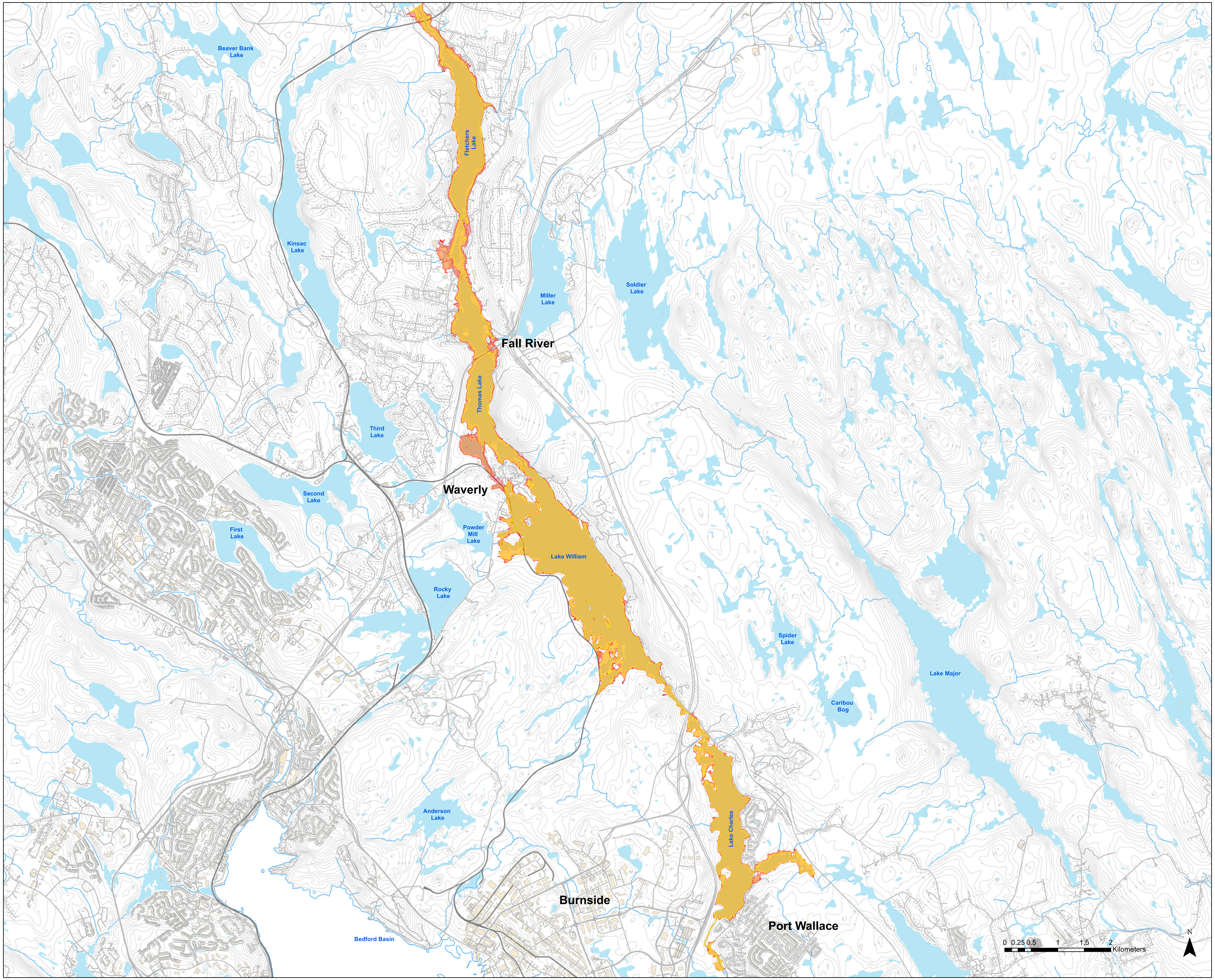

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Shubenacadie Lakes System Floodplain Study

Flood Line Delineation

Map 7

Future Development
Future IDFs

Legend

- 1 in 5 Year Rainfall Event (CC), Future Development
- 1 in 20 Year Rainfall Event (CC), Future Development
- 1 in 100 Year Rainfall Event (CC), Future Development
- Buildings
- Roads
- Railroads

SCALE: 1:31,500

Date: May 2020
CBCL Project #: 191107.00

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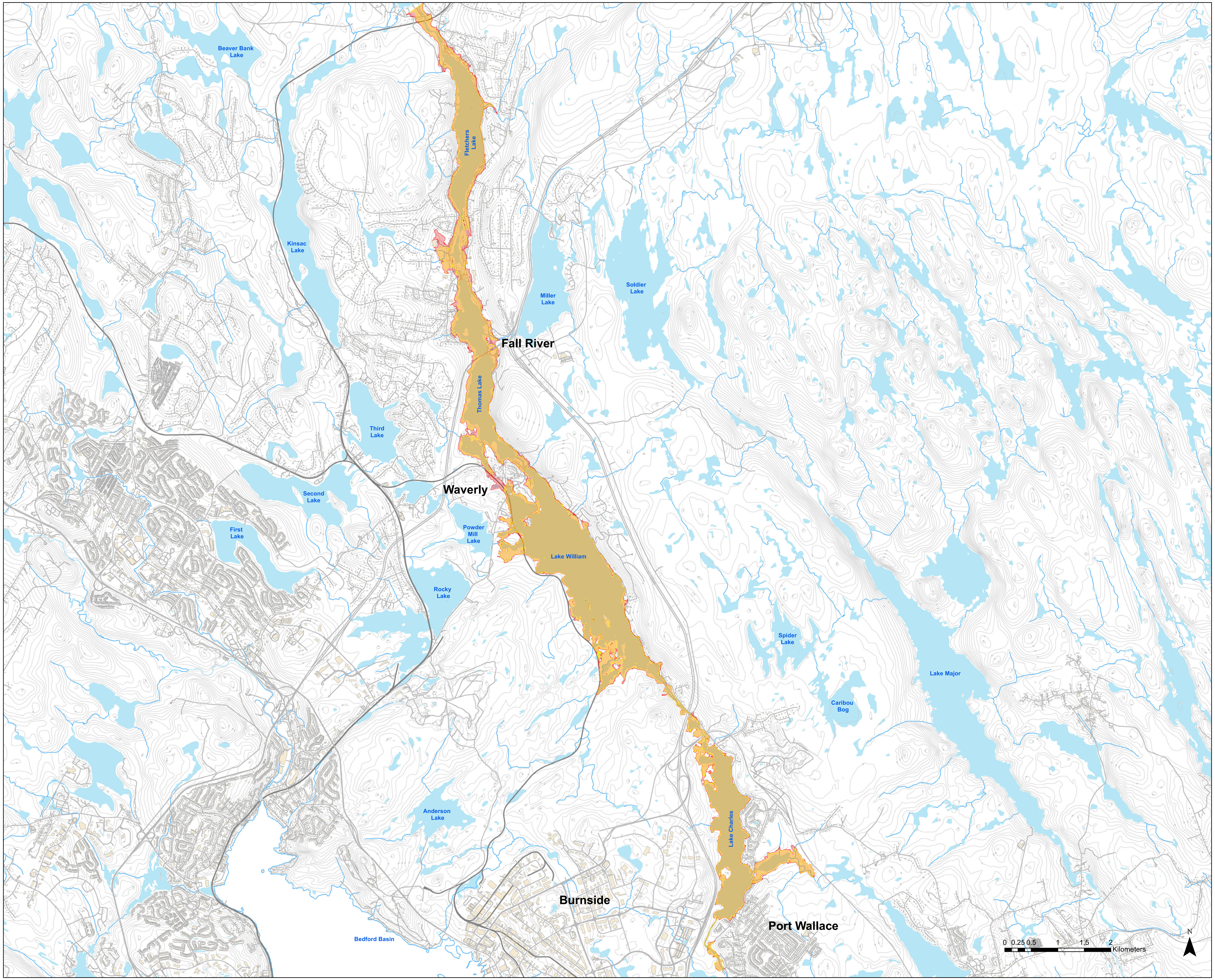

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Shubenacadie Lakes System Floodplain Study

Flood Line Delineation

Map 8

Hydraulic Structure Jam

Legend

- 1 in 100 Year Rainfall Event, Structure Jam Scenario
- 1 in 100 Year Rainfall Event (CC), Structure Jam Scenario
- Buildings
- Roads
- Railroads

SCALE: 1:31,500

Date: May 2020
CBCL Project #: 191107.00

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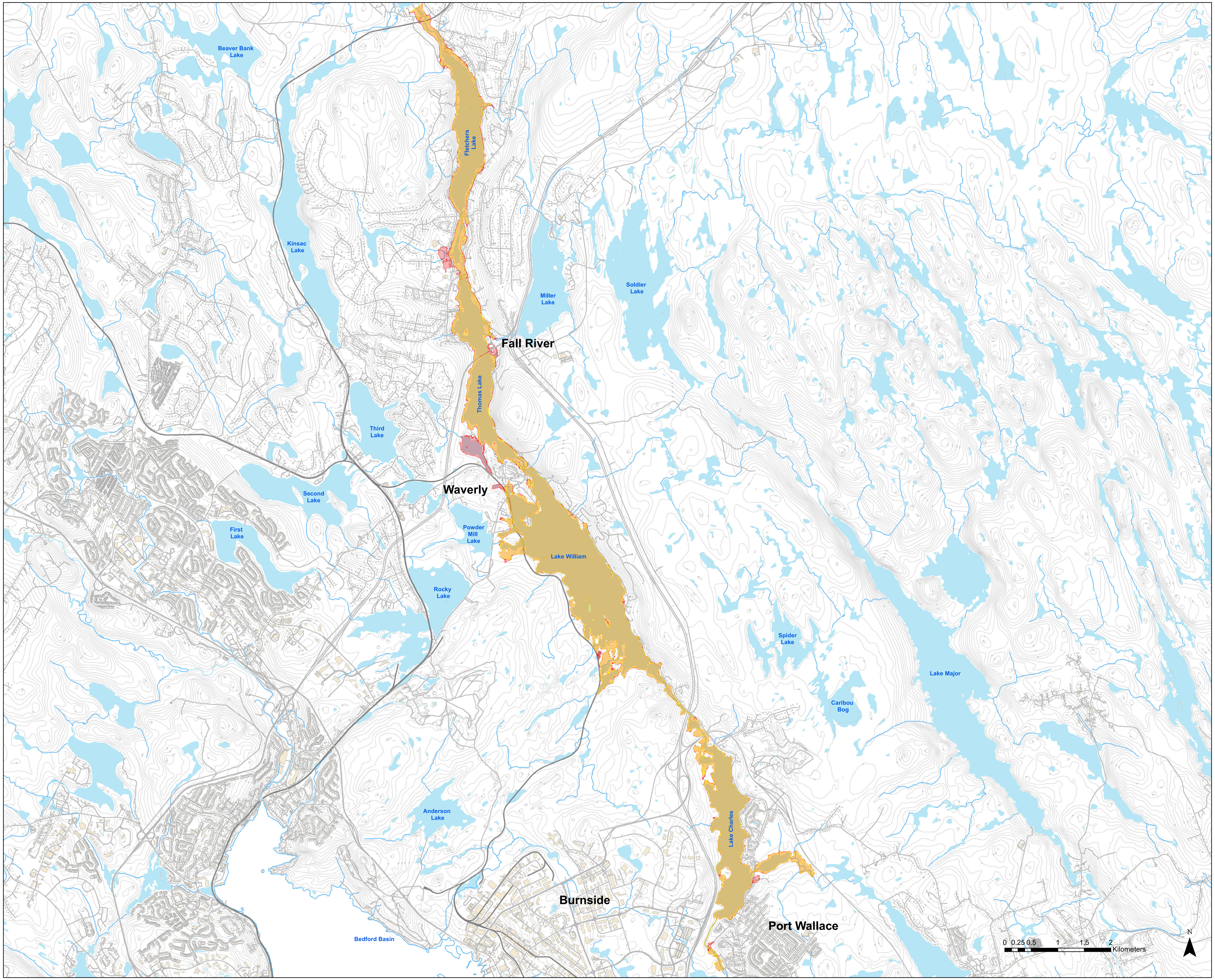

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Shubenacadie Lakes System Floodplain Study

Flood Line Delineation

Map 9

Comparison of Current and Future IDFs, Future Development 1 in 20 Year Rainfall Event

Legend

- 1 in 20 Year Rainfall Event, Future Development
- 1 in 20 Year Rainfall Event (CC), Future Development
- Buildings
- Roads
- Railroads

SCALE: 1:31,500

Date: May 2020
CBCL Project #: 191107.00

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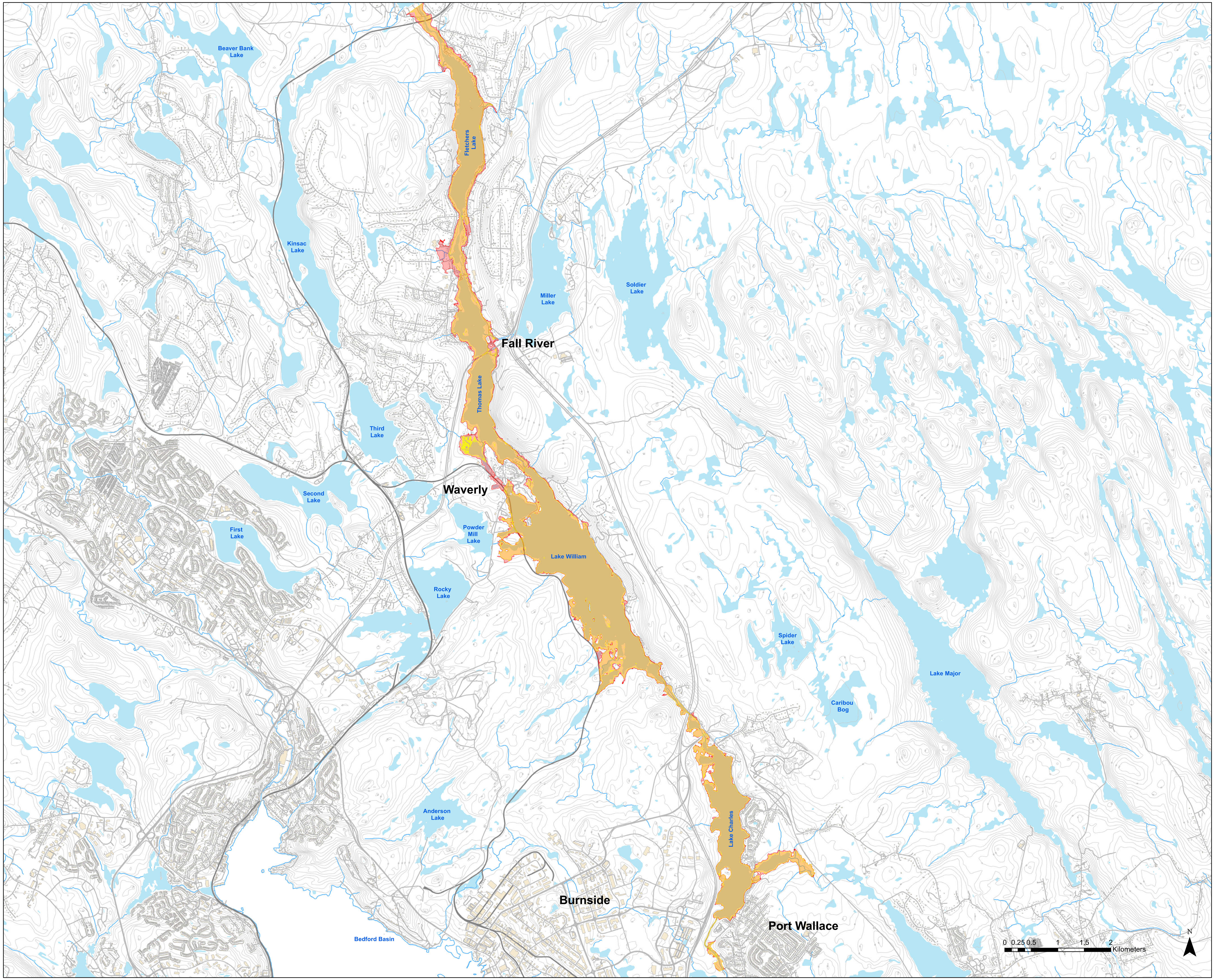

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Halifax Regional Municipality

Shubenacadie Lakes System Floodplain Study

Flood Line Delineation

Map 10

Comparison of Current and Future IDFs, Future Development 1 in 100 Year Rainfall Event

Legend

- 1 in 100 Year Rainfall Event, Future Development
- 1 in 100 Year Rainfall Event (CC), Future Development
- Buildings
- Roads
- Railroads

SCALE: 1:31,500

Date: May 2020
CBCL Project #: 191107.00

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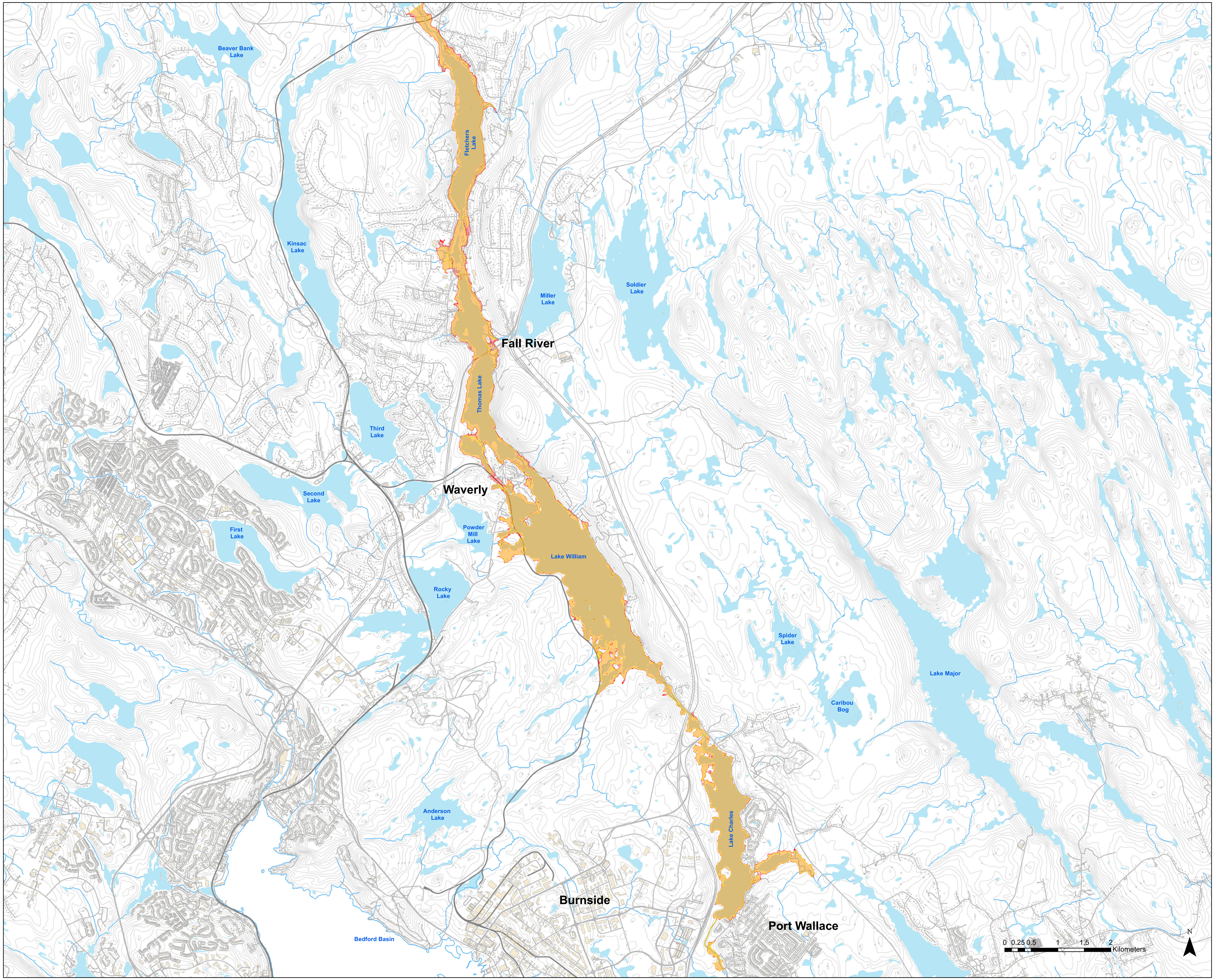

Halifax Regional Municipality

Shubenacadie Lakes System Floodplain Study

Flood Line Delineation

Map 11

Recommended Base Floodway and Flood Fringe

Legend

- Floodway (1 in 20 Year Rainfall Event (CC))
- Floodway Fringe (1 in 100 Year Rainfall Event (CC))
- Buildings
- Roads
- Railroads

SCALE: 1:31,500

Date: May 2020
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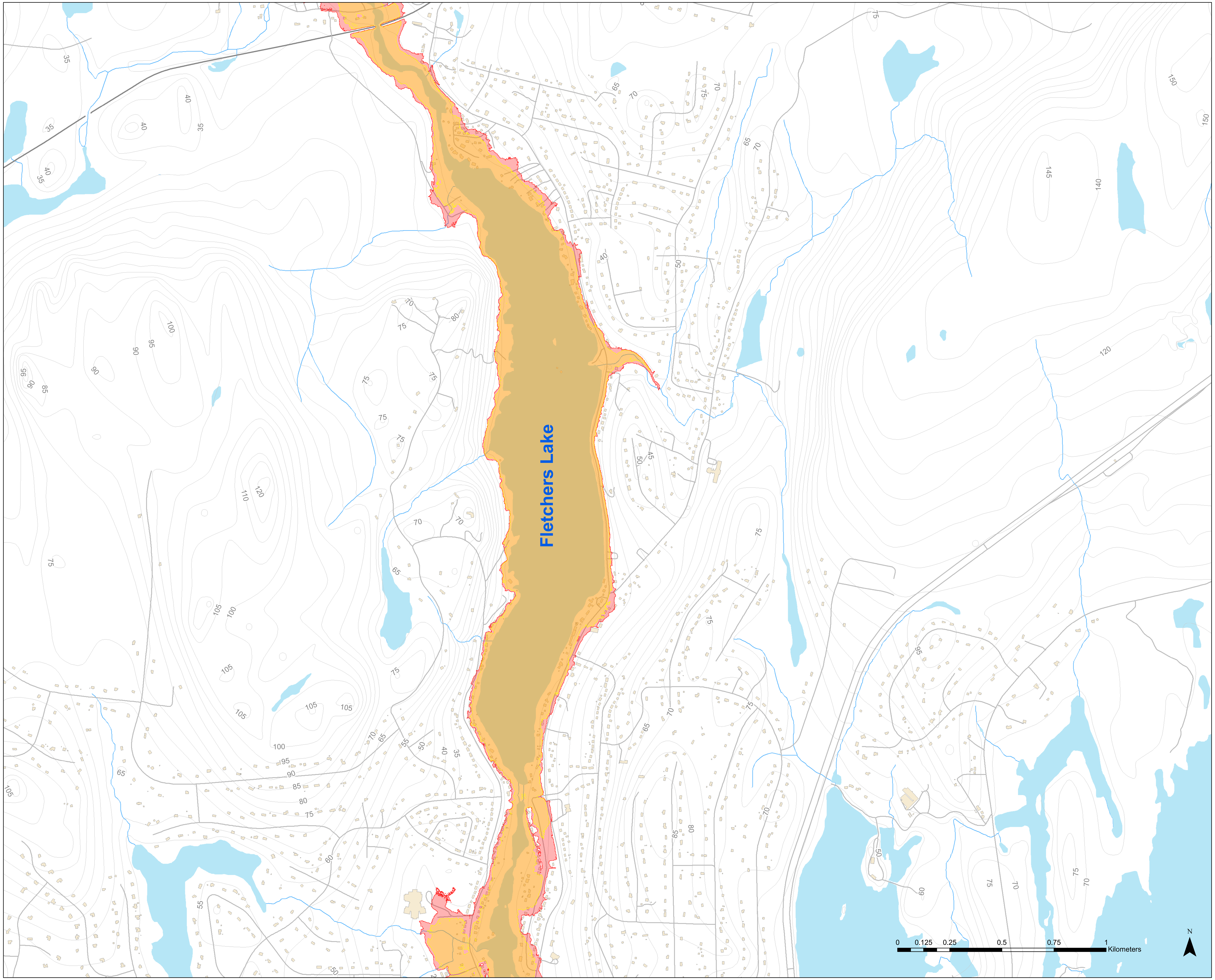

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Shubenacadie Lakes System Floodplain Study

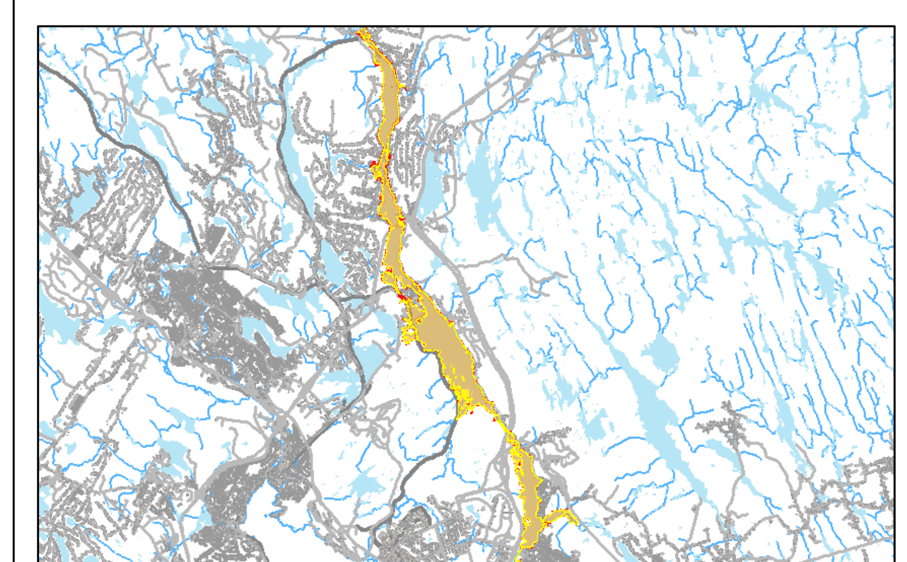
Flood Line Delineation

Map 12

Recommended Base Flood
Fletchers Lake

Legend

- Floodway (1 in 20 Year Rainfall Event (CC))
- Floodway Fringe (1 in 100 Year Rainfall Event (CC))
- Buildings
- Roads
- Railroads



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Date: May 2020
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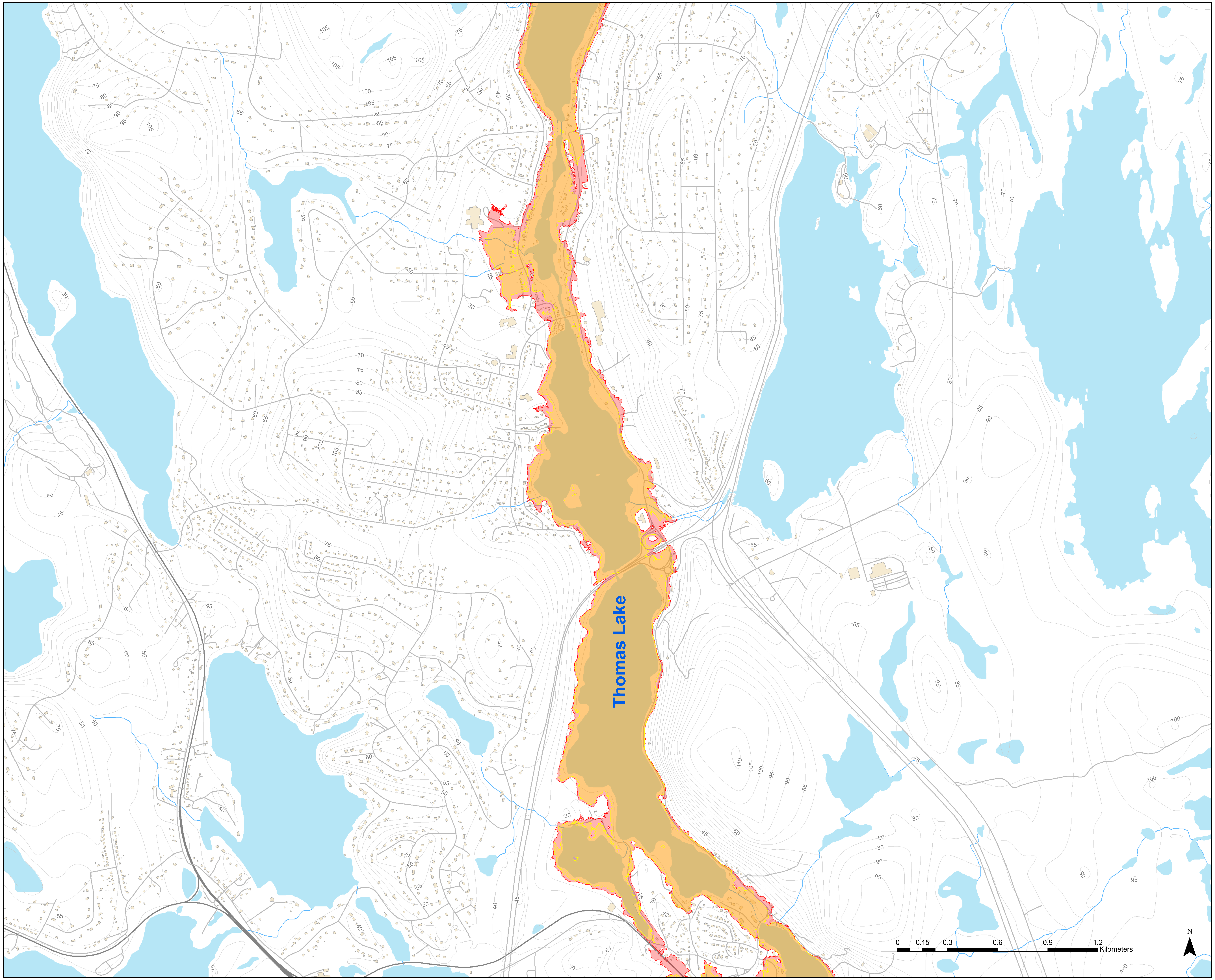

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Shubenacadie Lakes System Floodplain Study

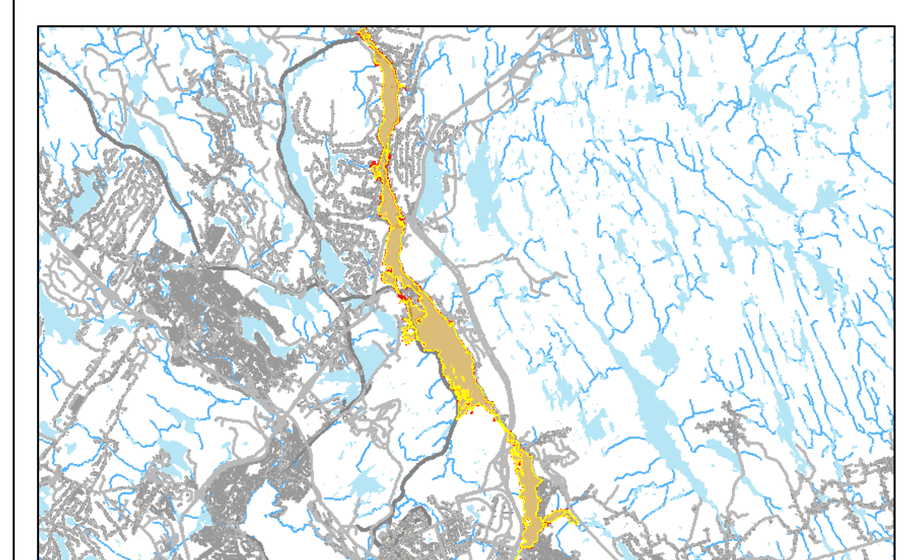
Flood Line Delineation

Map 13

Recommended Base Flood Thomas Lake

Legend

- Floodway (1 in 20 Year Rainfall Event (CC))
- Floodway Fringe (1 in 100 Year Rainfall Event (CC))
- Buildings
- Roads
- Railroads



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Date: May 2020
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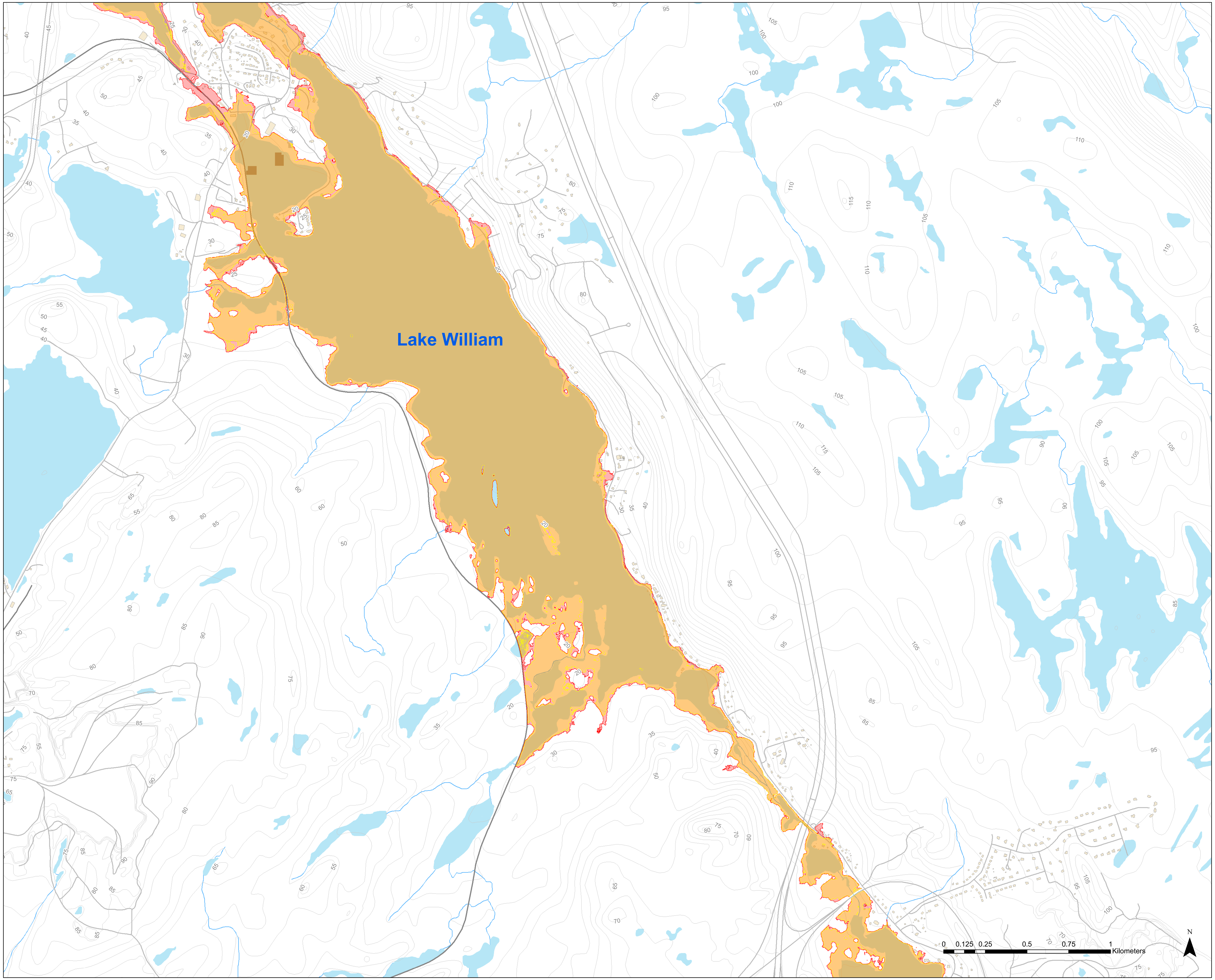

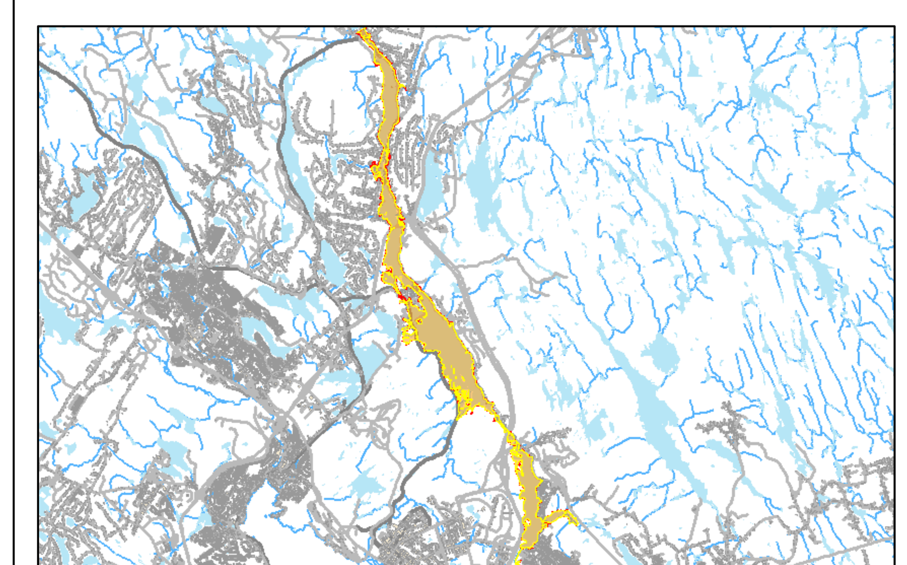

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Halifax Regional Municipality

Shubenacadie Lakes System
Floodplain Study

Flood Line Delineation

Map 14
Recommended Base Flood
Lake William

Legend

- Floodway (1 in 20 Year Rainfall Event (CC))
- Floodway Fringe (1 in 100 Year Rainfall Event (CC))
- Buildings
- Roads
- Railroads

SCALE: 1:10,000

Date: May 2020
CBCL Project #: 191107.00

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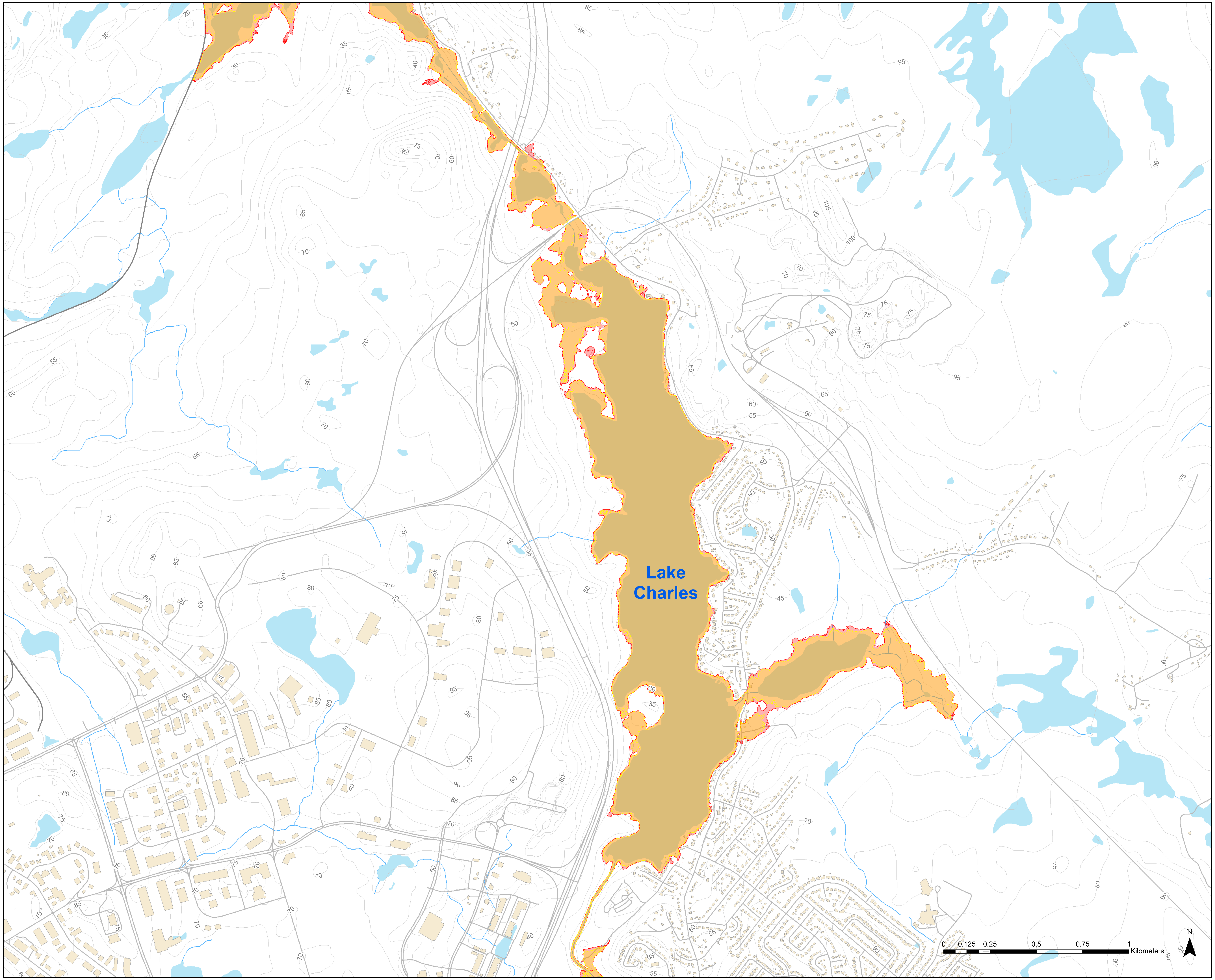

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Halifax Regional Municipality

Shubenacadie Lakes System Floodplain Study

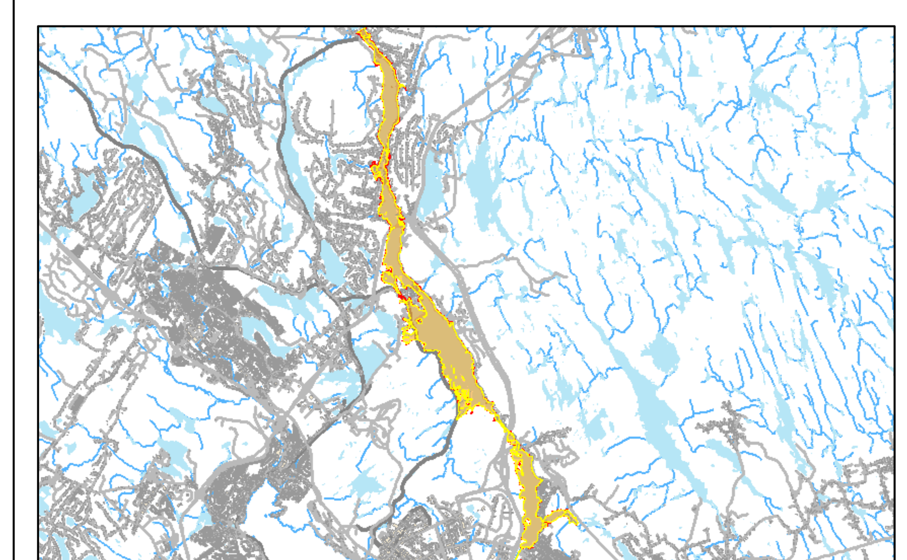
Flood Line Delineation

Map 15

Recommended Base Flood
Lake Charles

Legend

- Floodway (1 in 20 Year Rainfall Event (CC))
- Floodway Fringe (1 in 100 Year Rainfall Event (CC))
- Buildings
- Roads
- Railroads



SCALE: 1:9,000

Date: May 2020
CBCL Project #: 191107.00

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