NSCC-AGRG Technical Report: 2022-23 Minas Basin Modelling

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Executive Summary

The Nova Scotia Community College – Applied Geomatics Research Group (NSCC-AGRG) was sub-contracted by Dillon Consulting Ltd. to develop a hydrodynamic model of the Minas Basin, Nova Scotia. Models were developed with DHI MIKE 2D HD modelling software using river discharge and coastal water levels elevated by potential coincident storm surges for return periods of 1 in 20 and 1 in 100-years, along with the effects of relative sea level rise and Antarctic ice sheet melt considering climate change for present levels, 2050, and 2100. A digital elevation model (DEM) of the Minas Basin study area was built using topographic lidar data from the Province of Nova Scotia (GeoNova) and Canadian Hydrographic Service (CHS) NONNA bathymetric data. NSCC-AGRG collected elevation data with a ZenMuse L1 lidar unit mounted on a DJI Matrice 300 RTK drone over the Habitant and Gaspereau rivers on August 16th and October 14th, 2022, to fill in data gaps in the provincial lidar. For model validation purposes, NSCC-AGRG deployed 2 pressure sensors along the Gaspereau river on September 16th and October 5th, 2022. Flood extents and depth maps were generated for the coastal and river components of the Minas Basin to reflect recommended scenarios presented in the recent provincial guidelines.

Table of Contents

Executive Summary ii

Table of Contents iii

Table of Figures iv

1 Introduction 1

2 Methods 2

  2.1 Study Area 2

  2.2 Data Collection and Processing 2

    2.2.1 Topography and Deep-Water Bathymetry 3

    2.2.2 Lidar Collection 3

    2.2.3 Water Level Data 3

    2.2.4 Structures 5

    2.2.5 Met-Ocean Data 5

    2.2.6 Total Water Level 6

    2.2.7 Hydrodynamic Modelling 7

3 Results 14

  3.1 Hydrodynamic Modelling 14

4 Discussion 15

5 References 17

Table of Figures

Figure 1 displays the domain of the hydrodynamic model, including the pressure sensor deployment locations, freshwater discharge, and dikes. 2

Figure 2 displays the DEMs generated for the Gaspereau River (left) and Habitant River (right) from L1 lidar surveys. 3

Figure 3 displays the pressure sensor mounting apparatus (left) and the Gaspereau River at low tide (right). 4

Figure 4 displays the water levels observed by the pressure sensor deployed upstream in the Gaspereau River by AGRG. 4

Figure 5 displays the water levels observed by the pressure sensor deployed downstream in the Gaspereau River by AGRG. Erroneous readings detected between November 21st-26th, 2022 were not used in the model calibration or validation. 5

Figure 6 shows the guidelines for computing total sea level (Jamieson et al., 2019). 6

Figure 7 shows the mesh model domain of varying mesh densities showing location of Canard and Habitant rivers (A), Cornwallis (B), Gaspereau (C), moderate density area leading into the rivers (D), and minimum density and ocean model boundary (E). Insets (below) show the resulting mesh with elevations interpolated from the 15 m DEM illustrating the density of the mesh; focusing on the Canard (right) and mouth of the Gaspereau (left). 8

Figure 8 showing the lidar DEM of the Gaspereau before channelization (A) and after (B). The procedure uses coarse cross sections to extract the water surface by elevation (C). The river channel was select selected (D), and a model of river width per cross section was generated (E) such that a channel elevation could be computed. Euclidean distance to water grid now shown (F). 9

Figure 9 shows all coastal boundary water level elevations used to drive each of the sea level and storm surge scenarios. Higher High Water Large Tide (HHWLT) was simulated alone and with a 1 in 20-year and 1 in 100-year storm surge. Both Storm surge scenarios were also simulated with projected sea level rise at HHWLT in 2050 and 2100. 10

Figure 10 shows the freshwater discharge curve modelled and provided by Dillon Consulting Ltd. to represent a 1 in 5-year high discharge event. Note that the Canard and Habitant freshwater discharge were not used in the modelled scenarios. 11

Figure 11 shows results from the model validation comparing the predicted WebTide (black), the observed water levels at the AGRG Gaspereau tide gauge (blue) and the model output at the location of the gauge with and without river discharge (red and red dashed). The residual between the observed water level (blue) and the model out with discharge (solid red) is also indicated (dashed) as well as the linear trend of the residual (dotted). 13

Figure 12 shows the maximum inundation extents and surface elevations for the HHWLT modelled scenarios. 14

Figure 13 shows the maximum inundation extents and surface elevations for the 2050 and 2100 modelled scenarios. 15

Figure 14 displays the maximum surface elevation output of the HHWLT (constant discharge) simulation from the HD model overlayed on the swamp polygon layer (NSTDB). 16

List of Tables

Table 1 displays the bathymetric and topographic elevation data used to develop the flex mesh. 3

Table 2 lists the total sea level for the Minas Basin under various scenarios. 7

Table 3 indicates the Environment Canada river gauge information used to estimate reasonable freshwater inputs based on observed discharges in the Cornwallis and Gaspereau rivers. 11

Table 4 shows the calculated estimated discharge rates used for the model validation and base HHWLT simulation and their location the discharge was input into the hydrodynamic model. Note that freshwater input was not included for the Canard or Habitant.. 11

Table 5 lists the parameters used for the MIKE 21 2D Flow Model FM hydrodynamic model. 12

1 Introduction

Approximately 10% of the world's population live only 10 m above the current sea level, including many of those that live within the Gaspereau watershed who face the threat of flooding. Observations of the global mean sea level (GMSL) show it is rising and the rate has been accelerating since 2000 (Golledge, 2020). The increased rate of sea level rise has largely been attributed to increased ocean warming (Cheng et al., 2019), which can be linked to global warming.

The Nova Scotia Community College – Applied Geomatics Group (NSCC-AGRG), in collaboration with Dillon Consulting Ltd., was tasked with developing a coastal and estuarine flood model of the Minas Basin. The estuarine component required coupling a coastal circulation model with a fluvial model to capture the interaction of the ocean and fluvial hydrodynamics. For this purpose, NSCC-AGRG used the DHI suite of tools including the MIKE 21 2D Flow Model FM (Flex Mesh) hydrodynamic model. Fresh water inputs were provided by engineers from Dillon who conducted the upstream fluvial floodplain analysis utilizing the PCSWMM modelling software.

In this report, hydrodynamics in coastal and estuarine systems were simulated by incorporating the effects of potential storm surges for return periods of 1 in 20 and 1 in 100-year, in addition to Higher High Water Large Tide (HHWLT) along with relative sea level rise resulting from climate change and subsidence. In addition, an extra 65 cm sea level rise due to the projected collapse of the West Antarctic ice sheet collapse was also included (James et al., 2014). The resultant flood extent maps were successfully generated for both present and future conditions, utilizing the described storm surge and sea level rise scenarios.

2 Methods

2.1 Study Area

The coastal boundary of the study area spans from Medford Beach to Split Rock. The riverine component includes the Canard, Habitant, Cornwallis, and Gaspereau rivers up to the approximate location of their respective upstream constriction points (Figure 1). The extents for the study area were defined to accurately simulate the deep-water tidal movement and velocities coming from the open ocean into the coast and estuary.

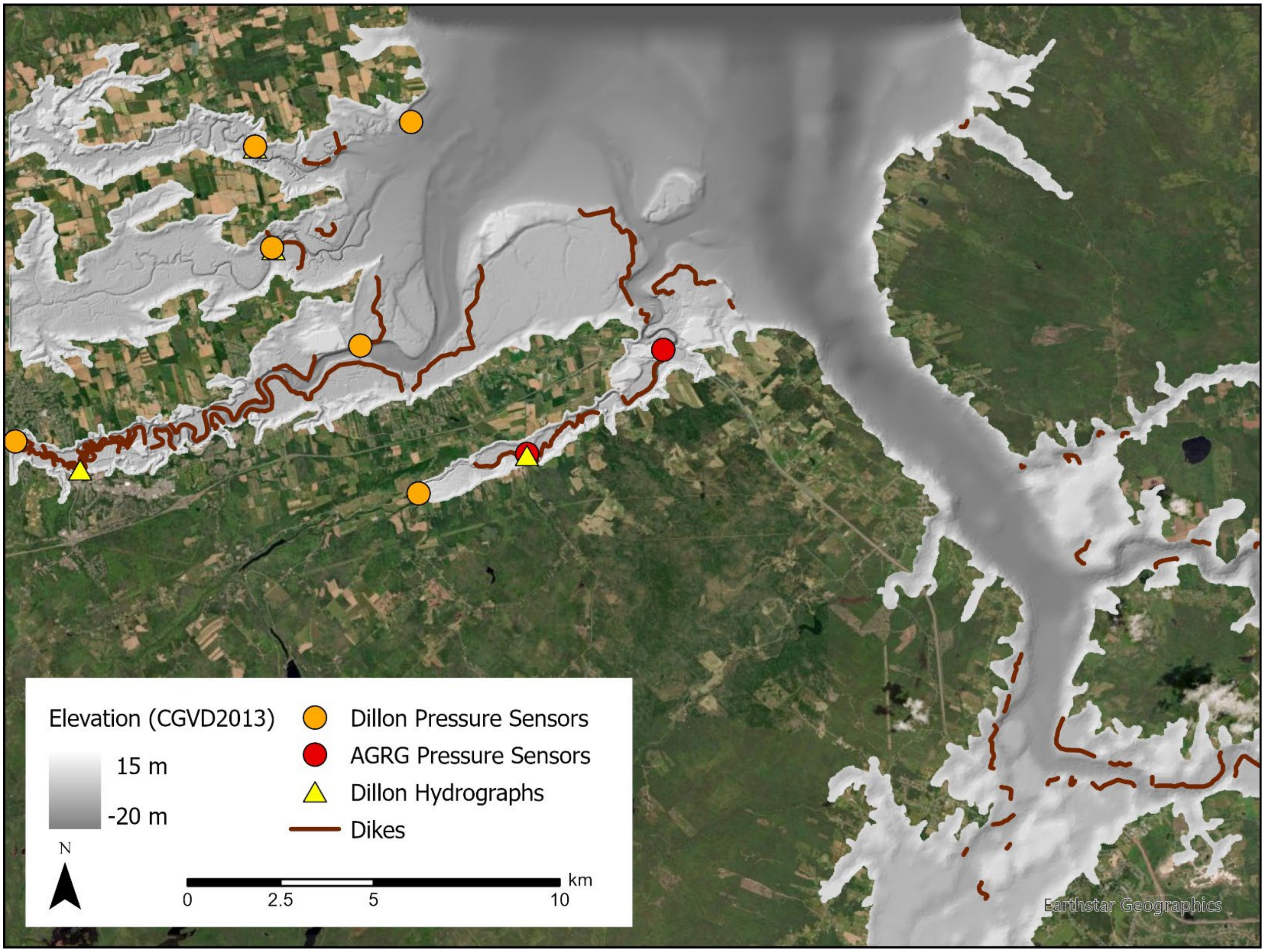


Figure 1 displays the domain of the hydrodynamic model, including the pressure sensor deployment locations, freshwater discharge, and dikes.

2.2 Data Collection and Processing

Elevation data were compiled from GeoNova, CHS, and NSCC-AGRG to accurately represent the near-shore bathymetric and coastal elevations (Table 1). Pressure sensors were deployed by Dillon and NSCC-AGRG for the purpose of model validation and dike locations were obtained from the Nova Scotia Topographic Database (NSTDB).

Table 1 displays the bathymetric and topographic elevation data used to develop the flex mesh.

Provider	Data Type	Sensor	Native Resolution	Year Collected
Province of Nova Scotia (GeoNova)	Topographic lidar	REIGL VQ1560i and Q780	1 m	2019-2020
NSCC-AGRG	Topographic lidar	ZenMuse L1	50 cm	2022
Canadian Hydrographic Service (CHS)	Bathymetric sonar	Single and multibeam sonar	10 m	Last updated 2022

2.2.1 Topography and Deep-Water Bathymetry

A terrestrial DEM with a resolution of 1 m was obtained from GeoNova used to represent topographical elevations. Bathymetry data were obtained from CHS in the coastal areas to represent deep water elevations.

2.2.2 Lidar Collection

NSCC-AGRG collected supplementary lidar of the Habitant and Gaspereau rivers to fill in data gaps. A DJI Matrice 300 RTK drone equipped with a ZenMuse L1 lidar unit was used to conduct three surveys in the fall of 2022. The Gaspereau River was first surveyed on September 15th and 16th upriver near the first pressure deployment, then revisited on October 14th to collect data downstream near the second deployed pressure sensor. On this same day in October, a lidar survey was conducted in the Habitant River to fill in additional data gaps. These data were processed using DJI's proprietary Terra software, then the point cloud was exported for further processing, tiled, and gridded at 50 cm using AGRG's Lidar Data Frame scripts processing tools built on NumPy, LasPy, and other assorted Python libraries.

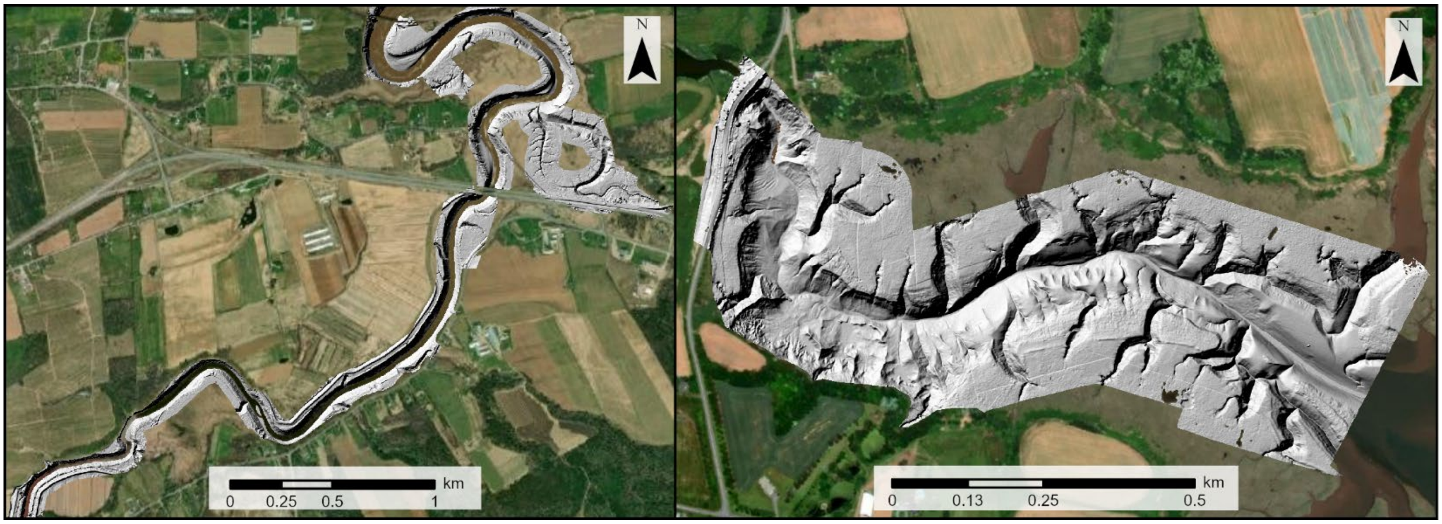


Figure 2 displays the DEMs generated for the Gaspereau River (left) and Habitant River (right) from L1 lidar surveys.

2.2.3 Water Level Data

HOBO water level loggers were deployed in two locations in the Gaspereau River on September 15th and October 5th, 2022 (Figure 1). These loggers were programmed to collect measurements at 5-minute intervals. Water levels were derived by calculating the difference between the absolute pressure measured by the sensor and the atmospheric pressure documented by the weather station in Kentville, NS. Water level measurements were converted to CGVD2013 by measuring the sensor elevation using a survey-grade GNSS. Water level data derived from the pressure sensors was used for validating the calibration model. The readings collected during the deployment period are presented in Figure 4 and Figure 5.

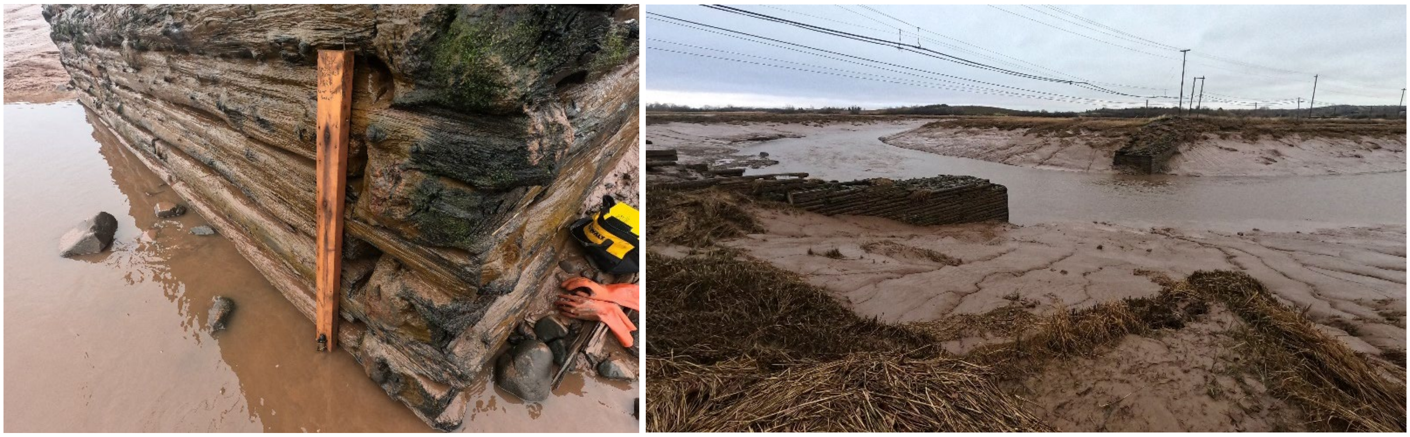


Figure 3 displays the pressure sensor mounting apparatus (left) and the Gaspereau River at low tide (right).

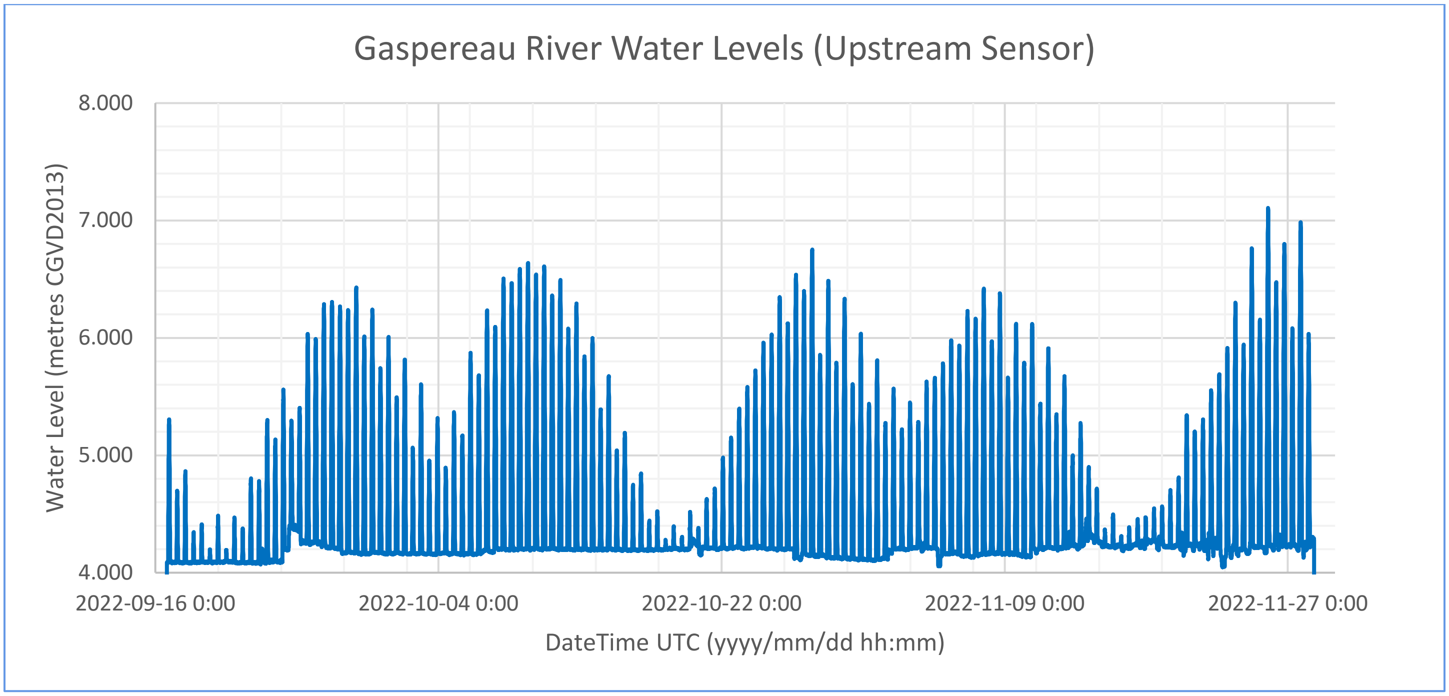


Figure 4 displays the water levels observed by the pressure sensor deployed upstream in the Gaspereau River by AGRG.

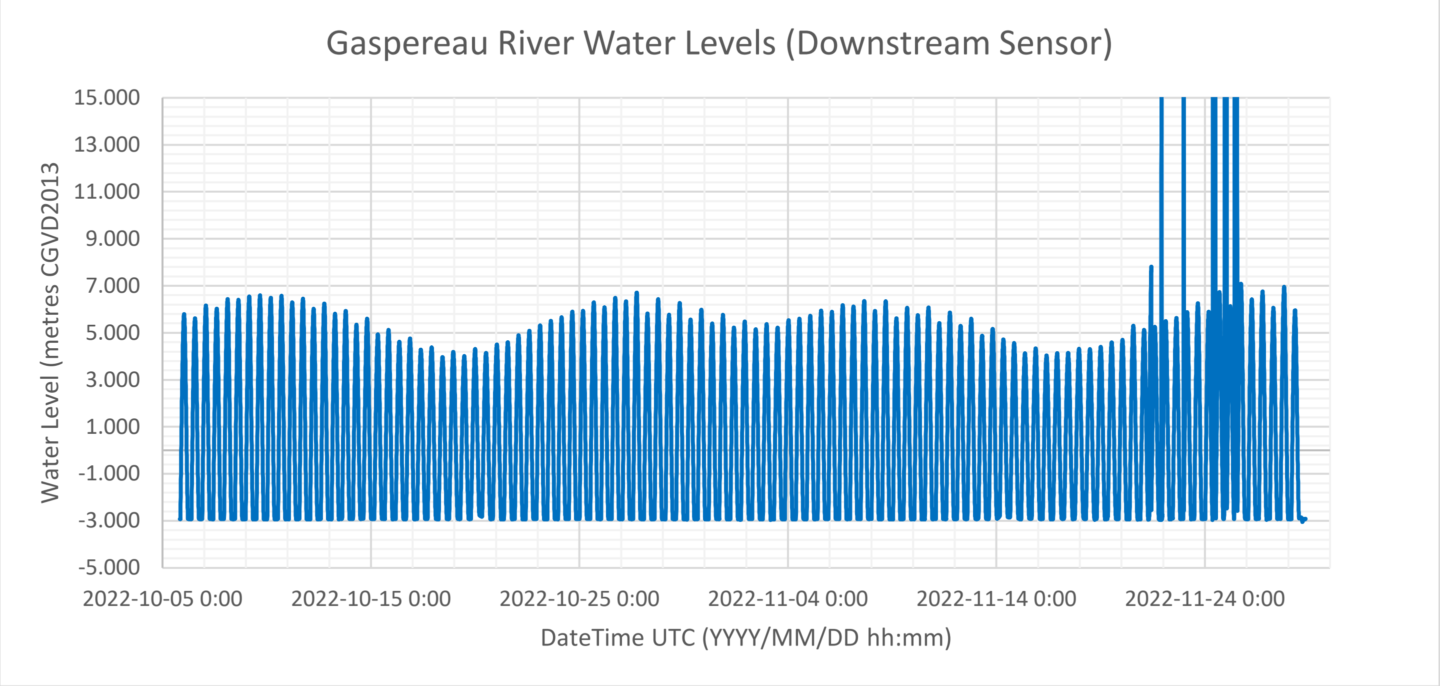


Figure 5 displays the water levels observed by the pressure sensor deployed downstream in the Gaspereau River by AGRG. Erroneous readings detected between November 21st-26th, 2022 were not used in the model calibration or validation.

2.2.4 Structures

Dyke locations were obtained from the NSTDB. These line features were converted to points and attributed with crest level values extracted from the DEM (section 2.2.7.2).

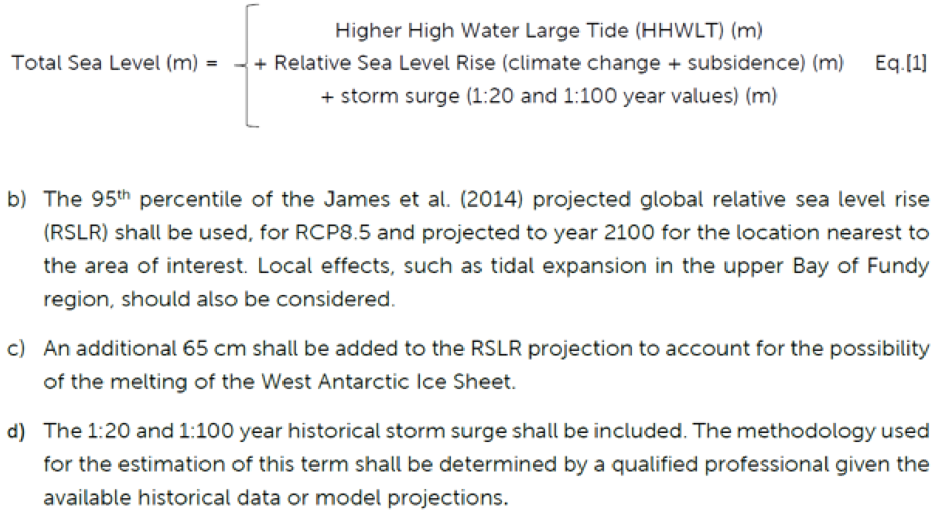
2.2.5 Met-Ocean Data

Dillon Consulting Ltd. produced a 5-year return period hydrograph for the rivers within the Gaspereau watershed and required a typical tidal boundary condition to be integrated with their discharge. NSCC-AGRG examined two years of tidal predictions with the Department of Fisheries and Oceans (DFO) WebTide tool along the coastal boundary of the Minas Basin. A period of high spring tides (April 8th-12th, 2020) was selected and used to drive the present-day model and provide Dillon with a tidal boundary for their river discharge.

For the main coastal modelling component, WebTide was used to generate a time-series of water surface elevation for a week-long period (October 18th-25th, 2022) that coincided with the deployment of the water level sensors. The tidal boundary obtained from WebTide was used to validate the model against the pressure sensor readings. To simulate HHWLT, obtained from HyVSEPS, the tidal signal was scaled such that high tide equalled HHWLT. Additional total water level components such as storm surge, Relative Sea Level Rise (RSLR) and ice sheet collapse were incorporated into the tidal signal in successive model iterations. Wind, atmospheric pressure, and waves were not used as model boundary conditions.

2.2.6 Total Water Level

The Nova Scotia Department of Municipal Affairs presented guidelines to be followed for flood line mapping cases (Jamieson et al., 2019). These guidelines state that the total sea level rise to be used in riverine and coastal flood mapping is to be computed by Equation 1 (Figure 6).



$$\text{Total Sea Level (m)} = \left\{ \begin{array}{c} \text{Higher High Water Large Tide (HHWLT) (m)} \\ + \text{ Relative Sea Level Rise (climate change + subsidence) (m)} \\ + \text{ storm surge (1:20 and 1:100 year values) (m)} \end{array} \right. \quad \text{Eq.[1]}$$

b) The 95th percentile of the James et al. (2014) projected global relative sea level rise (RSLR) shall be used, for RCP8.5 and projected to year 2100 for the location nearest to the area of interest. Local effects, such as tidal expansion in the upper Bay of Fundy region, should also be considered.

c) An additional 65 cm shall be added to the RSLR projection to account for the possibility of the melting of the West Antarctic Ice Sheet.

d) The 1:20 and 1:100 year historical storm surge shall be included. The methodology used for the estimation of this term shall be determined by a qualified professional given the available historical data or model projections.

Figure 6 shows the guidelines for computing total sea level (Jamieson et al., 2019).

An HHWLT value for the Minas Basin was extracted using HyVSEPS, and the resulting conversion to CGVD2013 yielded a value of 6.85 m. The projected relative sea level change at a coastal site depends on local vertical motion of the ground, spatial variation in redistribution of glacial meltwater in the global oceans, and regional changes to sea level due to dynamic oceanographic effects in addition to projected global sea level change. As recommended by Jamieson et al (2019), the James et al (2021) 95% RSL upper limit of RSL for 2050 and 2100 was used. To determine the storm surge return periods, we used Richards and Daigle (2011) similar to the van Proosdij et al. (2018) report where the 1 in 20-year return period is estimated to be 0.96 m and the 1 in 100-year return period is estimated to be 1.13 m. In addition to HHWLT, storm surge return periods (1 in 20 and 1 in 100-year) and RSL, we also included a 0.65 m contribution from the Antarctic ice sheet collapse for 2100 and prorated this value to 0.33 m for 2050. See Table 2 for the water levels used for the coastal flood risk scenarios.

Table 2 lists the total sea level for the Minas Basin under various scenarios.

Scenario	HHWLT (m CGVD2013)	RSL (m)	1 in 20-year Return (m)	1 in 100-year Return (m)	Antarctic Ice Collapse (m)	Total Sea Level (m CGVD2013)	Freshwater Input
Present Day	6.85	0.00	0.00	0.00	0.00	6.85	1:5
Present Day – 1:20 Year	6.85	0.00	0.96	0.00	0.00	7.81	1:5
Present Day – 1:100 Year	6.85	0.00	0.00	1.13	0.00	7.98	1:5
2050 – 1:20 Year	6.85	0.47	0.96	0.00	0.33	8.61	1:5
2050 – 1:100 Year	6.85	0.47	0.00	1.13	0.33	7.65	1:5
2100 – 1:20 Year	6.85	1.15	0.96	0.00	0.65	9.61	1:5
2100 – 1:100 Year	6.85	1.15	0.00	1.13	0.65	9.78	1:5

2.2.7 Hydrodynamic Modelling

NSCC-AGRG used the DHI suite of tools including the MIKE 21 2D Flow Model FM (Flex Mesh) hydrodynamic model. Fresh water inputs were provided by engineers from Dillon who conducted the upstream fluvial floodplain analysis using PCSWMM.

2.2.7.1 Flex Mesh Generation

The hydrodynamic model's flex mesh extent encompassed the Canard, Habitant, Cornwallis, and Gaspereau rivers up to their respective upstream constriction points. A variety of sources and resolutions of topographic and bathymetric data were compiled to generate a high-quality grid to complete the flex mesh surface model for the Minas Basin domain. The model domain was generated using GeoNova lidar datasets, NSCC-AGRG lidar datasets and CHS NONNA bathymetry data. The datasets were converted from raster images into las point clouds, merged into a las dataset and then a surface was interpolated using the LAS Dataset to Raster tool in ArcGIS Pro. Additional manual edits were necessary in areas where the datasets showed significant offsets. The domain was then inspected, and the water surface was clipped out to ensure that more accurate channel bathymetries values could be interpolated. The resulting raster was resampled to 15 m.

The 15 m raster was imported into the Mike DHI Flex Mesh generator toolkit and was used to interpolate elevation values to a mesh of progressively finer resolution. This was done to reduce processing time of the hydrodynamic model and ensure maximum stability while allowing increased spatial precision in areas of interest by setting regions of mesh node density by maximum area. Highest mesh density was allotted to the Canard, Habitant, Cornwallis, and Gaspereau River channels (with a maximum node spacing of 40 m^2) whereas the northern coastal boundary of the model in the mouth of the Minas Basin as well as the Windsor area were set to a coarse node spacing of a maximum of 10,000 m^2. Additional zones were included to transition node density from low to high from 10,000, 1000, 560, 120, and 40 m^2 progressively such that moderate density was achieved across the wider area of interest and areas of high flow could be modelled more accurately (Figure 7).

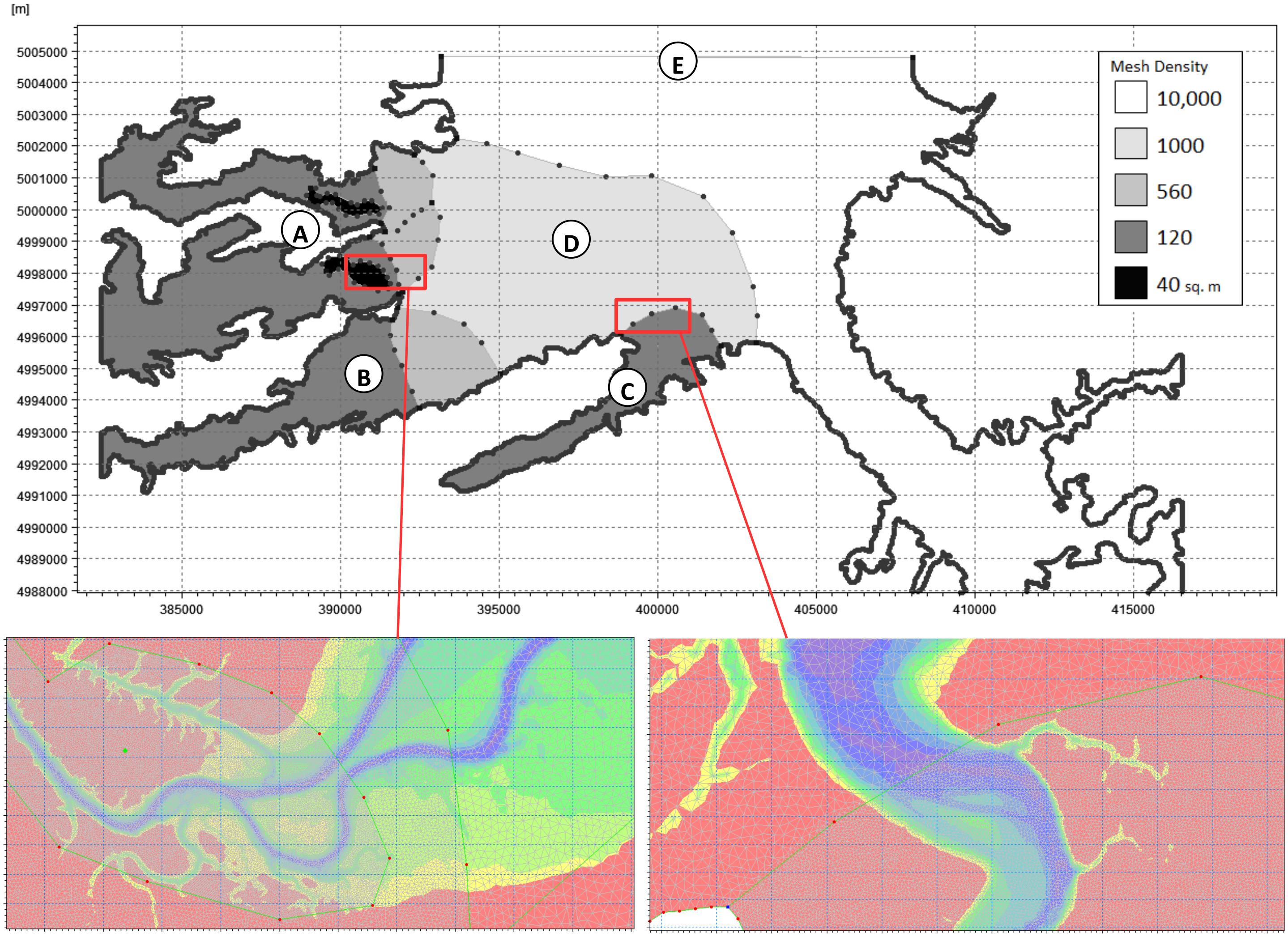


Figure 7 shows the mesh model domain of varying mesh densities showing location of Canard and Habitant rivers (A), Cornwallis (B), Gaspereau (C), moderate density area leading into the rivers (D), and minimum density and ocean model boundary (E). Insets (below) show the resulting mesh with elevations interpolated from the 15 m DEM illustrating the density of the mesh; focusing on the Canard (right) and mouth of the Gaspereau (left).

2.2.7.2 Dike Structures

Dike structures were accounted for in the hydrodynamic model as separate line features in the Mike DHI model setup. This ensured that dike elevations and extents would be properly maintained and represented in the model despite the various spatial resolutions of the flex mesh and any associated interpolations of the lidar elevation data. These dike lines elevations were generated every 5 meters directly from the lidar elevation based on a local 15 meter maximum. Special care was taken to extend all dike lines manually if required by visual inspection and such that no extensive dike overtopping occurred in the results of either the validation period or any present-day high tide hydrodynamic simulation outputs. As such, a total 73 such individual dike structures were included in the hydrodynamic model simulations.

2.2.7.3 River Channel Estimation

In most cases, the lidar data used for the mesh generation was collected at low tide and low discharge conditions. In some instances, however, isolated interpolation artefacts were identified and removed by directly modifying the elevation model.

In the upper Gaspereau River, the channel was obscured by water during collection of the lidar. The following workflow was executed to remove the water surface from the lidar data and enforce an approximate channel for the Gaspereau River. Coarse crosslines of the river were made, and the minimum elevations were extracted using the surface information tool. The lines were then interpolated, and the DEM was differenced from the interpolation to identify water. A threshold of approximately 0.5 m was set, and the polygon of the main river water surface was selected using region group. The Euclidean distance between the riverbanks was calculated, and the result was clipped to the inside of the river. The maximum Euclidean distance to cross-sections was extracted as the river width. A raster calculation was performed, subtracting the water surface from the distance to cross-sections multiplied by a factor of 4 – such that the channelized elevation would match good bathymetric data downstream (eq. 1). Finally, the resulting mosaic was blended back to the DEM (Figure 8). This process was essential for proper hydrodynamic modelling of the Gaspereau River.

$$[eq. 1] \qquad ChannelElevation = \ WaterElevation \ - (BankDistance/ChannelWidth) * 4.0$$

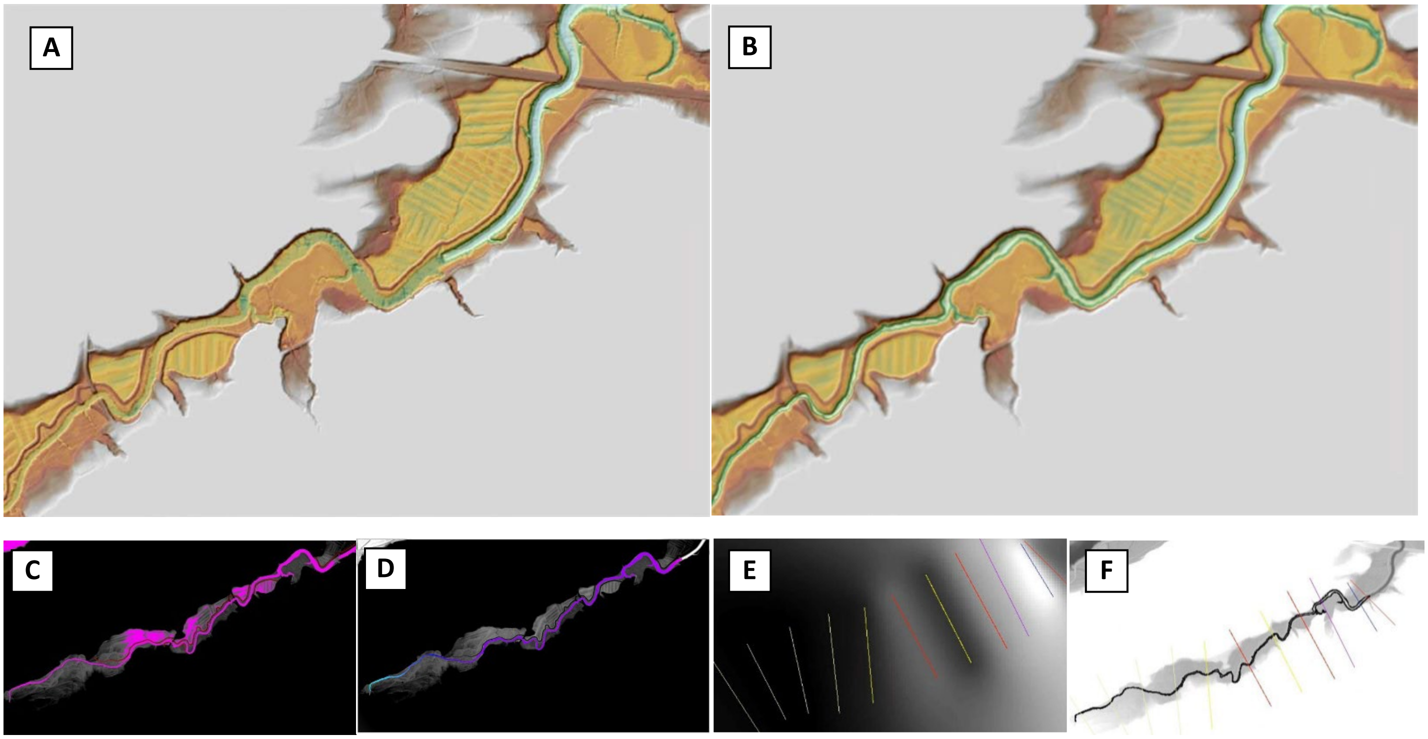


Figure 8 showing the lidar DEM of the Gaspereau before channelization (A) and after (B). The procedure uses coarse cross sections to extract the water surface by elevation (C). The river channel was select selected (D), and a model of river width per cross section was generated (E) such that a channel elevation could be computed. Euclidean distance to water grid now shown (F).

2.2.7.4 Boundary Conditions

Tidal predictions from a spring tide period (April 8th-12th, 2020) obtained from WebTide were scaled such that high tide equated to HHWLT as defined by HyVSEPS. The coastal and estuarine components were modelled with the river discharge and coastal water level elevated by potential coincident storm surge for return periods of 1 in 20 and 1 in 100-year added to Higher High Water Large Tide (HHWLT) along with relative sea level rise (climate change + subsidence) and an additional 65 cm sea level rise caused by the projected collapse of the West Antarctic ice sheet (James et al, 2014). These storm surge and sea level conditions form the basis for all the model simulations and are displayed in Figure 9. Wind and atmospheric pressure were not considered as boundary conditions in the model.

Flood depth maps were generated for present and future conditions using the described storm surges and sea level rise scenarios.

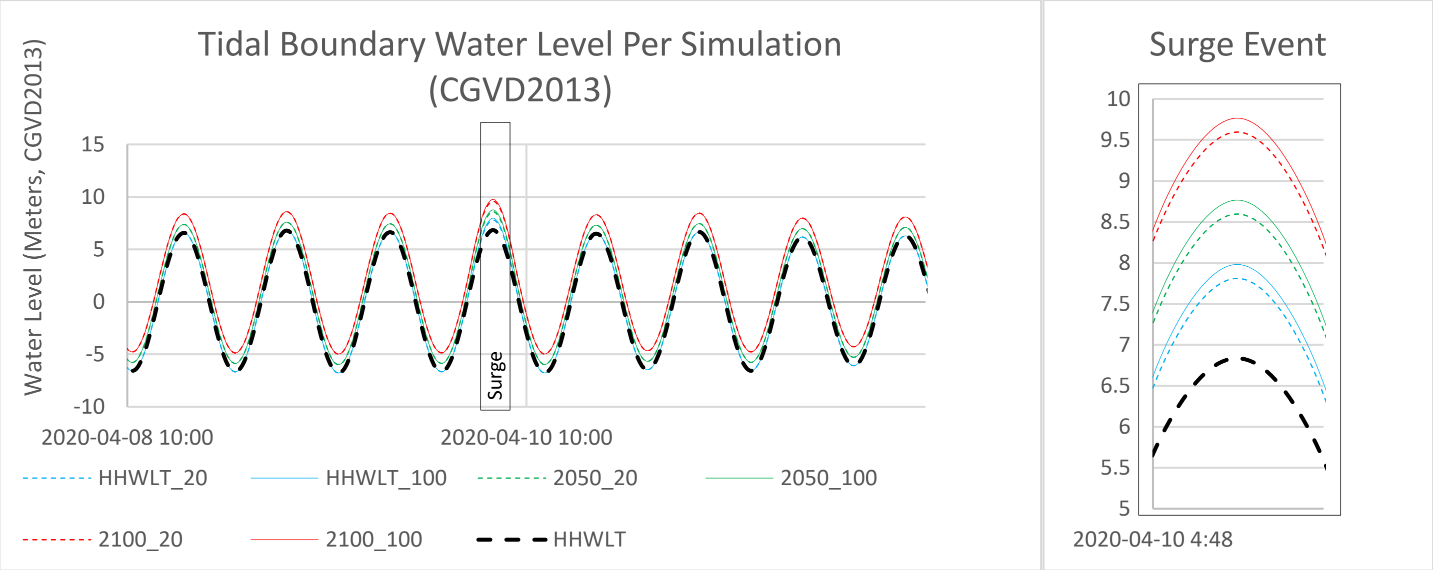


Figure 9 shows all coastal boundary water level elevations used to drive each of the sea level and storm surge scenarios. Higher High Water Large Tide (HHWLT) was simulated alone and with a 1 in 20-year and 1 in 100-year storm surge. Both Storm surge scenarios were also simulated with projected sea level rise at HHWLT in 2050 and 2100.

2.2.7.5 Freshwater Boundaries

Fresh water inputs were provided by Dillon Consulting Ltd. to simulate a 1 in 5-year discharge event for each of the 4 rivers (Figure 10). These inputs were only introduced into the model as required for the Cornwallis and Gaspereau rivers whereas the Canard and Habitant rivers contain diked control structures where upstream the freshwater interaction would be handled by Dillon directly. The locations used to input these discharge curves for the given scenarios is indicated in Table 4.

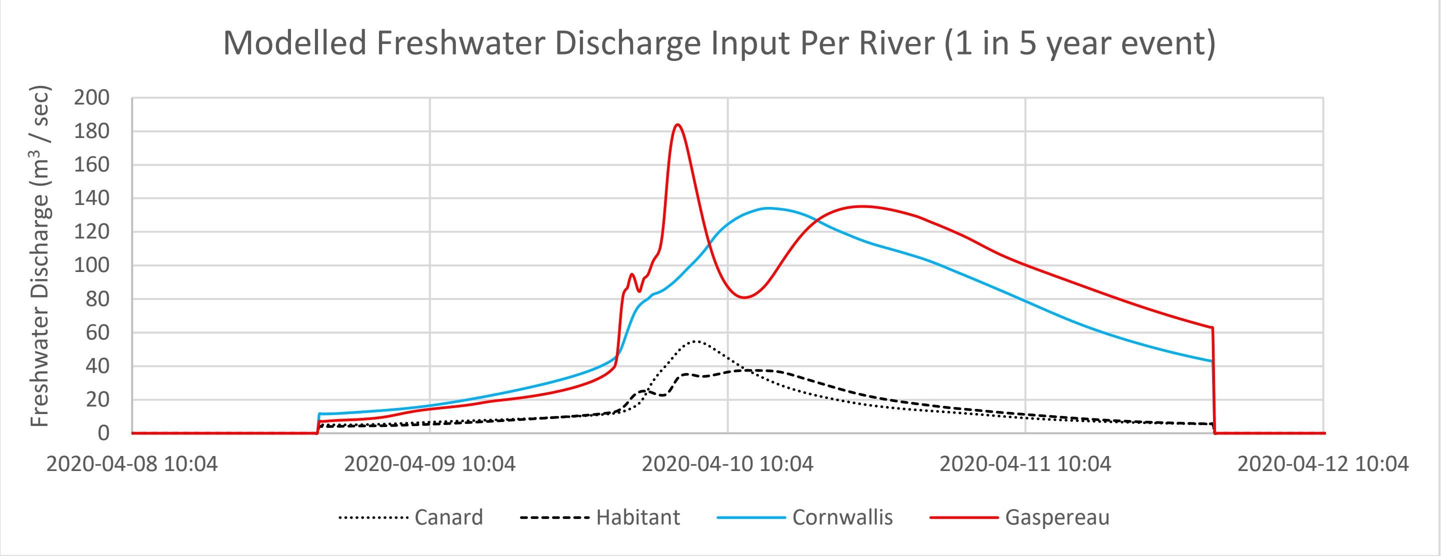


Figure 10 shows the freshwater discharge curve modelled and provided by Dillon Consulting Ltd. to represent a 1 in 5-year high discharge event. Note that the Canard and Habitant freshwater discharge were not used in the modelled scenarios.

For validation and for testing HHWLT scenarios, a reasonable estimate of baseflow for the Cornwallis and Gaspereau rivers was computed as a ratio to the relative drainage area with the October discharge average river discharge from the long-term Environment Canada river gauge located further upstream in the Cornwallis River. A comparative analysis was also conducted using a shorter archived record of discharge measurements from the upper Gaspereau watershed which showed a 92% agreement in the average discharge per drainage area and 90% agreement considering only October observations (Table 3). Thus, the value of 0.0132 m^3/s per sq. km of drainage area was used to estimate a constant river discharge for each river system for calibration and a base HHWLT simulation. This resulted in an estimated freshwater input of 4.66 m^3/s for the Cornwallis River and 6.88 m^3/s for the Gaspereau River (Table 4).

Table 3 indicates the Environment Canada river gauge information used to estimate reasonable freshwater inputs based on observed discharges in the Cornwallis and Gaspereau rivers.

ECCC Station (Id)	River	Years	Latitude	Longitude	Drainage Area	Average October Discharge
Cambridge (01DD002)	Cornwallis	2000-2020	45º03’53”	-64º38’07”	90.8 sq. km	**1.69 m^3/s (*0.0132 per sq. km*)**
Martin’s Bridge (01DD001)	Gaspereau	1915-1920	45º03’35’’	-64º22’55’’	486 sq. km	9.80 m^3/s (*0.0147 per sq. km*)

Table 4 shows the calculated estimated discharge rates used for the model validation and base HHWLT simulation and their location the discharge was input into the hydrodynamic model. Note that freshwater input was not included for the Canard or Habitant.

River	Total Drainage Area	Estimated Discharge	Model Input Easting	Model Input Northing
Gaspereau	520.7 sq. km	**6.88 m^3/s**	396413.4 m	4992420.5 m
Cornwallis	532.8 sq. km	**4.66 m^3/s**	384367.1 m	4992058.1 m
Habitant	56.0 sq. km	0.74 m^3/s	N/A	N/A
Canard	53.1 sq. km	0.70 m^3/s	N/A	N/A

2.2.7.6 Model Simulation

Hydrodynamic simulations were driven by tidal predictions along the coastal boundary using time series files generated by WebTide. Dillon Consulting Ltd. required a 72-hr HHWLT time-series for each of their boundary locations using their 1 in 5-year discharge event as input for their hydraulic model. NSCC-AGRG ran their model simulation for four days (April 8th-12th, 2020) in total to allow for one full tidal cycle as a warm-up period before the 1-5-year discharge events developed by Dillon were applied.

The simulation period of the model was chosen after conducting a 2-year analysis of tidal predictions derived from WebTide. The highest water levels within this timeframe were observed during a spring tide on April 10th, 2020. This four-day timeframe was maintained for successive model runs with 1 in 20-year and 1 in 100-year storm surge events for present day, 2050, and 2100 utilizing the 1 in 5-year freshwater discharge. The model parameters used in each simulation are listed in Table 5, and measured and modelled water levels are shown in Figure 9.

Water level readings from the downstream pressure sensor deployed by NSCC-AGRG were compared with water levels extracted at the same location in the model. Initial comparisons showed an average difference of 15 cm between the pressure sensor and model readings. The tidal elevation along the coastal boundary was multiplied by a factor of 1.14 which resulted in modelled water levels that more closely reflected the pressure sensor readings.

Table 5 lists the parameters used for the MIKE 21 2D Flow Model FM hydrodynamic model.

Parameter		**Value**
Start Time		2020/04/08 10:00:00 AM (UTC)
End Time		2020/04/12 10:00:00 AM (UTC)
Time Step Interval		600 s
Number of Time Steps		576
Shallow Water Equation	**Time and Space Discretization**	High Order
	Minimum Time Step	0.05 s
	Maximum Time Step	1 s
	Critical CFL Number	0.8
Drying Depth		0.005 m
Wetting Depth		0.1 m
Eddy Viscosity (Smagorinsky Formulation)		0.28 (constant)
Bed Resistance (Manning Formulation)		32 $m^{1/3}/s$

2.2.7.7 Model Validation

The flex mesh hydrodynamic model was run using WebTide predicted tides and validated using observed pressure sensor conditions from October 18th to October 25th, 2022. The Gaspereau watershed study area presented significant challenges for deploying water level sensors, and NSCC-AGRG faced a tight timeframe between the contract award and onset of winter to carry out the sensor deployment. Consequently, the model calibration and validation utilize the same dataset.

The validation model was run progressively while observing the output in several iterations such that for each run minor adjustments were made based on simulation results. These adjustments included modifications to the dike structures, improvements to river channel geometry, model parameters, and boundary conditions. With each iteration the modelled water level output was compared to the AGRG pressure sensor in the lower Gaspereau River (Figure 1) at the appropriate location.

It is noted that while the observed water levels bottom out (when the pressure sensor became exposed at low tide) the modelled water level exhibited a signal of slowed draining at low tide which resolved to a higher than observed water level. This discrepancy could likely be attributed to a remaining issue in the channel geometry where blockages at certain elevations remain downstream which artificially limited the model's ability to drain water in the Gaspereau during low tide. This issue was a known limitation in the model and was due to a lack of high-quality bathymetry data in the river channels. A phase offset was visible in the residual of the observed and modelled water level which was likely also related to restricted flow. The overall residual was < 20 cm error, and < 5 cm at high tide toward the end of the validation simulation period (Figure 11).

In the first 5 days of the model simulation, in what should be considered the warm-up period, there was a difference in high-tide levels between the measured and modelled water levels. As the model progressed, the reduction in this difference was significant, and the model was considered to accurately predict the measured water level during the period that was used for inundation mapping (Figure 11).

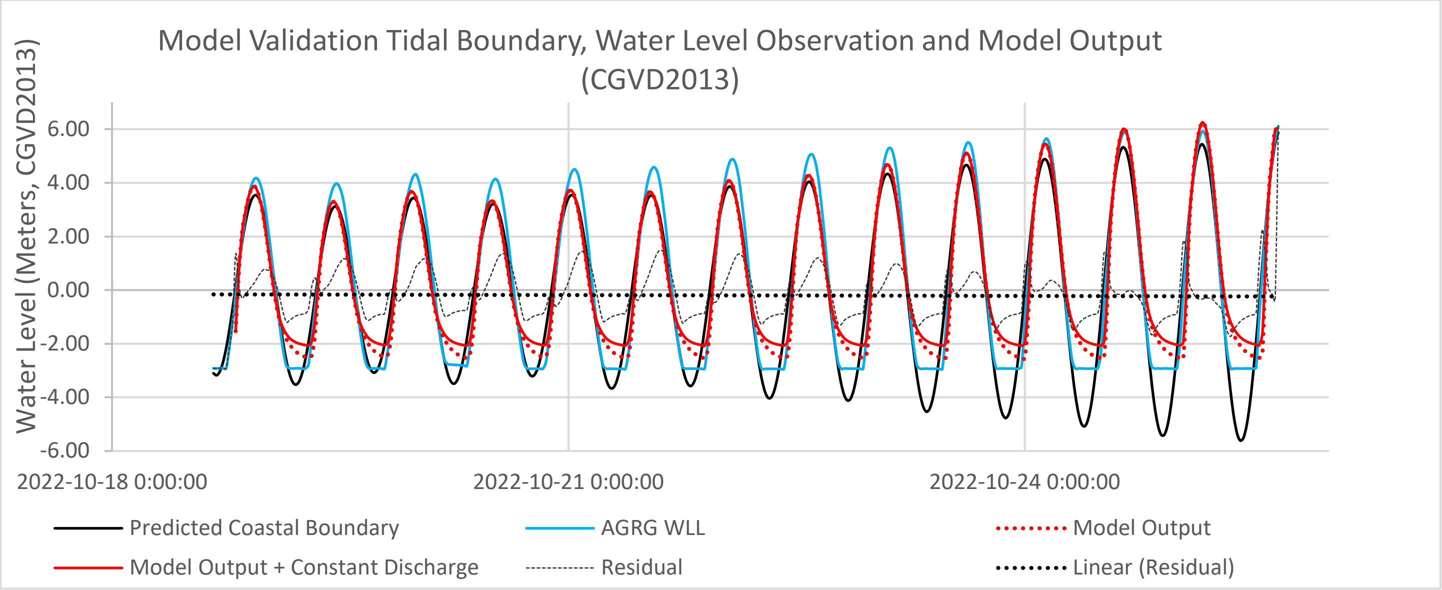


Figure 11 shows results from the model validation comparing the predicted WebTide (black), the observed water levels at the AGRG Gaspereau tide gauge (blue) and the model output at the location of the gauge with and without river discharge (red and red dashed). The residual between the observed water level (blue) and the model out with discharge (solid red) is also indicated (dashed) as well as the linear trend of the residual (dotted).

3 Results

3.1 Hydrodynamic Modelling

Hydrodynamic models were run for the 1 in 20-year and 1 in 100-year storm surge events for present day, 2050, and 2100 utilizing 1 in 5-year freshwater discharge. An additional present-day model was run which included a constant discharge value and is discussed in more detail in section 2.2.7.5. Hydrodynamic models were converted into grids by calculating the maximum surface elevation of inundated areas during the simulation period, which is provided in Figure 12 and Figure 13.

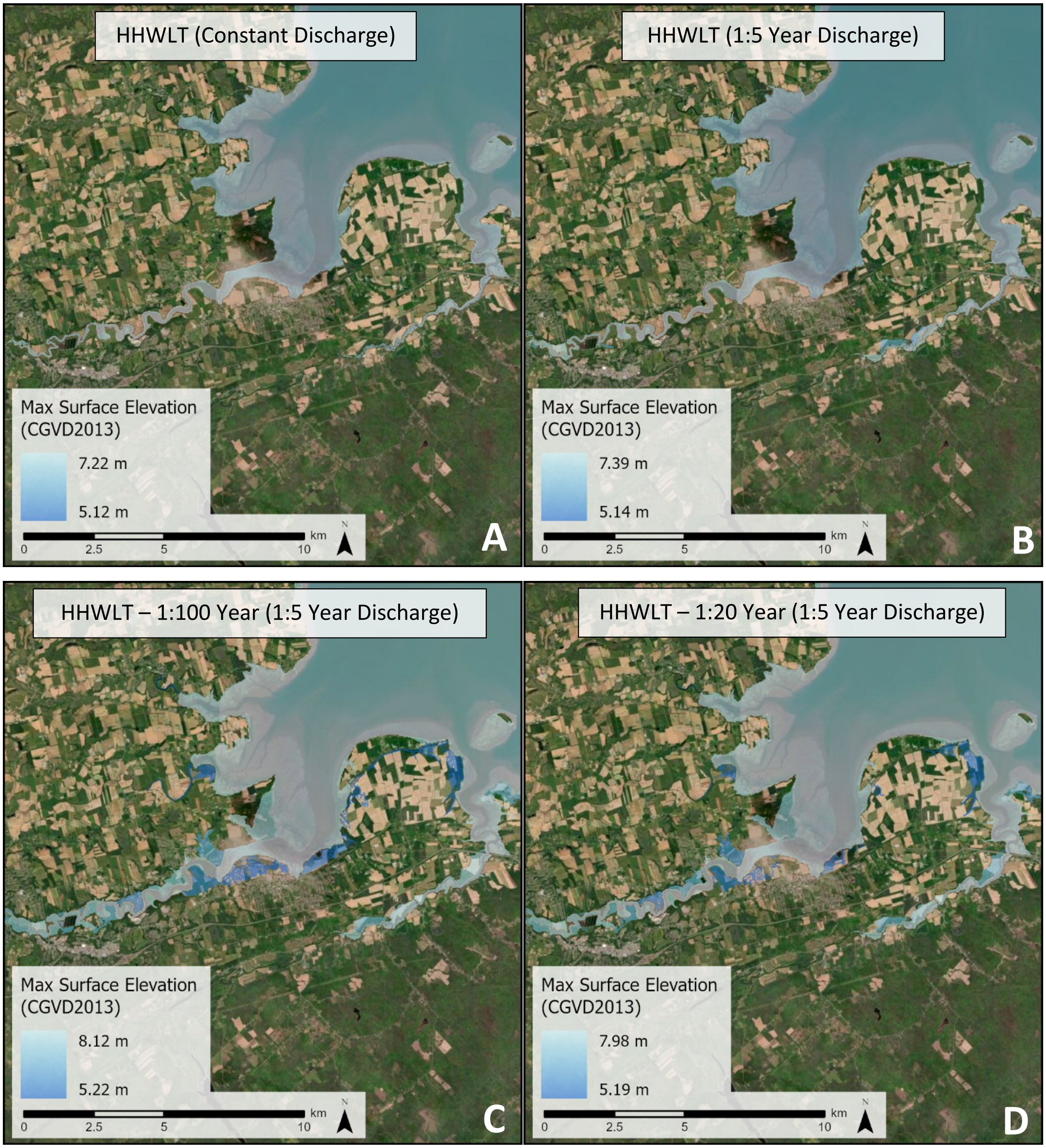
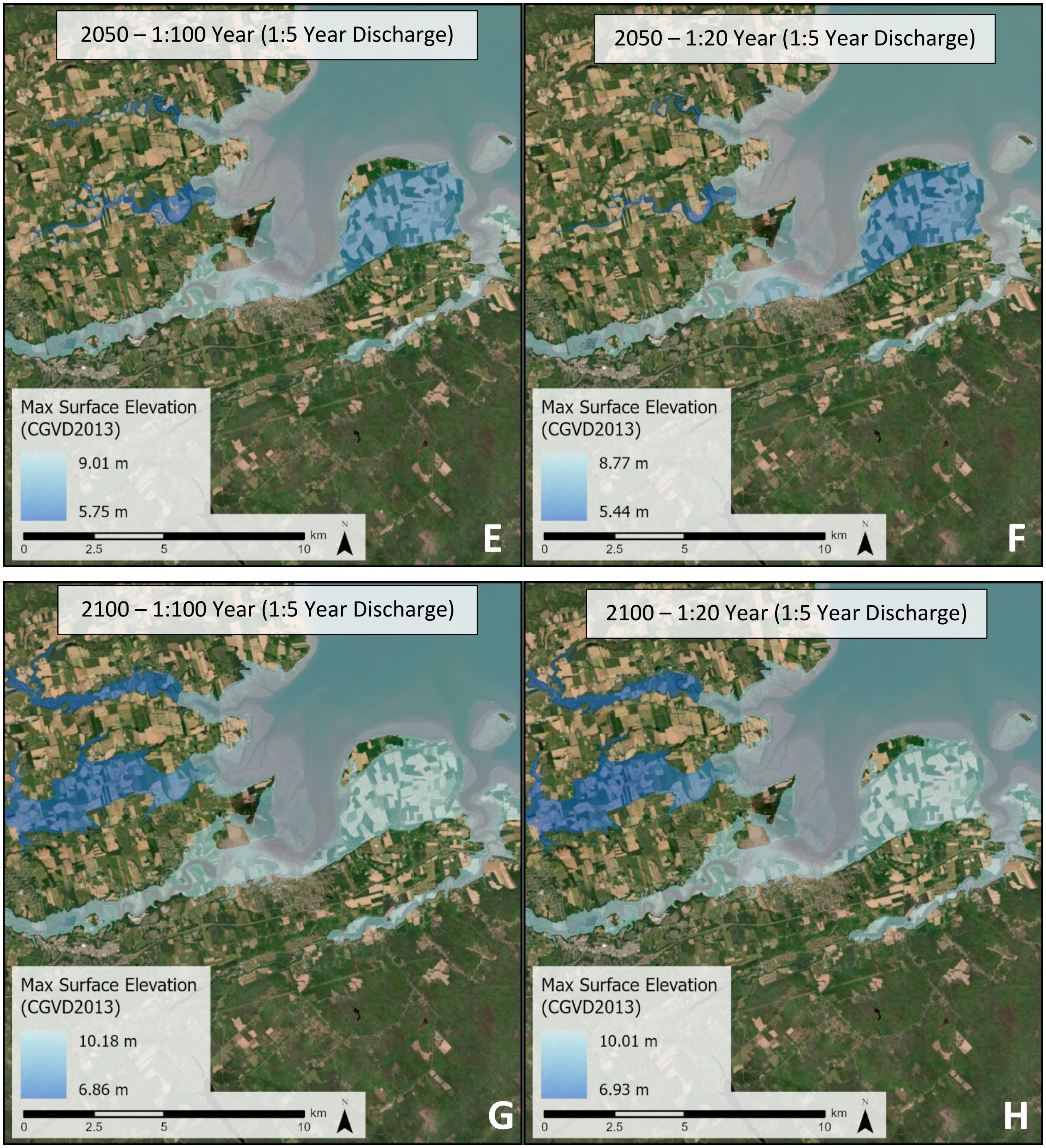


Figure 12 shows the maximum inundation extents and surface elevations for the HHWLT modelled scenarios.



2050 – 1:100 Year (1:5 Year Discharge)

2050 – 1:20 Year (1:5 Year Discharge)

2100 – 1:100 Year (1:5 Year Discharge)

2100 – 1:20 Year (1:5 Year Discharge)

Figure 13 shows the maximum inundation extents and surface elevations for the 2050 and 2100 modelled scenarios.

4 Discussion

Hydrodynamic models were run for the 1 in 20 and 1 in 100-year storm surge events for present day, 2050, and 2100. The model results were converted into grids by calculating the maximum surface elevation of inundated areas during the simulation period.

Several water level loggers deployed by both Dillon Consulting Ltd. and NSCC-AGRG were not used in the final validation of the hydrodynamic model for reasons such as having a deployment location upstream of an aboiteau or having insufficient data during the model simulation period.

While the inundation results of the model appeared to be realistic, no data were available to empirically validate the model extent. An appropriate method for validating the extent was to compare the simulated results with a swamp polygon layer obtained from the NSTDB, which portrays transition zones between land and water that are often subject to flooding. By overlaying the HHWLT maximum surface elevation layer with a constant discharge on top of the swamp area polygon, both layers were mostly in agreement as shown in Figure 14, however, some discrepancies were observed, particularly in the Gaspereau River. These inconsistencies may be attributed to inaccurate elevation values in several areas of the channel, primarily caused by insufficient bathymetric data.

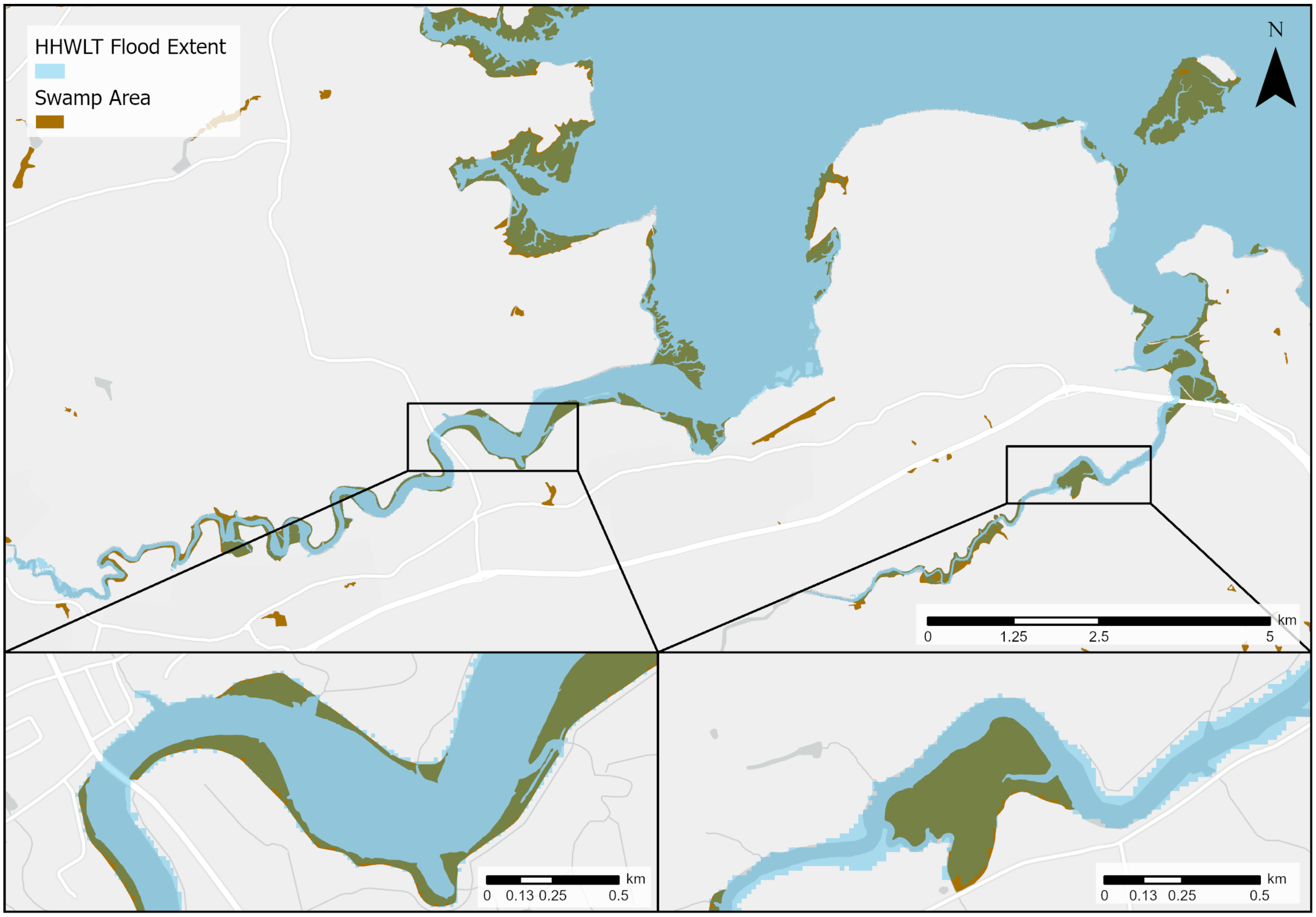


Figure 14 displays the maximum surface elevation output of the HHWLT (constant discharge) simulation from the HD model overlayed on the swamp polygon layer (NSTDB).

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