



Extreme Storm Event Flood Hazard Mapping at Point Tupper

Prepared for Municipality of the County of Richmond



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June 19, 2026

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Dear Troy:

RE Extreme Storm Event Flood Hazard Mapping at Point Tupper

CBCL is pleased to submit this report on the extreme storm event flood hazard mapping at Point Tupper. Please do not hesitate to contact the undersigned with any questions or comments you may have with regards to the contents of this report.

Yours very truly,

CBCL Limited

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Project No.: 251323.00

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Project No: 251323.00

Executive Summary

In June 2025, the Municipality of the County of Richmond (MOCR) issued a Request for Proposals (RFP) seeking the services of a qualified firm to complete Extreme Storm Event Flood Hazard Mapping along the coastal areas of Richmond County at the industrial developments in the Point Tupper area. CBCL Limited (CBCL) was engaged by MOCR in August 2025 to complete this task. The project is a pilot study that uses specifications from the Nova Scotia Municipal Flood Line Mapping (MFLM) initiative as a starting point. Project-specific scenarios tailored to site conditions and MOCR project requirements included combining the following key elements.

- ▶ 20- and 100-year return period scenarios
- ▶ Scenarios based on Hurricane Fiona, with alternative enhanced conditions related to storm track and timing relative to the high tide
- ▶ 2050 and 2100 horizons for sea level rise projections

Analysis was performed of existing data, such as bathymetry and topography, water level measurements at the nearby Canadian Hydrographic Services (CHS) tide gauge, Hurricane Fiona intensity data, and future sea level rise (SLR) projections. Using this data, a series of analyses and numerical models were used to investigate extreme water levels at the project site, including:

- ▶ Tidal elevations assessed from published values for the local tide gauge,
- ▶ 20-year and 100-year storm surge assessed by extreme value analysis of tide gauge data,
- ▶ Hurricane Fiona water levels from tide gauge measurements,
- ▶ Enhanced Hurricane Fiona simulations performed with numerical model,
- ▶ Rainfall events assessed with storm water model,
- ▶ Wave run-up assessed with wave model,
- ▶ Sea level rise addition to the model outputs for year-2050 and year-2100 projections.

Key findings are outlined below.

- ▶ The site is primarily protected from coastal flooding due to two geographical features: the topography of the site is generally high above the coastal water levels and steep, and Point Tupper is relatively well protected from offshore swell wave penetration.
- ▶ The water surface elevation during Hurricane Fiona did not cause extensive flooding at Point Tupper due to the low tidal elevation during the peak of the storm surge.
- ▶ An extremely unlikely enhanced Hurricane Fiona scenario, investigating alternate tidal elevations and storm tracks produced modelled extreme water levels 2 m higher than those measured during the storm.
- ▶ The impacts of heavy rainfall on the coastal flooding downstream of the hydraulic structures (e.g. culverts) is negligible.
- ▶ Modelling indicates that the impacts to inland flooding, via hydraulic structure such as culvert, due to coastal water levels is negligible.

- ▶ The flooding due to wave run-up varies across the site, with larger waves expected at the south of the site. In the south of the site, the shoreline topology is steep and there is limited difference in expected flooding with and without waves.
- ▶ Coastal flooding during extreme events is expected to affect wharves and wharf infrastructure on the Point Tupper coast by end of century, such as those operated by McNally, Everwind, and Port Hawkesbury Paper. Jetty structures at the Point Tupper generating station are also expected to be affected by coastal flooding during extreme events by end of century.
- ▶ Wetland areas such as Ship Harbour, Bear Island Cove, and Bear Island are expected to experience inundation during extreme events.

Contents

1	Introduction	1
1.1	Background	1
1.2	Study Area	1
1.3	Study Objectives.....	2
1.3.1	How to Use This Report	3
1.3.2	Project Methodology Workflow	4
1.3.3	Assessment Scenarios.....	4
2	Analyses of Background Data	7
2.1	Vertical Datum	7
2.2	Coordinate Reference System	7
2.3	Bathymetry and Topography	7
2.4	Water Levels.....	10
2.4.1	Tidal Elevations.....	10
2.4.2	Total Extreme Water Levels.....	11
2.4.3	Sea Level Rise	14
2.4.4	Hurricane Fiona.....	16
2.4.5	Summary of Extreme Static Water Levels	19
2.4.6	Offshore Wind and Wave Conditions.....	20
3	Numerical Modelling	21
3.1	Description of Models.....	21
3.2	Hurricane Fiona Modelling	23
3.2.1	Model Inputs.....	23
3.2.2	Model Setup.....	24
3.2.3	Model Results	29
3.3	Hurricane Sensitivity Analysis.....	32
3.3.1	Sensitivity to Tidal Elevation	32
3.3.2	Sensitivity to Hurricane Track	33
3.3.3	Enhanced Hurricane Fiona Scenario	40
3.4	Nearshore Wave Modelling	42

3.5	Wave Run-Up	46
3.6	Compound Flooding Sensitivity Analysis	49
3.6.1	Hydrological and Hydraulic Model.....	49
3.6.2	Climate Change Impact on Precipitation Intensity.....	51
3.6.3	Impact of Coastal Water Levels on Inland Drainage.....	52
3.6.4	Impact of Rainfall Runoff on Coastal Flooding	52
4	Coastal Flood Mapping.....	55
5	Key Findings, Next Steps, and Limitations	63
5.1	Key Findings	63
5.2	Next Steps	64
5.3	Limitations	64
6	References.....	65
B.1	Introduction	69
B.2	Subcatchment Delineation.....	69
B.3	Land Cover, Soils, and Lakes.....	70
B.4	Stream Reaches	71
B.5	Hydraulic Structures	72
B.6	Calibration	72
B.7	Scenarios	73
B.8	Rainfall Analysis.....	74
B.9	Climate Change Projections.....	74
B.10	Results	75
	Impact of coastal water levels on inland drainage.....	75
	Impact of runoff on coastal flooding.....	78

Appendices

- A Offshore Wind and Wave Hindcast Analyses
- B Hydrological and Hydraulic Assessment
- C Survey Data Sheets
- D Run-up Modelling Results
- E Flood Maps

Abbreviations and Acronyms

Abbreviation	Definition/ Summary
CBCL Limited	CBCL
CD	Chart Datum
CGVD2013	Canadian Geodetic Vertical Datum of 2013
CHS	Canadian Hydrographic Services
DEM	Digital Elevation Model
EWL	Extreme Water Levels
GIS	Geographic Information Systems
HAT	Highest Astronomical Tide
HHWLT	Higher High Water Large Tide
HHWMT	Higher High Water Mean Tide
Hs	Significant Wave Height
HyVSEP	Hydrographic Vertical Separation Surfaces for Canadian Waters
LLWLT	Lower Low Water Large Tide
LLWMT	Lower Low Water Mean Tide
MOCR	Municipality of the County of Richmond
MSC50	Meteorological Services of Canada (50-year hindcast)
RFP	Request for Proposals
RP	Return Period
RSLC	Relative Sea Level Change
SSP	Shared Socioeconomic Pathways
SLR	Sea Level Rise
Tp	Peak wave period

1 Introduction

1.1 Background

The Municipality of the County of Richmond (MOCR) is located in a rural area of Cape Breton, Nova Scotia with a population of almost 9,000 with over 5,000 households. The Municipality covers 1,244 km². The coastal areas of Richmond County include a combination of rural land, communities living near the coastline, and significant water adjacent industrial areas and port infrastructure including the Point Tupper industrial area located on the Strait of Canso. Among other users, the Point Tupper area is home to Cabot Gypsum, Port Hawkesbury Paper, NSPI Point Tupper Generating Station, EverWind, Bear Head Energy, Invest Nova Scotia, Tupper Industrial Developers, McNally Corp, and MOCR¹.

MOCR issued a Request for Proposals (RFP) seeking the services of a qualified firm to complete Extreme Storm Event Flood Hazard Mapping along the pre-identified coastal areas of Richmond County at the industrial developments in the Point Tupper area. CBCL Limited (CBCL) was engaged by MOCR in August 2025 to complete this task. The project is a pilot study that uses specifications from the Nova Scotia Municipal Flood Line Mapping (MFLM) initiative as a starting point, with project-specific alternative scenarios tailored to site conditions and MOCR project requirements.

This study has been carried out using applicable and appropriate engineering design standards, driven by data analysis, numerical modelling, and engineering tools to analyze extreme water levels and to simulate waves and wave run-up for present day and future sea level rise conditions, to identify coastal flood hazard at the site. This includes present day conditions as well as projected future climate change conditions (sea level rise).

The study presents mapping from a variety of scenarios and may be used to identify the regions or infrastructure assets that may be at risk of flooding due to changing sea levels, extreme coastal water levels, and wave run-up.

1.2 Study Area

The project site is located at the Point Tupper area, in Richmond County, Nova Scotia (Figure 1-1). For the purposes of this project, the project area is defined as the coastal fronting from the intersection of Industrial Park Road and Henry Paint Street at the eastern end of Ship

¹ Point Tupper Prospectus: <https://welcometocapebreton.ca/wp-content/uploads/2023/04/Point-Tupper-Prospectus-2019-Apr-13-2023.pdf>

Harbour, then westerly down Henry Paint Street to the Strait of Canso, and southeasterly along the coast through Bear Head Cove, Seacoal Cove, terminating at Caribou Head. This area is shown by the green line in Figure 1-1.

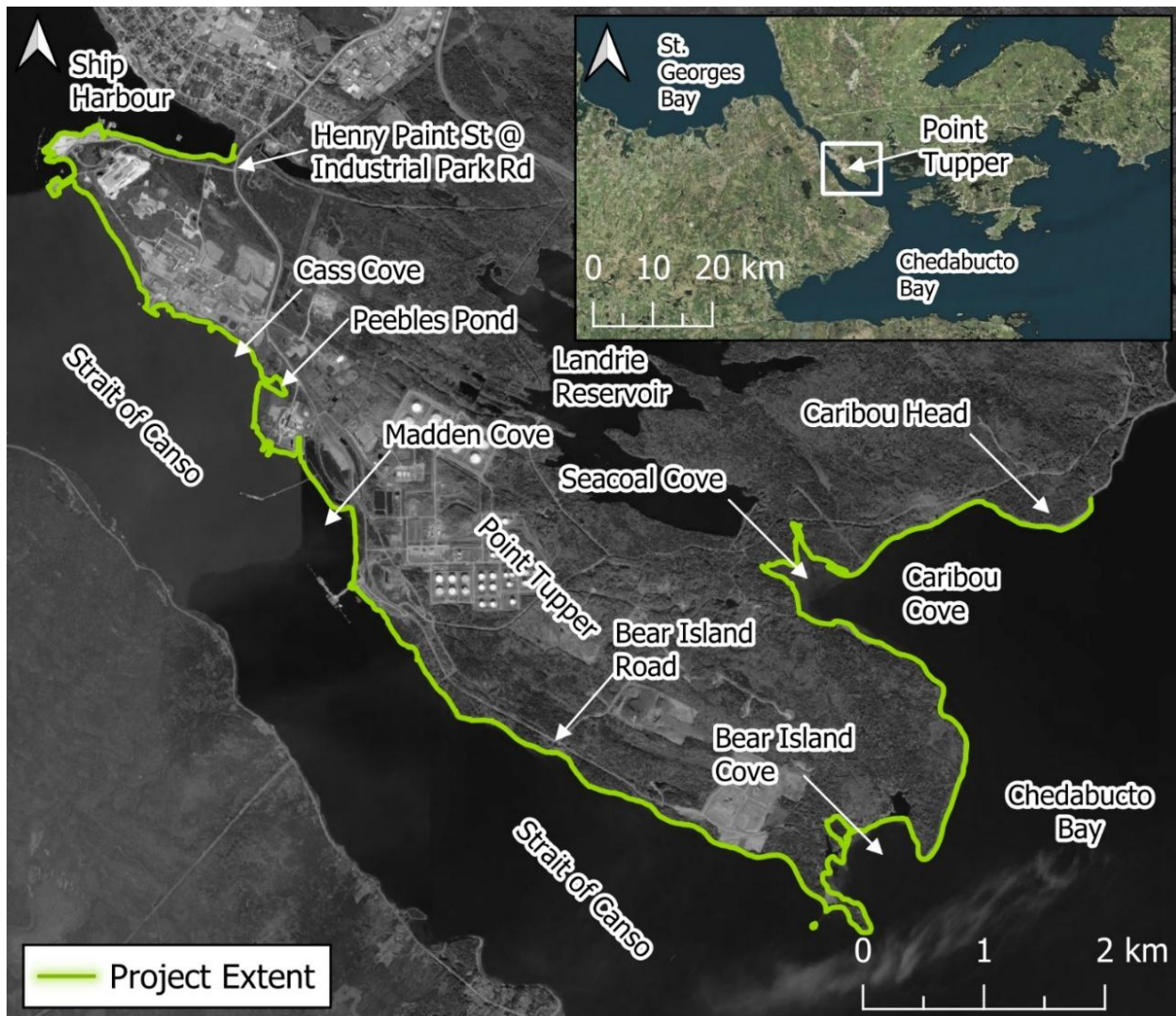


Figure 1-1: Map of project site and extent.

1.3 Study Objectives

MOCR commissioned CBCL to complete the present study. The project objective is to produce flood hazard mapping at the Point Tupper site for the scenarios listed below, as defined in the Terms of Reference from MOCR.

- Assessment of the impact that mean sea level rise (SLR) will have on tidal water levels at the coast of Point Tupper. (Section 2.4)

- ▶ Flood modelling that simulates Hurricane Fiona² to evaluate the region's coastal flooding risks for present-day conditions and sea level rise (SLR) scenarios representing year-2050 and year-2100 SLR. (Section 0)
- ▶ Flood modelling that investigates plausible alternative tracks and tidal levels for extreme water levels at Point Tupper during a Hurricane Fiona-type event. (Section 3.3)
- ▶ Modelling of wave conditions along the coast of Point Tupper during an extreme event. This includes both modelling of wave height at the coast, as well as the extent on shore that is expected to be affected by wave run-up. (Section 3.4, Section 3.5)
- ▶ Sensitivity analysis of the impacts of combined effects of storm surge and heavy rainfall in the project area. (Section 3.6)

1.3.1 How to Use This Report

This report presents flood **hazard** projections for MOCR, accompanies digital GIS files delimiting modelled flood lines for the Point Tupper site, and serves as a technical reference detailing the methodology used in the production of those flood lines and flood depth rasters.

The results show the extents of various flood event intensities, typically for the purposes of land use planning and flood mitigation. The hazard mapping quantifies the spatial extent and severity of flooding under various present and future storm scenarios. This mapping allows identification by MOCR of areas and elements exposed to the flood hazards.

The maps include specific design flood events, starting with return periods 20- and 100-year. Associated annual probability of exceedance for these events are 5% and 1%, respectively. The N-year return period does not mean the event will happen only once every N years. In fact, a N-year return storm has a 64% probability of occurring over a N-year interval. The design storm approach does not address the full range of potential flood events, hence the addition of unlikely but possible alternate hurricane scenarios in this work, for which the low probabilities cannot be quantified with confidence.

This report does not quantify flood **risk**, which incorporates socio-economic values such as negative impacts on life, property, infrastructure and/or operations. This work should be applied using a risk-based approach, which considers social, economic and environmental value of assets and operations at risk under a range of flood scenarios and evaluates consequences of losses. Use of this flood mapping should be based on further study which evaluates parameters outside the coastal flood mapping scope, including but not limited to:

- ▶ General planning lifetime for site development or operations,
- ▶ Design life for specific infrastructure types,
- ▶ Risk tolerance for existing and future development, infrastructure types, maintenance and operations.

The reader is referred to next steps and limitations in Section 5 for additional details.

² Hurricane Fiona (Sept. 2022) was the most intense storm on record to approach the region based on minimum central pressure.

1.3.2 Project Methodology Workflow

A processing flowchart of the key project workflow elements is presented in Figure 1-2, showing the path between available data, modelling and analysis, and finally the creation of flood maps and GIS flooding shapefiles. The details of the methodology of each element are described in the sections below.

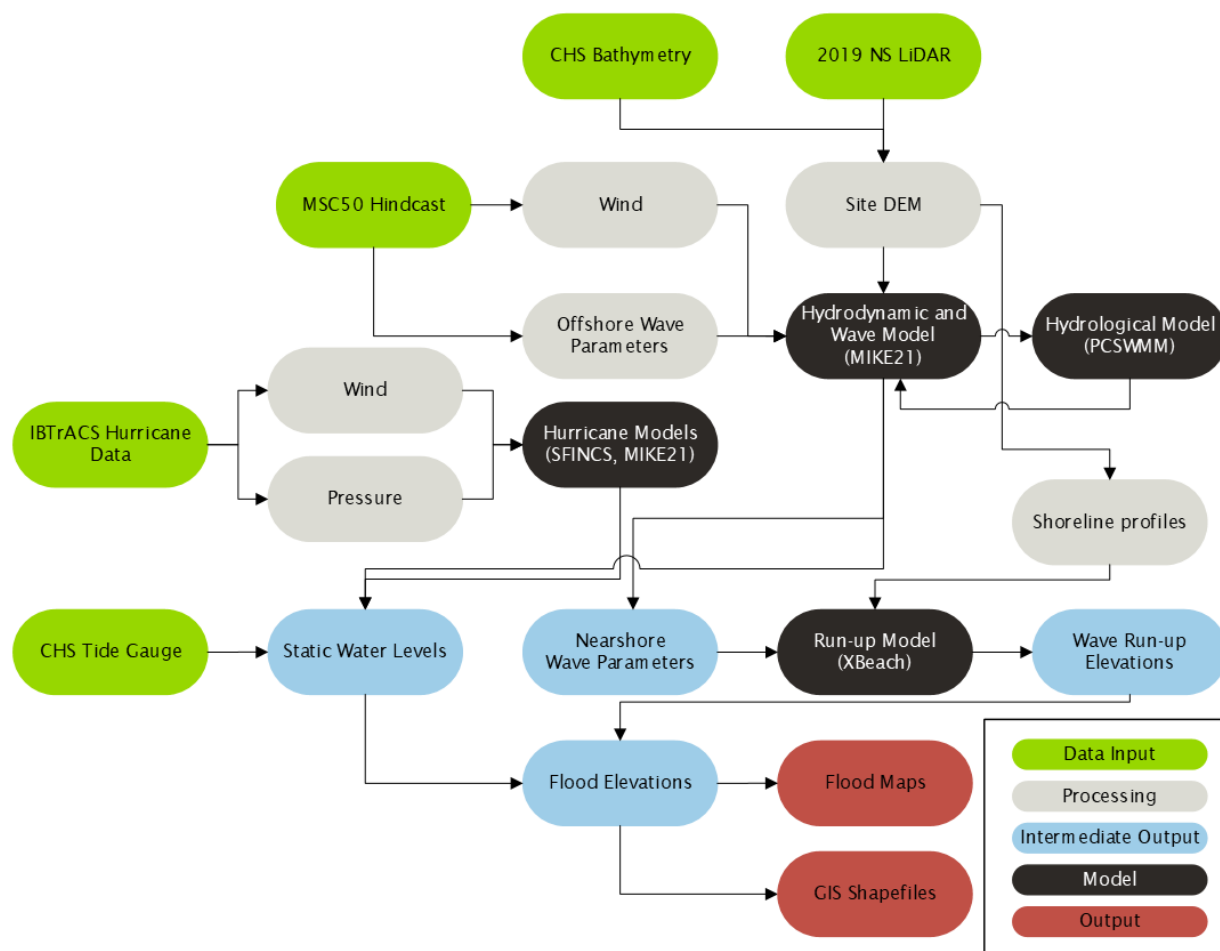


Figure 1-2: Project methodology flow chart.

1.3.3 Assessment Scenarios

The scenarios assessed for this project are summarized in Table 1-1. “Static” flooding refers to relatively slow-moving events that raise the water level of the sea surrounding the project site, such as high tides and storm surge. These events sustain extreme water levels for durations in the order of hours or minutes. Dynamic flooding refers to the relatively fast-moving effects of wave run-up in addition to static water level. Wave run-up effects are sustained for durations in the order of seconds.

The scenarios that were assessed as part of this project were selected to satisfy the requirements of the request for proposal (RFP)’s scope elements and additional scope item:

- ▶ Hurricane Flooding Simulation in present day/baseline conditions and multiple SLR timeframes (2050 and 2100) is represented by scenarios 4, 13, and 20.
- ▶ Sea Level Rise is represented by scenarios 1, 10, and 17.
- ▶ Compound flooding is represented by scenarios 2, 3, 6, 7, 11, 12, 18, 19, 22, and 23.
- ▶ Wave modelling during extreme events is represented by scenarios 8, 9, 15, 16, 24 and 25
- ▶ Hurricane Fiona Sensitivity Analysis is represented by scenarios 5, 13, and 21.

Note that these scenarios were chosen for compliance with the specifications of the project's RFP, and not for compliance with the Nova Scotia Municipal Flood Line Mapping (MFLM) program. Flood mapping for the Point Tupper area that is the focus of this study will also be produced as part of a separate project under the MFLM program which will follow the specifications, scenarios, climate change projections, etc., required by that program. The present project's flood mapping is intended as a complement to the MFLM flood mapping and is not presented as an alternative or replacement for it.

The baseline, or "Present day" climate horizon for the purposes of SLR projection is defined as the mean sea level in year-2020.

Table 1-1: Summary of scenarios assessed.

Scenario	Climate Horizon	Climate Scenario	Event	Flooding Type
1	Present Day	N/A	HAT	Static
2			20-year Storm Surge	
3			100-year Storm Surge	
4			Hurricane Fiona	
5			Hurricane Fiona (Enhanced Scenario)	
6			100-year Storm Surge + 20-year rainfall	
7			100-year Storm Surge + 100-year rainfall	
8			20-year Storm Surge + wave run-up	Dynamic
9			100-year Storm Surge + wave run-up	
10	2050	SSP5-8.5 (median)	HAT	Static
11			20-year Storm Surge	
12			100-year Storm Surge	
13			Hurricane Fiona	
14			Hurricane Fiona (Enhanced Scenario)	
15			20-year Storm Surge + wave run-up	Dynamic
16			100-year Storm Surge + wave run-up	
17	2100	SSP5-8.5 (median)	HAT	Static
18			20-year Storm Surge	
19			100-year Storm Surge	
20			Hurricane Fiona	
21			Hurricane Fiona (Enhanced Scenario)	
22			100-year Storm Surge + 20-year rainfall	
23			100-year Storm Surge + 100-year rainfall	
24			20-year Storm Surge+ wave run-up	Dynamic
25			100-year Storm Surge+ wave run-up	

2 Analyses of Background Data

2.1 Vertical Datum

All elevations in this project and report are referenced to the Canadian Geodetic Vertical Datum of 2013 (CGVD2013) unless otherwise noted.

A conversion of -1.43 m is used between elevations relative to Chart Datum (CD) and CGVD2013, based on Canadian Hydrographic Survey elevations at the Bedford Institute of Oceanography (BIO) (Robin et al., 2016, HyVSEP 2022v3).

$$Elev_{CGVD2013} = Elev_{CD} - 1.43 \text{ m}$$

A conversion of -0.57 m is used between elevations relative to the Canadian Geodetic Vertical Datum of 1928 (CGVD28) and CGVD2013, based on Natural Resources Canada's GPS-H conversion tool³ for the project site.

$$Elev_{CGVD2013} = Elev_{CGVD28} - 0.57 \text{ m}$$

2.2 Coordinate Reference System

The coordinate reference system used for this project is NAD83(CSRS)/UTM Zone 20N, EPSG: 2961.

2.3 Bathymetry and Topography

Bathymetry for the project was sourced from the Canadian Hydrographic Service's (CHS) Non-Navigational bathymetry dataset⁴, and converted from CD to CGVD2013 using the method outlined in Section 2.1. Bathymetry at Point Tupper is shown in Figure 2-1. For large scale wave models, such as the hurricane modelling, bathymetry that was more than 10 km from the project site was sourced from the General Bathymetric Chart of the Oceans (GEBCO⁵).

³ <https://webapp.csrscs-nrcan-rncan.gc.ca/geod/tools-outils/gpsh.php>

⁴ <https://data.chs-shc.ca/dashboard/map>

⁵ GEBCO Compilation Group (2024) GEBCO 2024 Grid (doi:10.5285/1c44ce99-0a0d-5f4f-e063-7086abc0ea0f)

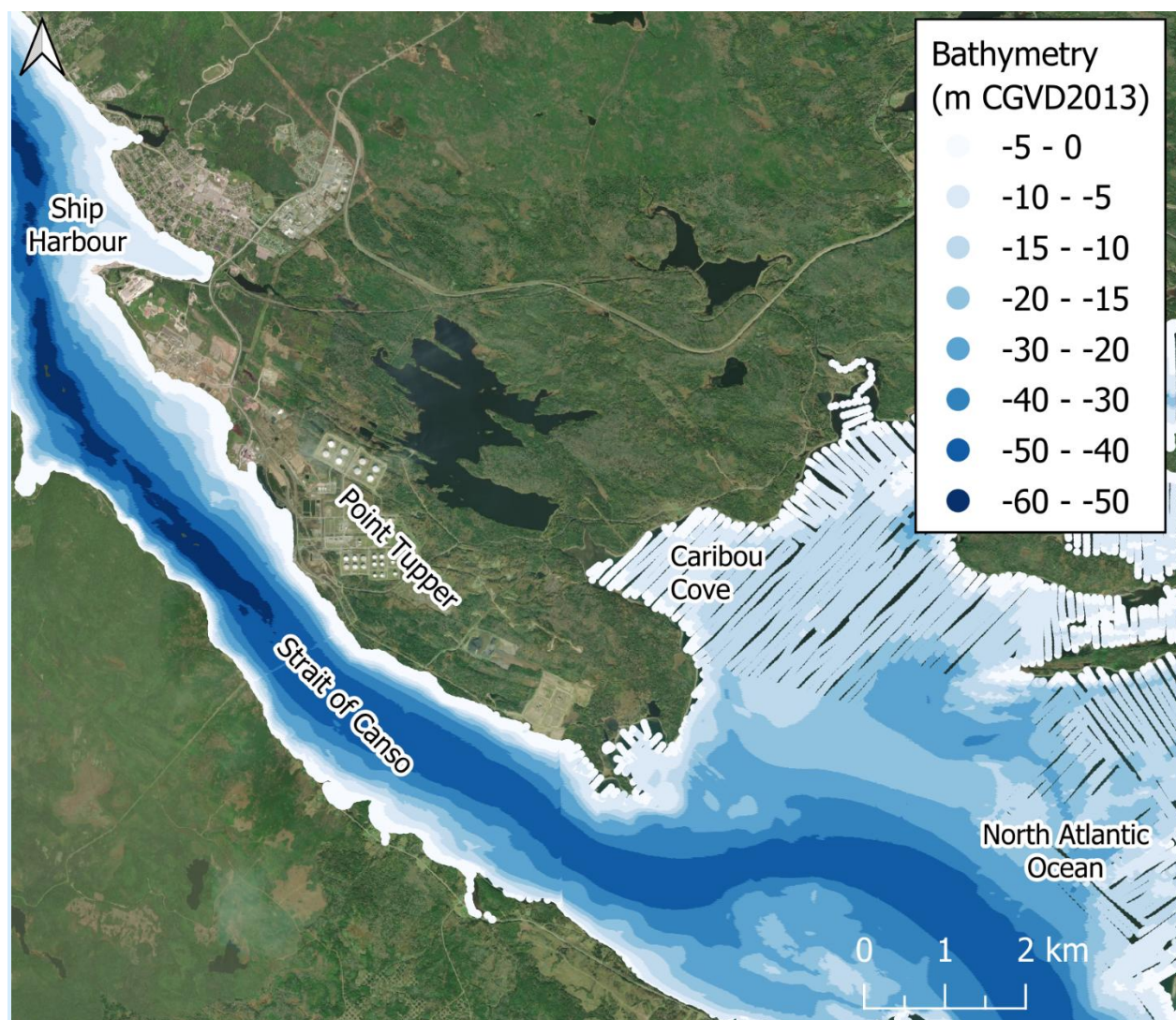


Figure 2-1: CHS bathymetry at Point Tupper.

Existing conditions topography for the project was sourced from the 2019 Nova Scotia LiDAR products⁶. The digital terrain model (DTM) is available as a processed 1 m resolution raster product that removes structures and foliage to represent the surface of the “bare earth”. The DTM used for this project is shown in Figure 2-2.

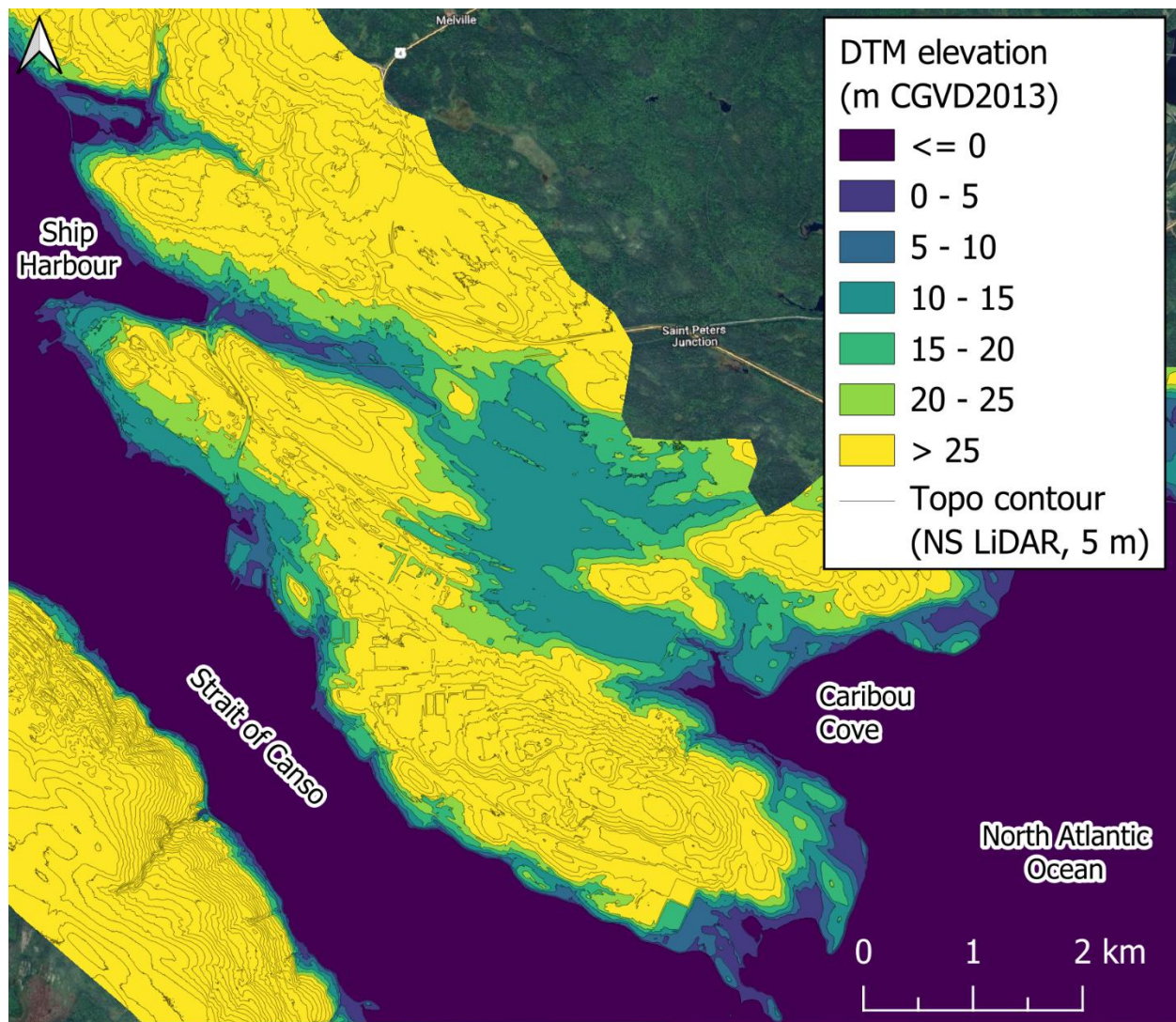


Figure 2-2: DTM showing existing conditions, derived from 2019 NS LiDAR. Topographic contours are presented at 5 m intervals.

⁶ <https://geonova.novascotia.ca/>

2.4 Water Levels

2.4.1 Tidal Elevations

Tidal elevations for the site are based on the published values at the nearby Port Hawkesbury permanent real-time tide station (DFO #00575), adjacent to the project site⁷. These elevations are sourced from the CHS tide data⁸ and presented in Table 2-1 relative to both chart datum (CD), as provided by CHS, and converted to the CGVD2013 datum⁹. The elevations are defined as follows¹⁰.

- ▶ Highest Astronomical Tide (HAT): The highest tidal level which can be predicted to occur under average meteorological conditions and under any combination of astronomical conditions.
- ▶ Higher high water large tide (HHWLT): The average over 19 years of the highest predicted high water level of each year.
- ▶ High Water Mean Tide (HWMT): The average height of all high waters at a place over a 19-year period.
- ▶ Mean Water Level (MWL): The average of all observed water levels over the period of record used to create the station's most recent constituents.
- ▶ Lower Low Water Mean Tide (LLWMT): The average height of the lower low waters at a place over a 19-year period.
- ▶ Lower Low Water Large Tide (LLWLT): The average over a 19-year period of the lowest predicted low water level of each year.

Table 2-1: Present day tidal elevations at the project site.

Tidal Elevation	m CD	m CGVD2013
Highest Astronomical Tide (HAT)	2.21	0.78
Higher High Water Large Tide (HHWLT)	2.18	0.75
Higher High Water Mean Tide (HHWMT)	1.83	0.40
Mean Water Level (MWL)	1.13	-0.30
Lower Low Water Mean Tide (LLWMT)	0.48	-0.95
Lower Low Water Large Tide (LLWLT)	0.15	-1.28

⁷ We note that the adjacent decommissioned station at Point Tupper (#00576) 2 km away has values which appear lower by up to 0.2 m, however these are legacy values from an older dataset (1971-1992). The updated tidal heights from the real-time station at Port Hawkesbury should be used.

⁸ Published at <https://www.tides.gc.ca/en/stations/00575>

⁹ See Section 2.1 for details of datum conversion

¹⁰ <https://www.tides.gc.ca/en/definitions-content-tides-and-currents>

2.4.2 Total Extreme Water Levels

When long-term tide gauge data is available, extreme water levels caused by storm surges can be calculated using a statistical extreme value analysis. For this project area, there was a long-term tide gauge station located in the upper Strait of Canso at Point Tupper between 1971-1992 and, after its decommissioning, another was installed 1.7 km away in Ship Harbour at Port Hawkesbury (operational between 2015 and present). Across the 50+ years of data collection, there were large gaps in the data; the two gauges combined have approximately 25 years of data available. Due to their proximity to one another, total water levels at both sites are very similar as confirmed by subsequent modelling, and for the purposes of this analysis are assumed to have negligible variation between the two tide gauge stations. The exception to this assumption is the difference in mean sea level due to long-term sea level rise which is accounted for in the analysis. The dataset was detrended to present-day mean sea level (2020 climate epoch) and used for extreme value analysis (EVA) of total water levels. The EVA consists in fitting a mathematical distribution to a set of observed peak values to estimate values associated with various return periods (RP) or annual exceedance probabilities (AEP). The statistical method used to analyze the distribution of exceedance over high levels is the Peak-Over-Threshold (POT) analysis using a Generalized Pareto Distribution (GPD) as the fitting method. The probability of events (i.e., the RP of storm events) is estimated based on joint probability analysis of these total water level peaks. This allows for the combined influence of storm surge, and tides on total extreme water levels to be considered, as well as for the capture of local phenomena such as nearshore wind set-up and harbour seiche¹¹.

The results of the extreme value analysis are shown in Figure 2-3. This plot includes the water levels of the highest storm events recorded on the tide gauge and the calculated extreme water levels for the corresponding RP using the extreme value analysis. Note the x-axis has a logarithmic distribution, and the increase in water levels for longer return periods is non-linear.

It is important to note that there is uncertainty associated with the estimation of extreme water levels, especially for return periods much larger than the duration of the observations (for example, 200 to 1000 years). The tide gauge data used to calculate extreme water levels has a duration of approximately 25 years. The calculated extreme water levels with RPs greater than the data collection period are much more sensitive to the extreme value fit calculated from the available tide gauge data, which leads to greater uncertainty in derived values. The uncertainty calculated for the 100-year total water level is in the order of +/- 0.1 m, and +/- 0.05 m for the 20-year total water level.

¹¹ While the amplitude of harbour seiche at the project site was not quantified, its influence would contribute to total water levels at the CHS tide gauge and would be captured within the extreme value analysis presented here.

Table 2-2 shows the results of the extreme value analysis. The data sets and associated analyses are presented in the following figures.

Table 2-2: Extreme value analysis of long-term tide gauge in the Strait of Canso.

Return Period [years]	Total Water Level [m CGVD2013]
100-year	1.38 (+/- 0.1 m)
20-year	1.27 (+/- 0.05 m)

This extreme value analysis of the total water levels at the tide gauge itself is considered representative for the Strait of Canso. Since the project area covers an area of several kilometres of coastline, and there is an expectation that there may be variable levels of storm surge (primarily wind and wave setup) in the region, a numerical model was developed to estimate the locally variable nearshore storm surge (see Section 3 for details).

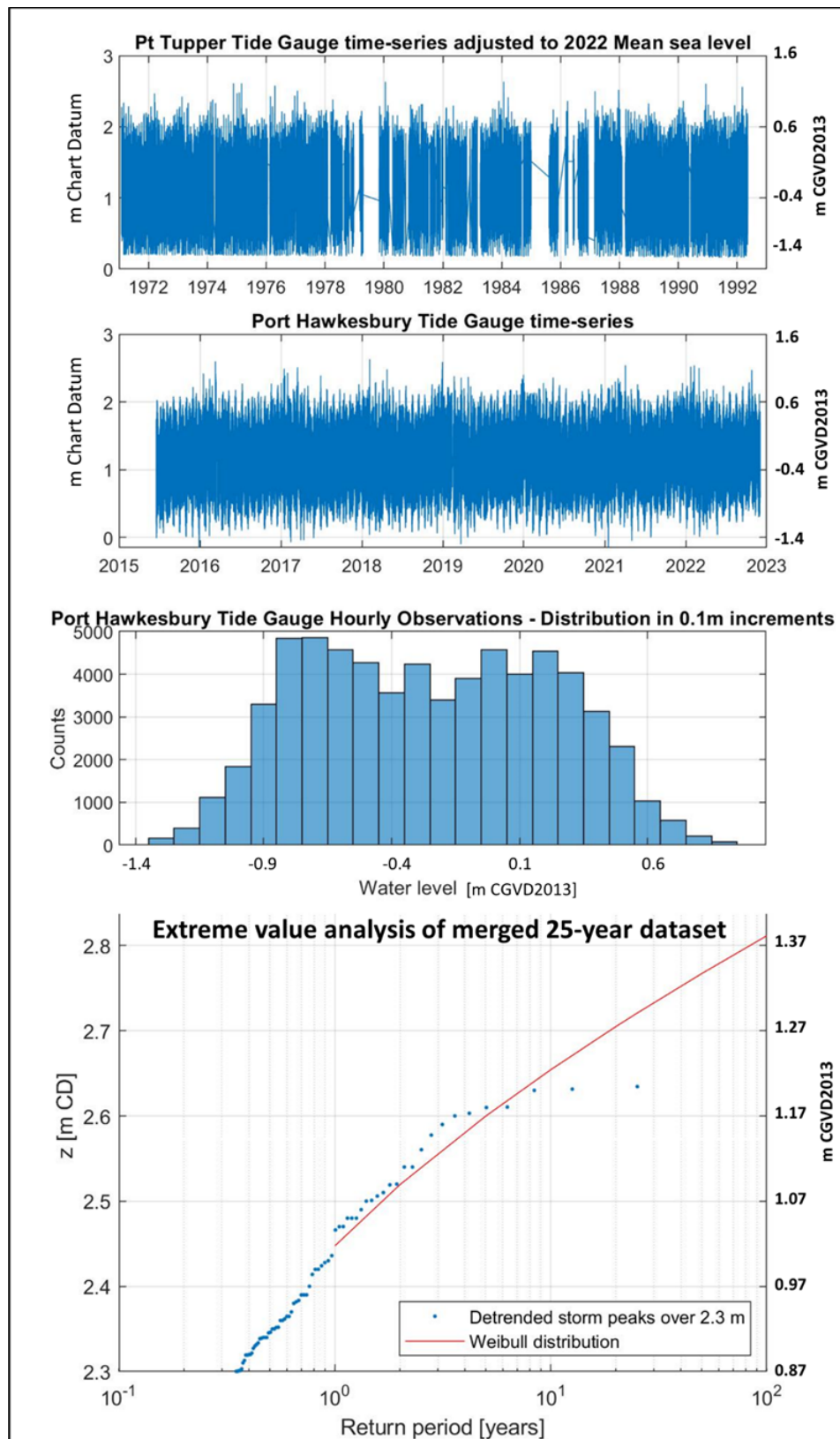


Figure 2-3: Analysis of long-term total water levels in the Strait of Canso. This includes the recorded peaks of storm events from the PH tide gauge and the calculated extreme water levels to the corresponding RP.

2.4.3 Sea Level Rise

Sea levels have been rising in the Maritimes since the end of the last ice age 10,000 years ago. This trend is expected to accelerate with climate change due to the expansion of ocean waters and melting of glaciers due to increased temperatures. Due to rising sea levels, more frequent and severe flooding of coastal infrastructure will occur due to an upward shift in the tidal elevations and extreme water levels. SLR projections have been developed by the Intergovernmental Panel on Climate Change (IPCC) in 2013 and published in the Fifth Assessment Report (AR5) and in 2021 the Sixth Assessment Report (AR6) was published. The most recent of these reports, IPCC AR6, is used for the SLR projections listed in this report. The IPCC is a scientific body of the United Nations responsible for advancing knowledge on climate change.

The IPCC AR6 report applied a new scenario framework to incorporate a combined analysis of future climate change impacts in terms of socioeconomics, vulnerabilities, and adaptation (Riahi *et al.*, 2017). The new scenarios are referred to as Shared Socioeconomic Pathways (SSPs) and vary based on socio-economic development, land use, demographics, among other factors. Some of the scenarios include SSP1-2.6 (low emission scenario), SSP2-4.5 (intermediate emission scenario), SSP3-7.0 (high emission scenario), and SSP5-8.5 (very high emission scenario). Additionally, two low-confidence scenarios concerning Antarctic ice sheet (AIS) stability are presented: SSP5-8.5 High ice sheet loss A, and SSP5-8.5 High ice sheet loss B.

AR6's SSPs replace the Representative Concentration Pathways (RCPs) used in previous IPCC reports.

Climatedata.ca has released the Relative Sea-Level Change tool (James *et al.*, 2021), which allows users to view and download sea level projections calculated by the AR6. The tool includes a data point for Point Tupper (Figure 2-4), which was used for the projection of SLR in the project area. The projections have been regionally downscaled from the AR6 report and incorporate land subsidence.

The AR6 SSP5-8.5 (median) climate scenario was used to project SLR elevations for this project. This scenario was chosen as a reasonable balance of risk, since this project concerns projections of flooding for critical infrastructure into the future, it is valuable to consider this more extreme scenario. At the same time, due to the uncertainty and low confidence of the AIS projections, the high ice sheet loss projections are deemed to be unreasonably conservative for the purposes of this assessment.

As climate science and SLR projections are constantly evolving, it is recommended to revisit these projections as new information becomes available.

SSP5-8.5 SLR projections are shown in Figure 2-4. The other projections listed above are provided for reference.

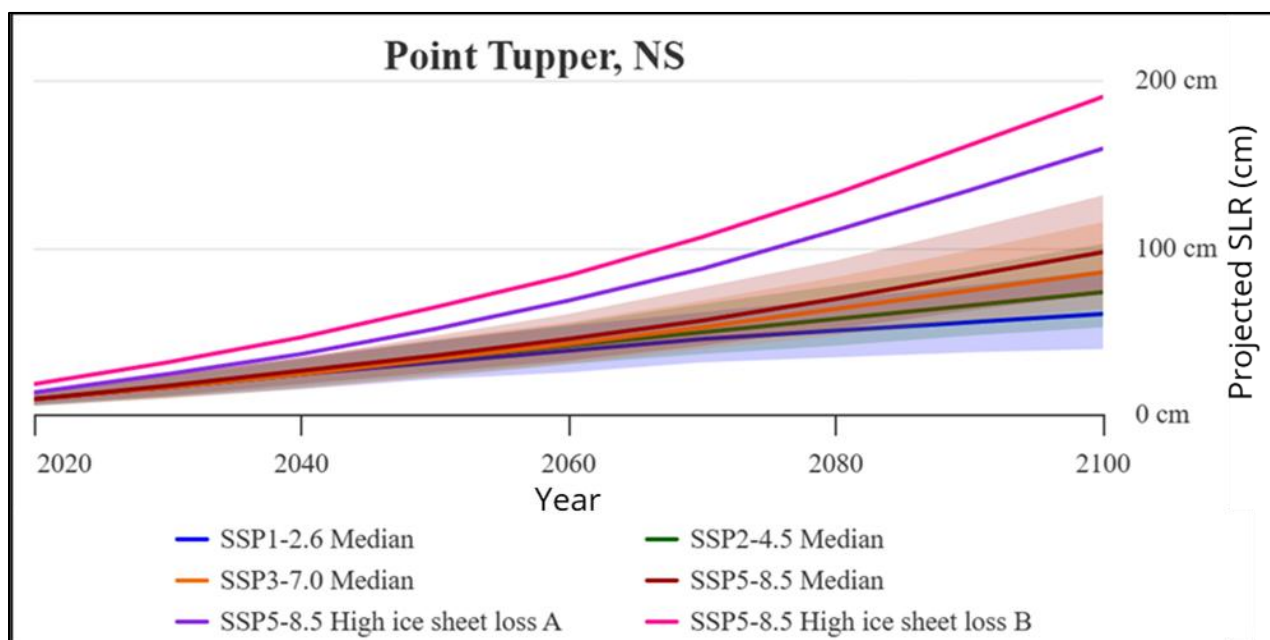


Figure 2-4: Sea level rise projections for the project area. The 17th and 83rd percentiles are the shaded lower and upper limits, while the solid line is the median (50th percentile) projection¹².

Table 2-3: SLR Projections at Point Tupper (m, relative to 1995-2014 conditions). SSP5-8.5 Median values are used in this project, with other projections provided for reference.

Scenario	Present Day	2050	2100
SSP1-2.6 Median	0.09	0.31	0.60
SSP2-4.5 Median	0.09	0.33	0.73
SSP3-7.0 Median	0.09	0.33	0.85
SSP5-8.5 Median	0.09	0.35	0.97
SSP5-8.5 High ice sheet loss A	0.13	0.51	1.58
SSP5-8.5 High ice sheet loss B	0.18	0.64	1.91

¹² https://climatedata.ca/maps/?var=sea_level&lat=45.60227&lng=-61.07574&zoom=11#

2.4.4 Hurricane Fiona

2.4.4.1 Tropical Cyclones

Tropical cyclones are powerful low-pressure systems that develop over warm ocean waters, characterized by strong winds, heavy rainfall, and storm surges. As these systems move northward into cooler waters and interact with mid-latitude weather patterns, they often undergo an extratropical transition. During this process, the cyclone loses its tropical characteristics but can retain or even intensify its wind field, resulting in post-tropical cyclones that still pose significant hazards. This transition typically occurs as the storm approaches Atlantic Canada, including Nova Scotia, where cooler sea surface temperatures and frontal systems drive structural changes in the storm.

2.4.4.2 Hurricane Fiona Intensity

Hurricane Fiona ranks among the most consequential cyclones to affect Atlantic Canada in the modern record. Fiona was the most intense storm to approach the region based on minimum central pressure (Figure 2-5). By maximum sustained winds, it was the sixth strongest system to pass within 300 km of Point Tupper. The destructive impact of the storm was amplified by the storm's track, which brought its core wind field directly over the site.

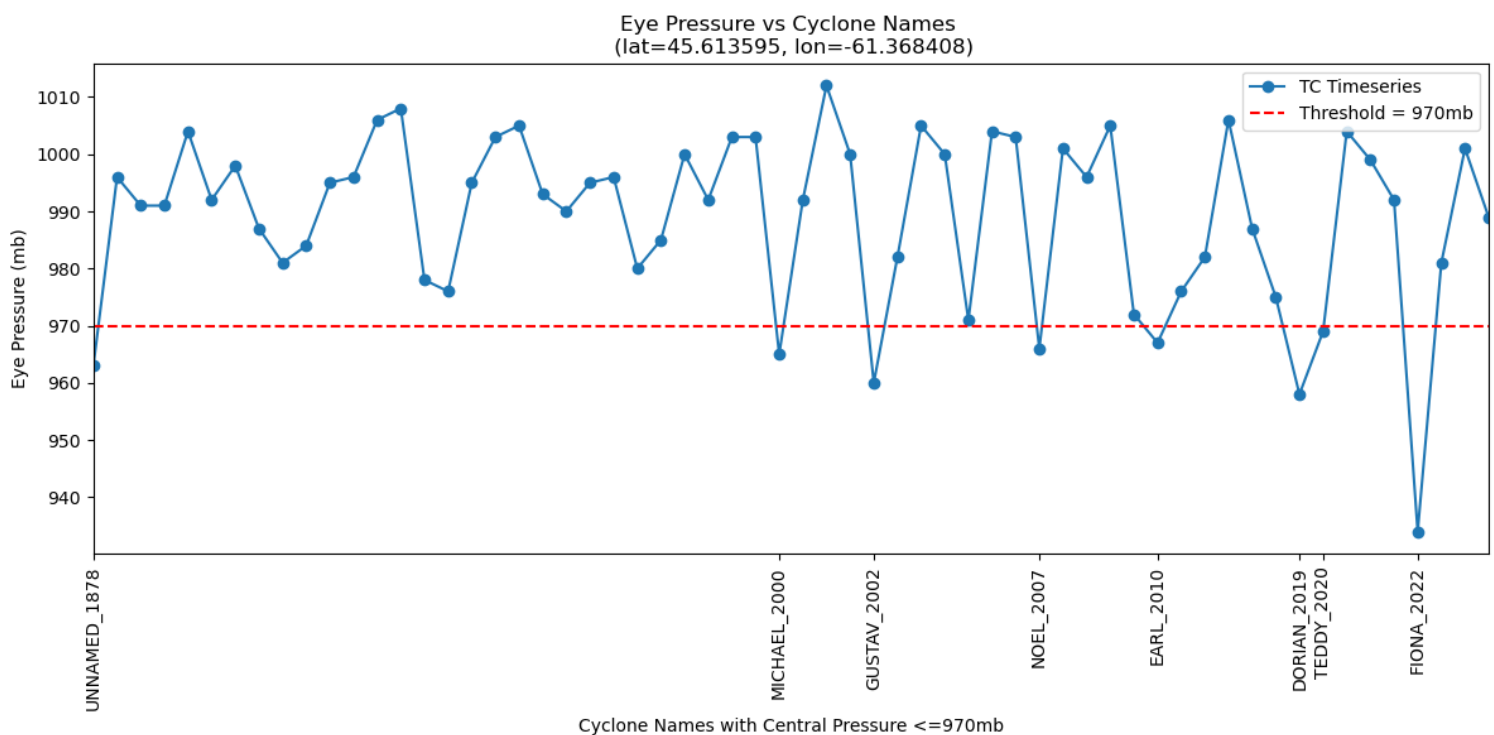


Figure 2-5: Central pressure of cyclones passing within 300 km of the project site. Cyclone names displayed for storms with central pressures below 970 mb.

Fiona originated as a tropical cyclone in the Caribbean basin (Figure 2-6), undergoing rapid intensification into a Category 4 hurricane before recurving northward. As it approached Nova Scotia, Fiona underwent extratropical transition, a process where the storm loses its tropical characteristics but often expands its wind field, increasing its potential for widespread damage.

Hurricane¹³ Fiona made landfall in Nova Scotia on the morning of September 24, 2022, as an “extremely strong extratropical cyclone” (NOAA, 2023). The storm’s minimum pressure was recorded by an Environment and Climate Change Canada buoy (44488) located in eastern Chedabucto Bay, less than 30 km from the southern tip of Point Tupper, with the centre of the storm track travelling less than 5 km from Point Tupper.

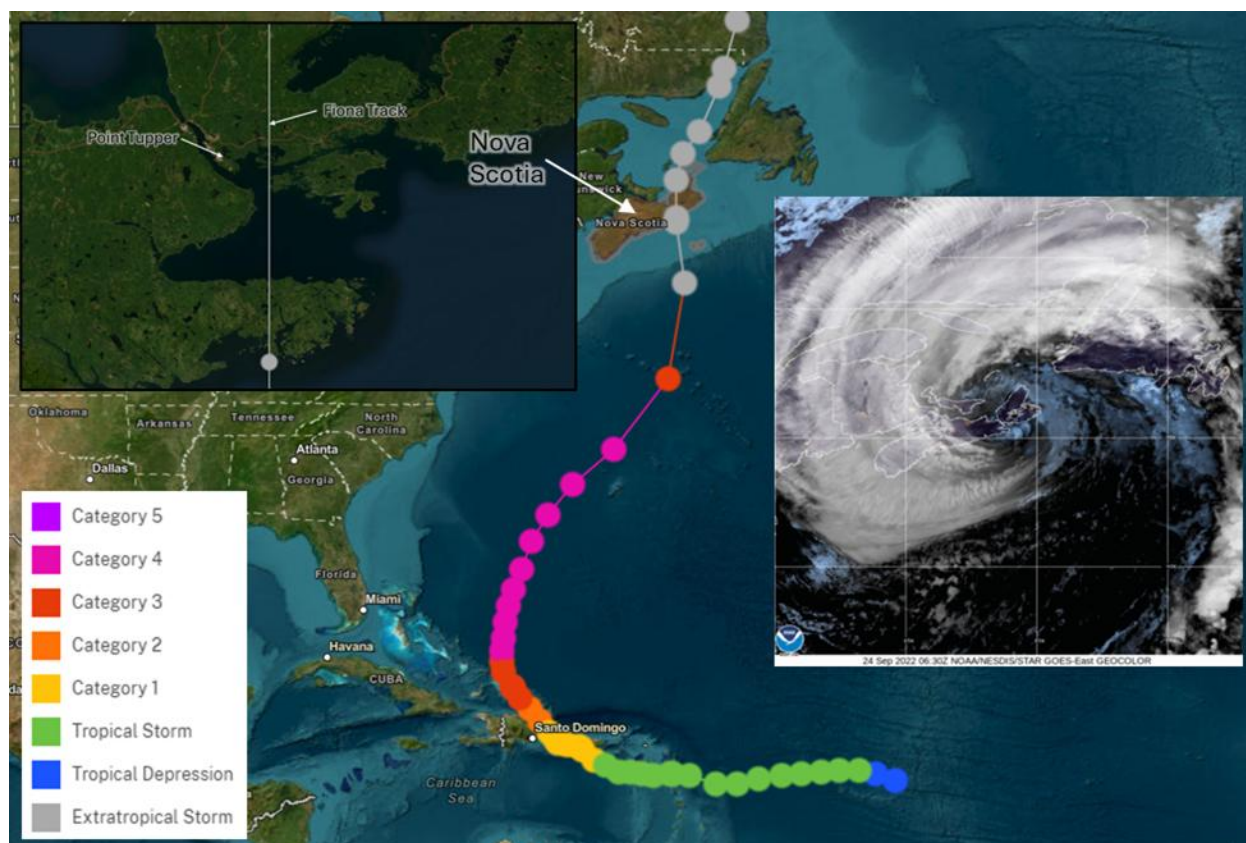


Figure 2-6: Track of Hurricane Fiona (2022) (sourced from coast.noaa.gov).

Fiona approached Point Tupper as a Category 2 hurricane, with sustained winds exceeding 150 km/h, before weakening to Category 1 intensity just prior to landfall. Despite this downgrade, Fiona’s destructive impact was amplified by its track, which brought the storm directly toward the coast rather than veering offshore. This trajectory, as illustrated in Figure 2-7 exposed large areas to hurricane-force winds and heavy rainfall, causing extensive infrastructure damage and prolonged power outages across Nova Scotia.

¹³ Note that Fiona had transitioned to a post-tropical cyclone when it had made landfall in Nova Scotia, meaning it no longer possessed enough tropical qualities to be officially designated as a hurricane. This is a meteorological definition and does not necessarily correlate to the potential destructiveness of the storm. At landfall, Post-tropical Cyclone Fiona had wind speeds comparable to a category 2 hurricane on the Saffir-Simpson Hurricane Wind Scale. For simplicity, Post-Tropical Cyclone Fiona will be referred to as Hurricane Fiona in this report.

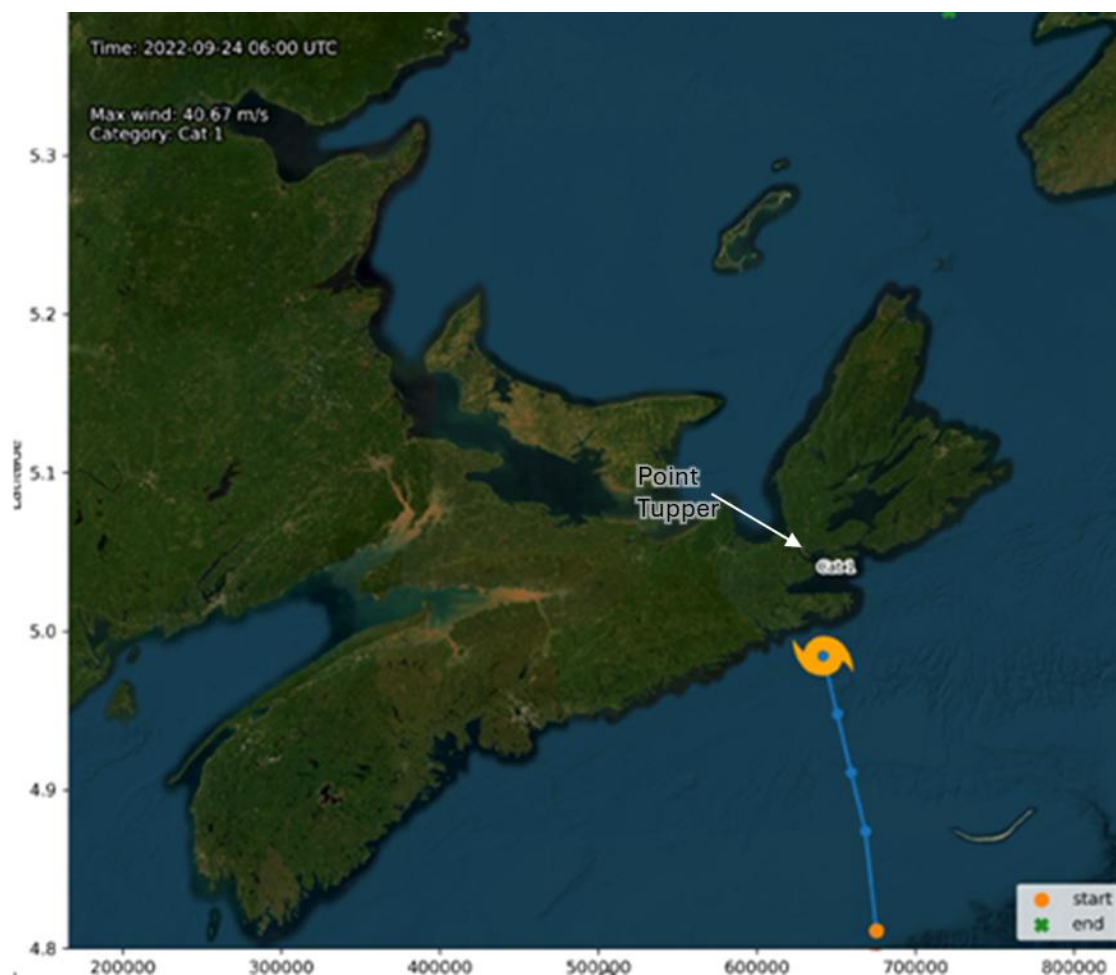


Figure 2-7: Hurricane Fiona's track before landfall: Category 1 at 6:00 UTC.

Figure 2-6 shows the size of the storm and the relation of its centre to Point Tupper, with a radius of approximately 100 nautical miles at landfall. Point Tupper experienced what was almost a “direct hit” from Hurricane Fiona, with significant storm impacts to PEI, northern Nova Scotia, the Magdalen Islands, and southwestern Newfoundland.

2.4.4.3 Storm Surge

The CHS tide gauge at Port Hawkesbury recorded water levels during the passage of Hurricane Fiona (Figure 2-8). This data shows that the highest recorded water level during the storm was 1.1 m CGVD2013 (2.5 m CD). The site was fortunate that the peak water levels coincided with a low tide on September 24, 2022, as the storm passed. If the predicted tide is subtracted from the observed water levels the difference is 2.01 m at its peak. This value is referred to as the **storm surge residual, which peaks at 2.0 m above the astronomical tide**. Since the tides and the passage of the storm are independent of one another, this storm surge residual may have happened at any tidal elevation which would have greatly increased the total observed water levels and led to significantly more flooding at the site. This is investigated in further detail in Section 3.3.1.

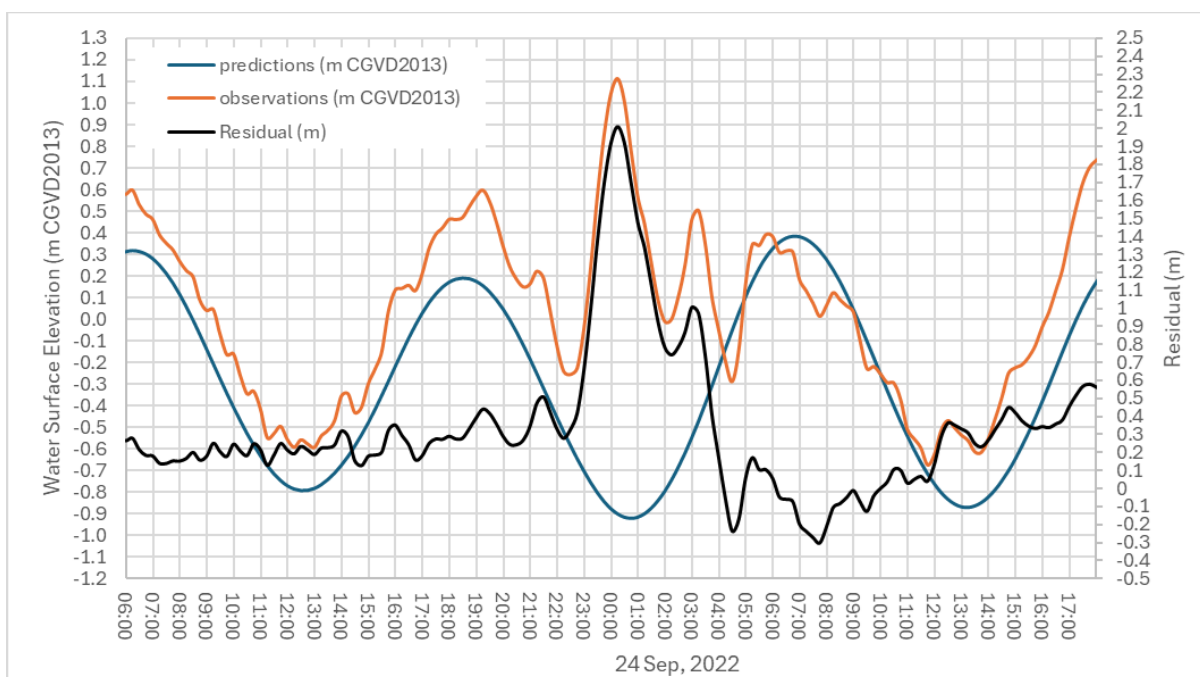


Figure 2-8: Hurricane Fiona water levels as measured at the Port Hawkesbury tide gauge (m rel. CGVD2013) (Sourced from tides.gc.ca).

2.4.5 Summary of Extreme Static Water Levels

The relevant calculated extreme static water level values for the Point Tupper project site, based on the analysis presented in the preceding sections, are summarized in Table 2-4.

Table 2-4: Extreme static water levels at the project site (CHS tide gauge, SSP5-8.5 median SLR scenario) (m CGVD2013).

Extreme Static Water Level	Present Day	2050	2100
Highest Astronomical Tide (HAT)	0.78	1.04	1.66
Hurricane Fiona	1.10	1.36	1.98
20-Year RP Extreme Water Level	1.27	1.53	2.15
100-Year RP Extreme Water Level	1.38	1.64	2.26

These water levels are expected to be held for a time (in the order of hours or minutes) and to change relatively slowly and are thus termed “static” water levels. Water levels expected to change quickly, such as the flooding caused by individual wave run-up and uprush, are termed “dynamic” water levels. Dynamic water levels are the focus of the wave run-up modelling section (Section 3.5) in this report.

2.4.6 Offshore Wind and Wave Conditions

2.4.6.1 Data Source

The offshore wind and wave climate analysis was completed based on the MSC50 Wave and Wind hindcast. This dataset is a 65-year hindcast funded by the Climate Research Division of Environment Canada and the Federal Program of Energy Research and Development and was provided for this study by Environment Canada. This data spans the period from January 1954 to December 2018, and contains hourly time series of wind (speed, direction) and significant waves (height, period, direction) for the location 45.20°N -60.70°W (Data point M6008267). The data set is a state-of-the-art hindcast, i.e. data computed from all existing wind and wave measurements were re-analysed and input to a 0.1-degree resolution ocean wave growth model that includes the effects of depth and ice cover. The MSC50 hindcast was developed by Oceanweather Inc. and is distributed by Environment Canada (Swail, et al., 2006). Monthly and yearly wave and wind roses are presented in Appendix A.

2.4.6.2 Extreme Values

The statistical analysis of the long-term MSC50 wave data estimates the likelihood of observing extreme values of offshore wind and significant wave height peaks, with their associated peak periods and direction parameters. Return periods for extreme significant wave heights (1, 5, 10, 20, 50, 100-year) were estimated based on an analysis of storm peaks using the “Peak-Over-Threshold”¹⁴ (PoT) for each direction of exposure. Significant wave height thresholds for this analysis were selected for each directional bin at a level to extract an average of two peaks for every year in the dataset, i.e. for the 64-year dataset, 128 peaks were selected for the PoT analysis. The best fitting generalized Pareto statistical distribution (GPD) was used to derive the extreme values. A most probable peak period (T_p) was derived from extreme wave heights based on the joint frequency distributions from the storm peaks. Additional plots and details are shown in Appendix A.

These extreme values were used as inputs to the nearshore wave transformation modelling.

¹⁴The PoT procedure selects statistically independent storm peaks occurring more than 48 hours apart. An extreme value distribution is then fitted to the population of storm peaks for extrapolating extreme events and their associated return periods.

3 Numerical Modelling

3.1 Description of Models

The modelling of flood conditions, the action of waves, and the effects of rainfall on coastal water levels at the project site was achieved using a combination of numerical models described below and summarized in Table 3-1.

- ▶ Storm surge produced by Hurricane Fiona was modelled using a coupled hydrodynamic and spectral wave model (MIKE21 SW and HD modules, model version 2025 for both modules).
- ▶ Hurricane sensitivity analysis was performed using the the Deltares Super-Fast INundation of CoastS (SFINCS) (Leijnse, 2020) model to test an array of possible storm tracks, followed by high-resolution of a final enhanced track with MIKE21.
- ▶ Nearshore wave conditions were modelled using a spectral wave model (MIKE21 SW). Inputs to the spectral wave model were extreme offshore conditions, as described in Section 2.4.6 and bathymetry and topography as described in Section 2.3.
- ▶ The nearshore wave conditions that are outputs of the spectral wave modelling were passed to a wave run-up model (Deltares XBeach). This model simulates wave run-up elevations along selected shoreline profiles. This process is summarized in Section 3.5.
- ▶ Compound flooding was investigated by combining the outputs of extreme rainfall modelled with CHI's PCSWMM stormwater management model and storm surge modelling with MIKE21 HDSW.

Table 3-1: Summary of models applied in coastal assessment.

Area of Application	Model	Objective	Main Inputs and Calibration	Outputs
Hurricane Fiona Modelling	2D Hydrodynamic model DHI MIKE21 HD	Water levels during Hurricane Fiona	Wind and pressure fields. Tide gauge observations.	Nearshore water levels
Hurricane Fiona Sensitivity Analysis	SFINCS	Sensitivity analysis of alternate hurricane tracks	Wind and pressure fields.	Hurricane storm surge level in Chedabucto Bay

Area of Application	Model	Objective	Main Inputs and Calibration	Outputs
Nearshore Wave Modelling	2D Spectral Wave model DHI MIKE21 SW	Wave conditions for wave run-up modelling	Offshore wind and wave conditions	Extreme nearshore wave conditions
Wave Run-up Modelling	Deltares 1D non-hydrostatic XBeach	Elevations of wave run-up along representative profiles during extreme events	Nearshore wave conditions and nearshore water levels	Wave run-up elevations
Coastal Storm Surge	Existing 2D coupled wave and hydrodynamic model DHI MIKE21 HDSW	Water surface elevations for basis of compound flooding analysis	Offshore wind and waves, Tide gauge observations.	Extreme water surface elevations
Compound Flooding Sensitivity Analysis (SWM)	CHI's PCSWMM stormwater management model	Flow of stormwater at coastal outfalls during extreme events	Heavy precipitation. Extreme coastal water levels.	Rainfall runoff
Compound Flooding Sensitivity Analysis (Coastal)	2D Hydrodynamic model DHI MIKE21 HD	Influence of heavy precipitation on coastal flooding	Coastal stormwater discharge. Offshore tidal water level predictions. Coastal storm surge.	Water levels seaward of hydraulic structures due to extreme precipitation and extreme storm surge.

Since the same methodology was not applicable for all assessed scenarios, Table 3-2 summarizes the models or methods applied for each of the scenarios described in Table 1-1.

Table 3-2: Assessed events and model or method applied.

Event	Scenarios (as per Table 1-1)	Model or Method Applied
HAT	1, 10, 17	CHS Tide Elevations
20-year Storm Surge	2, 11, 18	EVA of CHS tide gauge data
100-year Storm Surge	3, 12, 19	
Hurricane Fiona	4, 13, 20	CHS Tide Gauge Measurements
Hurricane Fiona (Enhanced Scenario)	5, 14, 21	MIKE21 HDSW Hurricane Model
100-year Storm Surge + 20-year rainfall	6, 22	EVA of CHS tide gauge data + PCSWMM
100-year Storm Surge + 100-year rainfall	7, 23	
20-year Storm Surge + wave run-up	8, 15, 24	EVA of CHS tide gauge data + CBCL MIKE21 HDSW + XBeach
100-year Storm Surge + wave run-up	9, 16, 25	
Year-2050 and year-2100 scenarios assessed as above +SLR. For XBeach modelling SLR added to model boundary conditions, for remaining scenarios SLR added to results.		

3.2 Hurricane Fiona Modelling

Modelling of storm surge at Point Tupper due to Hurricane Fiona was undertaken by building a hurricane model of Atlantic Canada and the Gulf of Saint Lawrence using the coupled hydrodynamic and spectral wave modules included with the MIKE21 software suite, with wind and pressure fields generated by the MIKE21 cyclone model based on the storm's best track data.

3.2.1 Model Inputs

3.2.1.1 Bathymetry

As discussed in Section 2.1, model bathymetry for the areas close to the site was sourced from the CHS Non-Navigational bathymetry dataset in CD, and converted to CGVD2013 using the method outlined in Section 2.1. Bathymetry at Point Tupper is shown in Figure 2-1. Bathymetry that was more than 10 km from the project site was sourced from the General Bathymetric Chart of the Oceans (GEBCO).

3.2.1.2 Hurricane Data

As discussed in Section 2.4.4, data concerning the track and severity of Hurricane Fiona is available through the National Oceanographic and Atmospheric Administration (NOAA), and the International Best Track Archive for Climate Stewardship (IBTrACS) project (Knapp et al. 2010). Through this agency, the tropical cyclone data relevant to the storm surge modelling can be accessed. This is provided as a timeseries of location, storm radius, pressure, and wind

speed, among other variables. Taken together, this data describes the track and evolution of the storm (Figure 2-6).

3.2.2 Model Setup

3.2.2.1 Model Mesh

The numerical grid, or mesh, for this project was built for an area encompassing Atlantic Canada out to the continental shelf, between (71°W, 41°N and 42°W, 52°N). The resolution of the flexible mesh is varied by bathymetric depth, with deep offshore areas having much larger resolution than shallower areas closer to land. Model cell resolution along the coast of Point Tupper is approximately 200 m, while at the model boundary is approximately 20 km. The 200 m nearshore resolution was chosen to adequately represent the scale of water level changes in the nearshore areas, with modelled storm surge values changing gradually from cell to cell, as well as to balance computational efficiency. The offshore resolution, which is in very deep water (1 to 5 km of water depth) and several hundred km from land, was chosen for computational efficiency. The model mesh's resolution was refined between the offshore and nearshore as a function of water depth.

3.2.2.2 Model Boundary Conditions

The Hurricane Fiona data (Section 3.2.1.2) was converted to two-dimensional wind and pressure fields using the MIKE21 Cyclone Wind Generation tool. This tool applies the Young and Sobey parametric hurricane model to the IBTrACS hurricane data. Default wind correction parameters were used for geostrophic correction, forward motion asymmetry, and inflow angle. A snapshot of the wind field used as input to the hurricane model is shown in Figure 3-1, with pressure field shown in Figure 3-2. These are uniform grids with a cell resolution of 0.05° x 0.05°, (approximately 4 km x 4km).

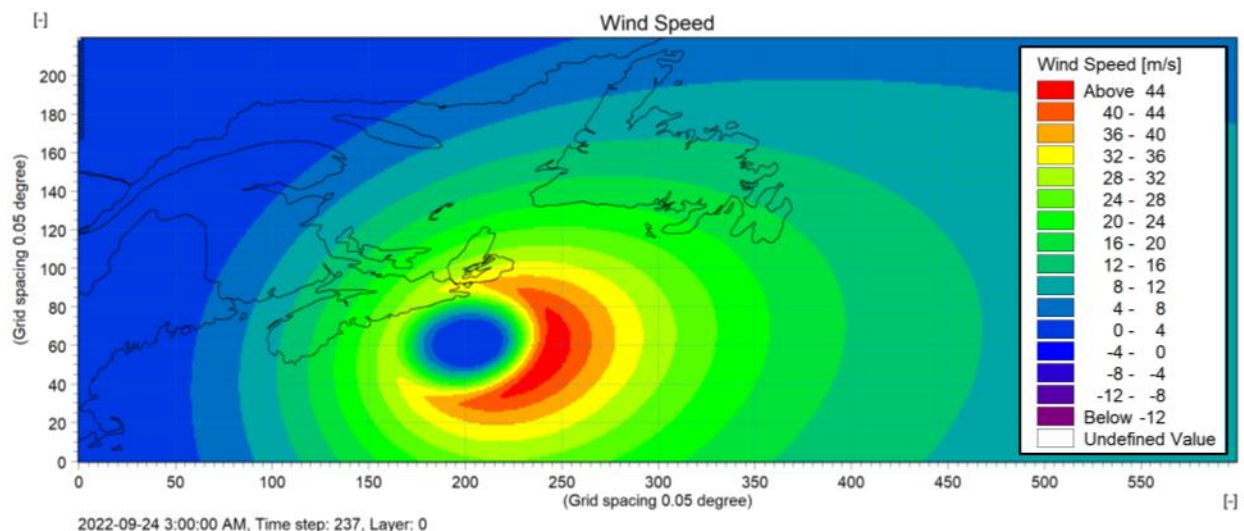


Figure 3-1: Wind field used as input for Hurricane Fiona modelling. Timestep shown is September 24, 2022, at 03:00 UTC.

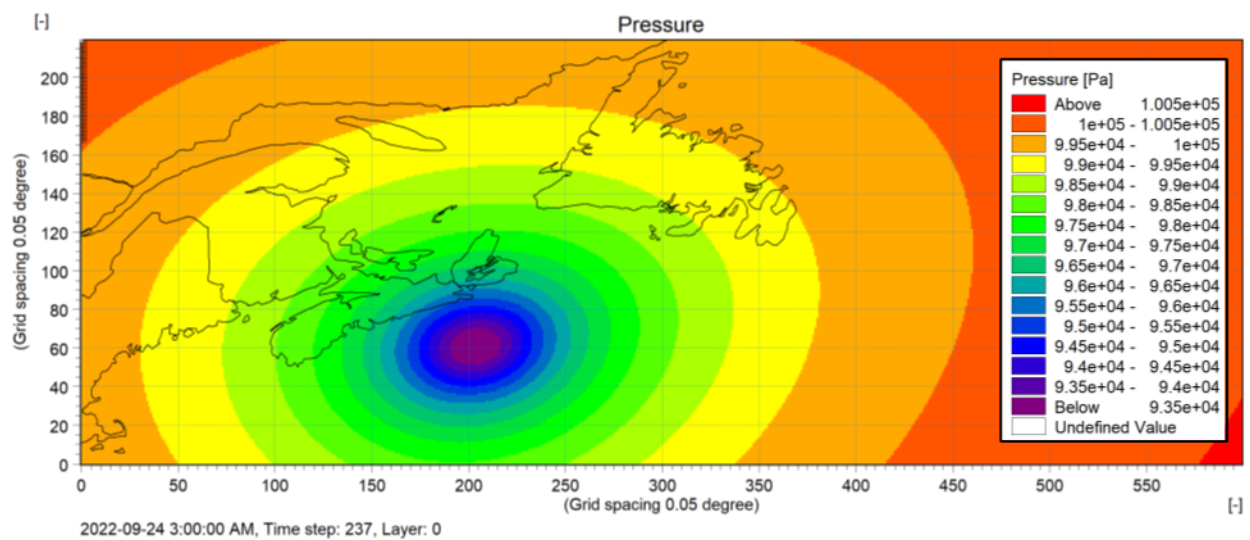


Figure 3-2: Pressure field used as input for Hurricane Fiona modelling. Timestep shown is September 24, 2022, at 03:00 UTC.

3.2.2.3 Hurricane Model Calibration

Calibration of the hurricane model was achieved by adjustment of the hydrodynamic module's wind speed parameters until the modelled peak storm surge residual was within 0.01 m of the measured peak storm surge residual at the Port Hawkesbury CHS tide gauge. This parameter¹⁵ was adjusted to vary with wind speed, with a linear variation between a friction factor of 0.001255 at wind speeds of 7 m/s to a friction factor of 0.00358 at wind speeds of 15 m/s.

A timeseries comparison of the measured and modelled storm surge residual at Port Hawkesbury is shown in Figure 3-3. Measured values are sourced from the CHS tidal station observations with the predicted tidal elevations removed, and modelled residuals are the water level heights above an assumed water surface elevation of 0 m. The peak of the storm agrees well between the measured and modelled storm surge, with oscillations and water surface disruptions in the measured data not present in the idealized modelled case.

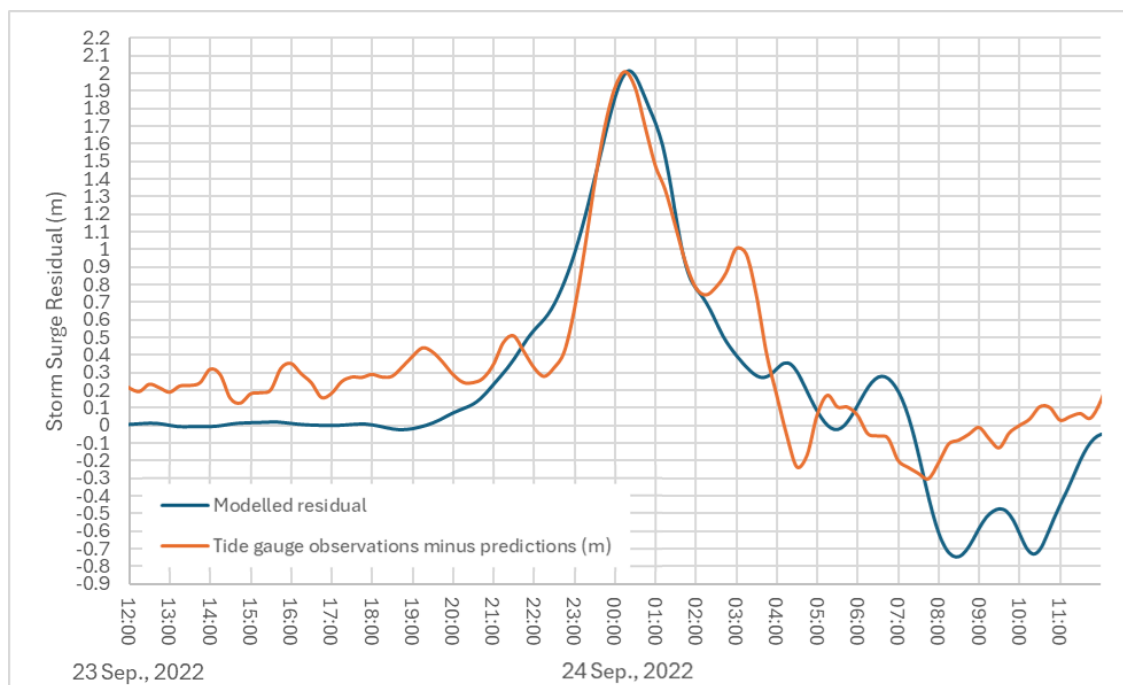


Figure 3-3: Modelled and measured storm surge residual at Port Hawkesbury tide gauge.

¹⁵ This drag coefficient is recommended as a model calibration parameter in the MIKE FM Hydrodynamic Module documentation. Additional hydrodynamic model parameters include a minimum timestep of 0.01 s, a maximum timestep of 600 s, and a CFL number of 0.8. Higher order time integration and space discretization were used. A constant bed resistance value (Manning's M) of 32 m^(1/3)/s was used. Spectral wave model setup parameters include a frequency discretization into 25 frequencies, and directional discretization into 16 directions. The SW model's minimum time step is 0.01 s, maximum time step is 600 s, and uses a "Low order, fast algorithm" geographical space discretization. Air-sea interaction is coupled with a background Charnock parameter of 0.01, growth parameter of 1.2, and wave age tuning parameter of 0.011.

A comparison of measured and modelled values across the Gulf of St. Lawrence is shown in Figure 3-4. Measured peak water level values during the storm are derived from CHS tide gauge data (observed water levels minus predicted water levels), and modelled values are the height of storm surge modelled by the Hurricane Fiona MIKE21 model. Tidal stations shown here were subject to significant storm surge during Hurricane Fiona¹⁶.

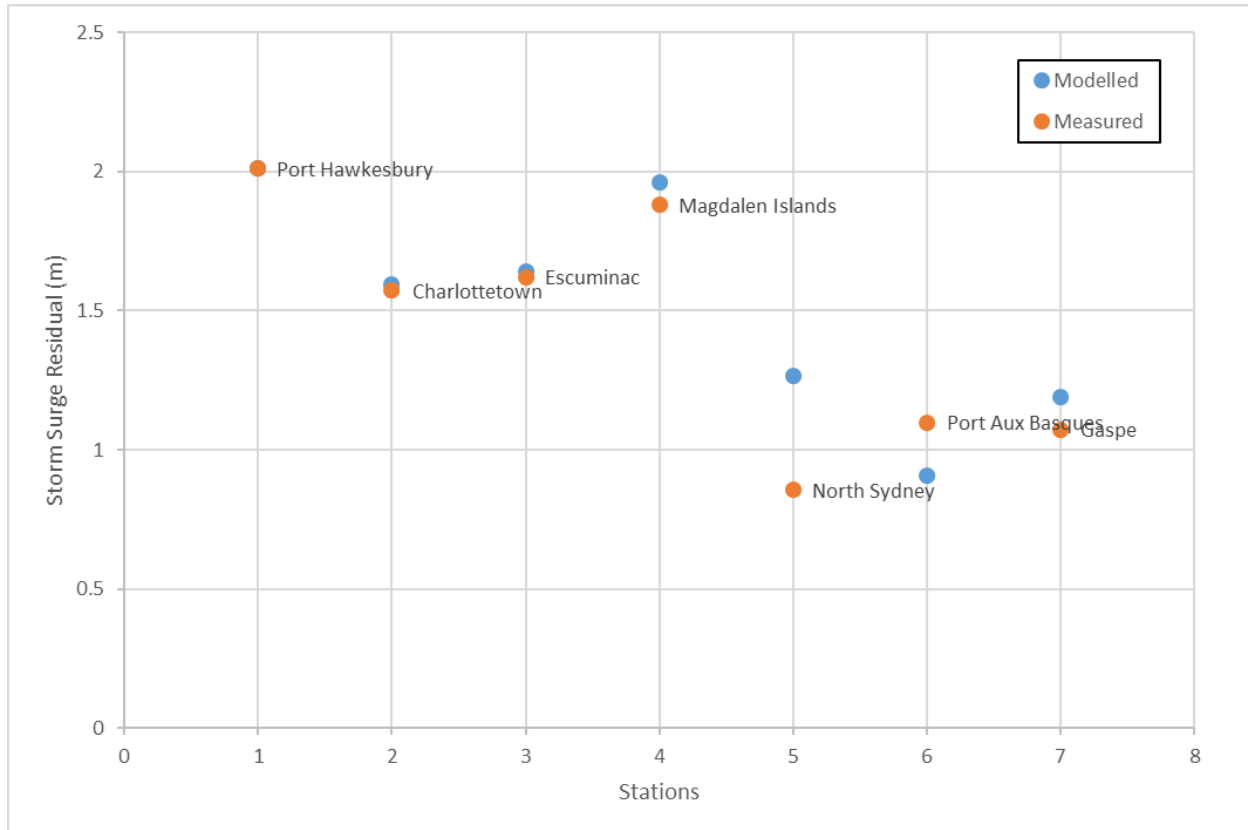


Figure 3-4: Comparison of measured and modelled storm surge residuals at Atlantic tide gauges.

The difference between measured value and modelled value of storm surge residuals for the Atlantic tide gauges is presented in Table 3-3.

¹⁶ It is believed a portion of the difference between observed and modelled storm surge at North Sydney (and potentially Port-aux-Basques) may be due to a local harbour seiche effect (i.e. long wave oscillation) specific to Sydney Harbour that is not captured by the large-scale hurricane model and is beyond the scope of this assessment.

Table 3-3: Difference between measured and modelled storm surge residual for Hurricane Fiona.

Tide Station	Measured Value (m)	Modelled Value (m)	Difference (m)	Difference (%)
Port Hawkesbury	2.01	2.01	0.00	0.1%
Charlottetown	1.57	1.59	0.02	1.3%
Escuminac	1.62	1.64	0.02	1.3%
Magdalen Islands	1.88	1.96	0.08	4.1%
North Sydney	0.86	1.27	0.41	32.3%
Port Aux Basques	1.10	0.91	-0.19	-20.9%
Gaspe	1.07	1.19	0.12	9.9%

3.2.3 Model Results

Results of the MIKE21 hydrodynamic and spectral wave modelling of Hurricane Fiona are shown below. Figure 3-5 show the modelled Fiona storm surge residual at its highest modelled level. This coincides with the recorded high-water levels at the CHS tide gauge. Figure 3-6 shows the modelled waves from the Hurricane Fiona modelling at this same time.

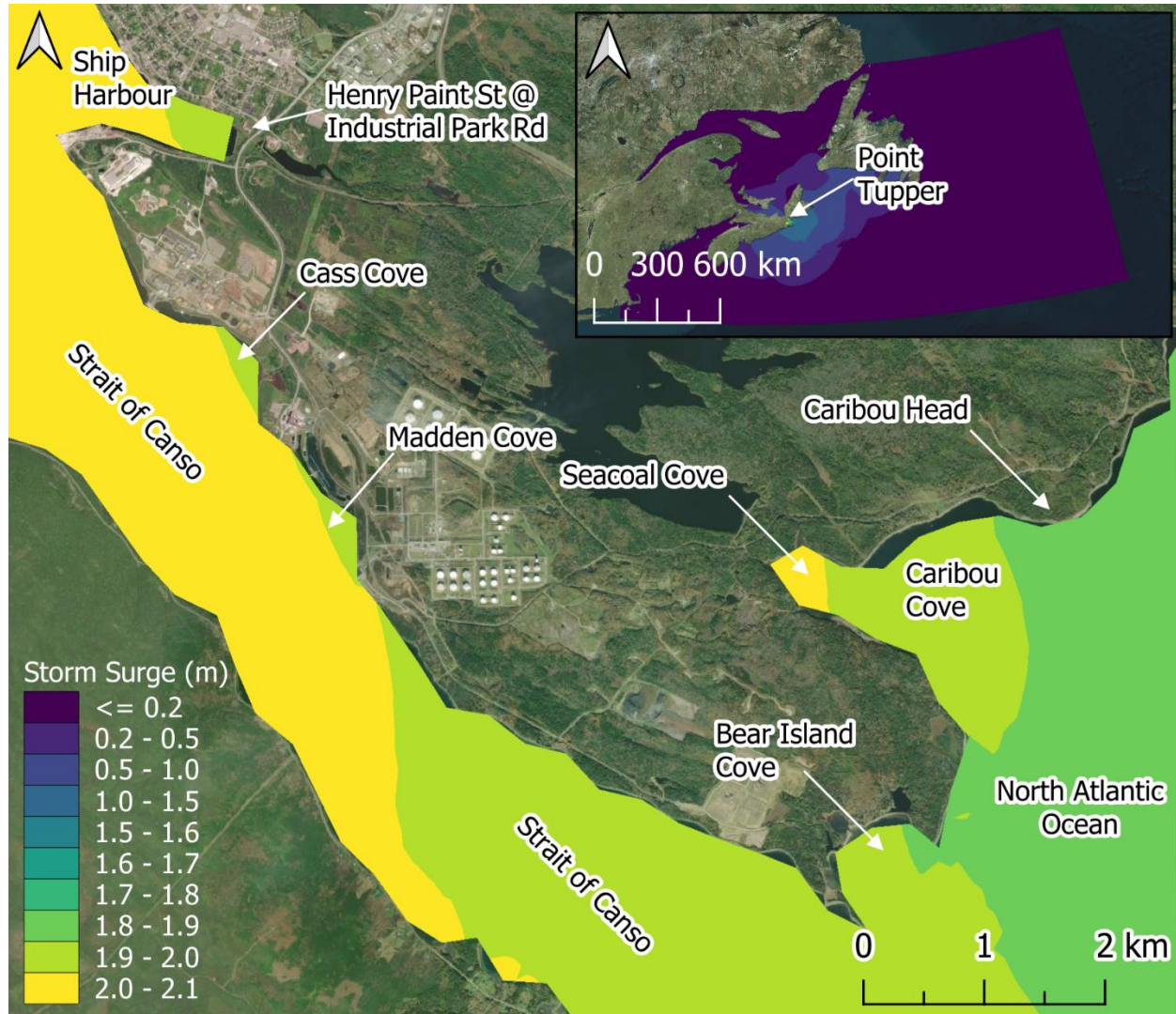


Figure 3-5: Storm surge model results for Hurricane Fiona (September 24, 2024, 03:20 UTC) showing storm surge residual at Point Tupper.

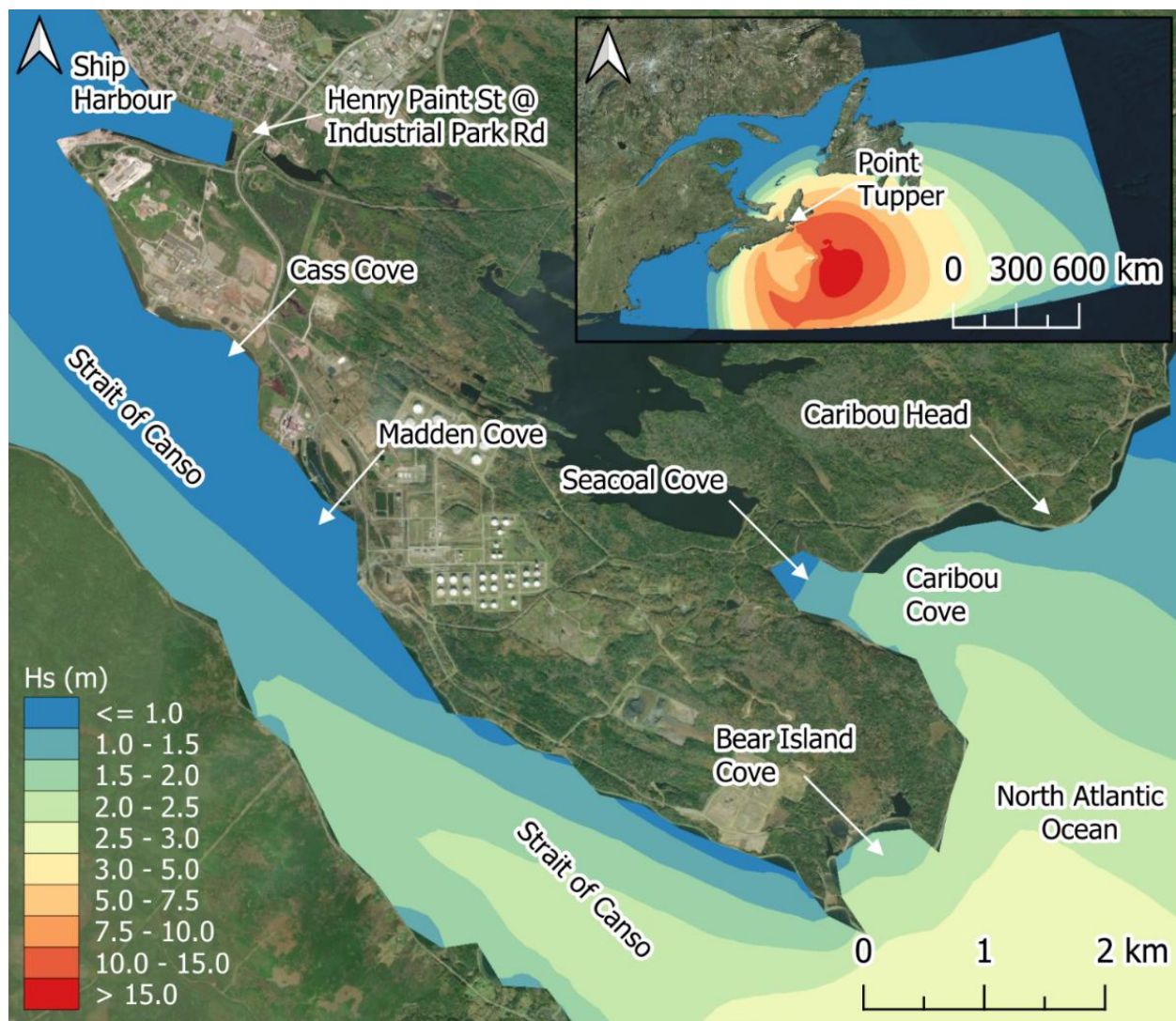


Figure 3-6: Wave model results for Hurricane Fiona (September 24, 2022, 03:20 UTC) showing modelled significant wave height at Point Tupper.

Table 3-4 summarizes the values of storm surge residual (see Section 2.4.4.3) and wave parameters during the peak modelled storm surge at locations shown in Figure 3-6.

Table 3-4: Summary of Hurricane Fiona model results at Point Tupper locations. Values during peak modelled storm surge (September 24, 2025, 2022 03:20 UTC).

Location	Storm Surge Residual (m)	Hs (m)	Tp (s)
Ship Harbour (CHS Tide Gauge)	2.01 (observed residual = 2.0 m)	0.30	2.0
Cass Cove	2.00	0.30	4.6
Madden Cove	1.99	0.40	4.4
Strait of Canso (Bear Island Road at Bear Island Road)	1.98	0.98	4.8
Bear Island Cove	1.93	1.75	5.0
Seacoal Cove	2.01	0.90	4.10
Caribou Head	1.87	1.30	3.8

The modelled storm surge residual values for Hurricane Fiona do not vary significantly throughout the project area, with differences in modelled values across the project site in the order of 0.1 m.

Additional storm surge modelling performed by CBCL for the Eastern Shore Coastal Flood Line Mapping project¹⁷, under the FHIMP program, shows modelled variation of water levels of less than 0.1 m during the 100-year storm surge event.

Sensitivity analyses with local slopes indicate that this limited spatial variability introduces no measurable decision-making difference between using a static surface and a spatially varying surface. It is therefore reasonable to apply the water levels calculated at Ship Harbour, the location of the CHS gauge, to the site.

Conversely, there is significant spatial variation in modelled wave heights during Hurricane Fiona, with Bear Island Cove's modelled wave values of 1.75 m compared to Ship Harbour's 0.3 m.

Therefore, for the purposes of flood mapping over the limited project area, dynamic water levels are based on spatially varying wave run-up modelling superimposed to extreme static water levels as calculated from the tide gauge and enhanced hurricane modelling. Mapping of these results is shown in Section 4.

¹⁷ The modelling report for this project is not published online but may be available by request through FHIMP program representatives.

3.3 Hurricane Sensitivity Analysis

The Hurricane Fiona Sensitivity Analysis is part of the site-specific scope for this project. The objective of the analysis is to determine to what extent flooding at Point Tupper would have increased if Hurricane Fiona had occurred at high tide and followed a different track. This section presents sensitivity analyses to support the development of an 'Enhanced' hurricane scenario.

3.3.1 Sensitivity to Tidal Elevation

Hurricane Fiona's largest storm surge occurred with a tidal elevation of approximately -0.90 m CGVD2013 (Section 2.4.4.3). This coincides with a low tide at the site. If this storm event were to have occurred during a different stage of the tidal cycle, the total water level (tide + storm surge) would have been considerably higher (Table 3-5). For example, had Hurricane Fiona's peak storm surge coincided with the HAT, the resulting total water level would have been 2.8 m CGVD2013, which is 1.7 m higher than the observed surge and 0.5 m higher than the water levels projects for the 100-year RP event with year-2100 SLR. This scenario is shown in preliminary flood maps in Section 4. If Hurricane Fiona had occurred just six hours later, at the high tide of September 24, 2022, the total water level would have been approximately 1.3 m higher than what was observed. Therefore, the 'Enhanced' hurricane scenario will be developed to purposely occur at HAT.

Table 3-5: Hurricane Fiona storm surge residual applied to various tidal elevations.

Reference Height	Tide m CGVD2013	Total Water Level (Fiona Surge + Tide) (m CGVD2013)
Highest Astronomical Tide (HAT)	0.78	2.79
Higher High Water Large Tide (HHWLT)	0.75	2.76
Higher High Water Mean Tide (HHWMT)	0.40	2.41
High Tide (September 24 2022)	0.37	2.38
Mean Water Level (MWL)	-0.30	1.71
Observed Hurricane Fiona peak	-0.90	1.11
Lower Low Water Mean Tide (LLWMT)	-0.95	1.06
Lower Low Water Large Tide (LLWLT)	-1.28	0.73

Note: for reference, estimated present 100-year return extreme water level is 1.38 m CGVD2013.

3.3.2 Sensitivity to Hurricane Track

3.3.2.1 Methodology

The analyses used Hurricane Fiona's storm intensity shortly before landfall (September 24, 2022, at 06:00 UTC) and applied it to alternative track ensembles. These enhanced storms were then modelled to derive nearshore storm surge levels. The methodology is summarized in the flowchart below.

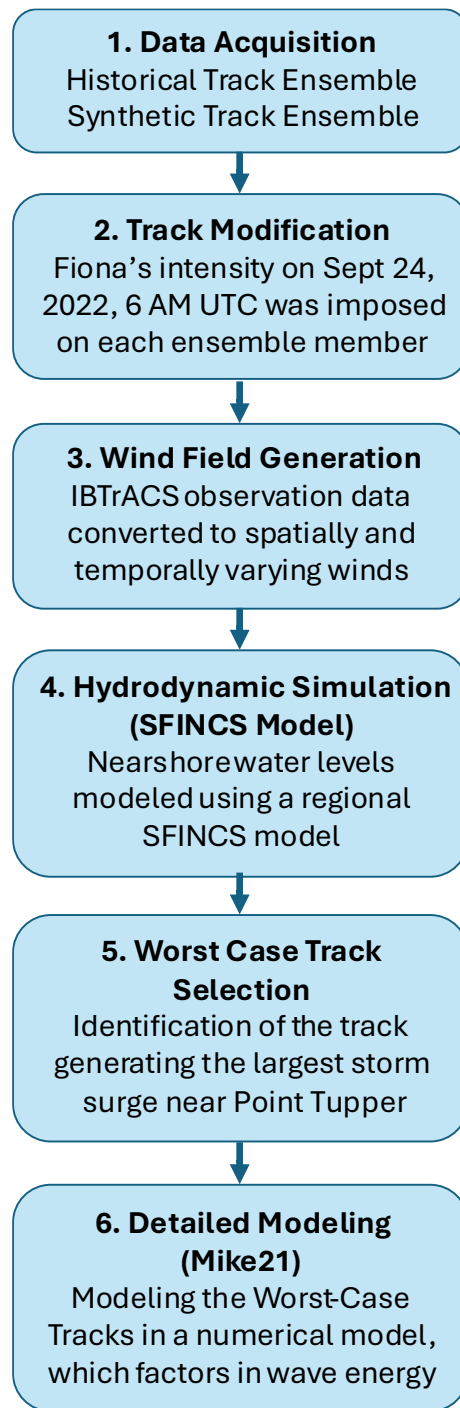


Figure 3-7: Methodology used to conduct the Hurricane Fiona sensitivity analysis.

The purpose of this analysis is to investigate potential worst-case tracks for the Point Tupper area using a lower resolution regional model followed by high-resolution modelling that resolves local bathymetry and site-specific processes.

3.3.2.2 Cyclone Track Ensemble and Wind Field Generation

Historical analysis using IBTrACS data reveals that Point Tupper has been exposed to 188 post-tropical cyclones within a 300 km radius since 1851. Among these, 44 reached Category 1 strength or higher. These findings highlight the region's vulnerability to strong winds and heavy precipitation from cyclones.

Ensembles of tracks were used as paths along which Fiona's winds and central pressure were forced. Two ensembles were used, one consisting of historical cyclone tracks passing within 300 km of Point Tupper and the other determined by random deviations of the original Fiona track after September 24, 2022, at 12 am UTC. These two ensembles are shown in Figure 3-8 below.

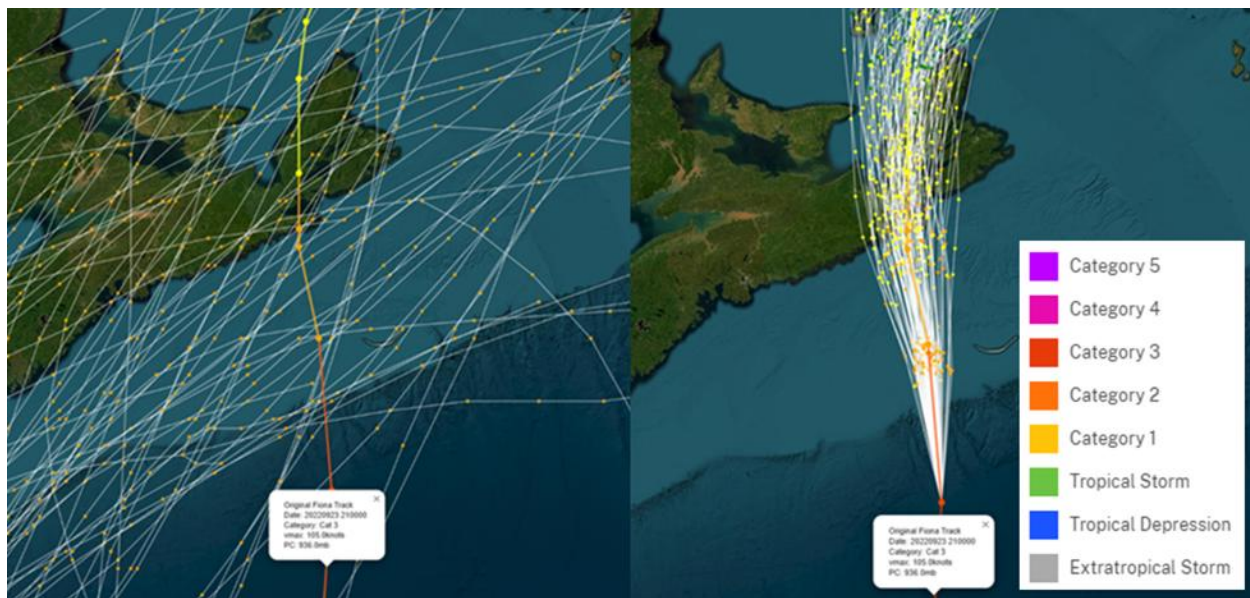


Figure 3-8: Hurricane Fiona ensembles: historical tracks (left) and synthetic tracks (right).

Once these relevant tracks were identified, the cyclone quadrant observation data from the IBTrACS were used to fit a tropical cyclone parametric wind field model (Holland, 2010). Observational data from Hurricane Fiona on September 24, 2022, at 6 am UTC were converted to wind fields as shown in Figure 3-9 and used to force a numerical model (SFINCS, described in the following section) and derive nearshore storm surge levels.

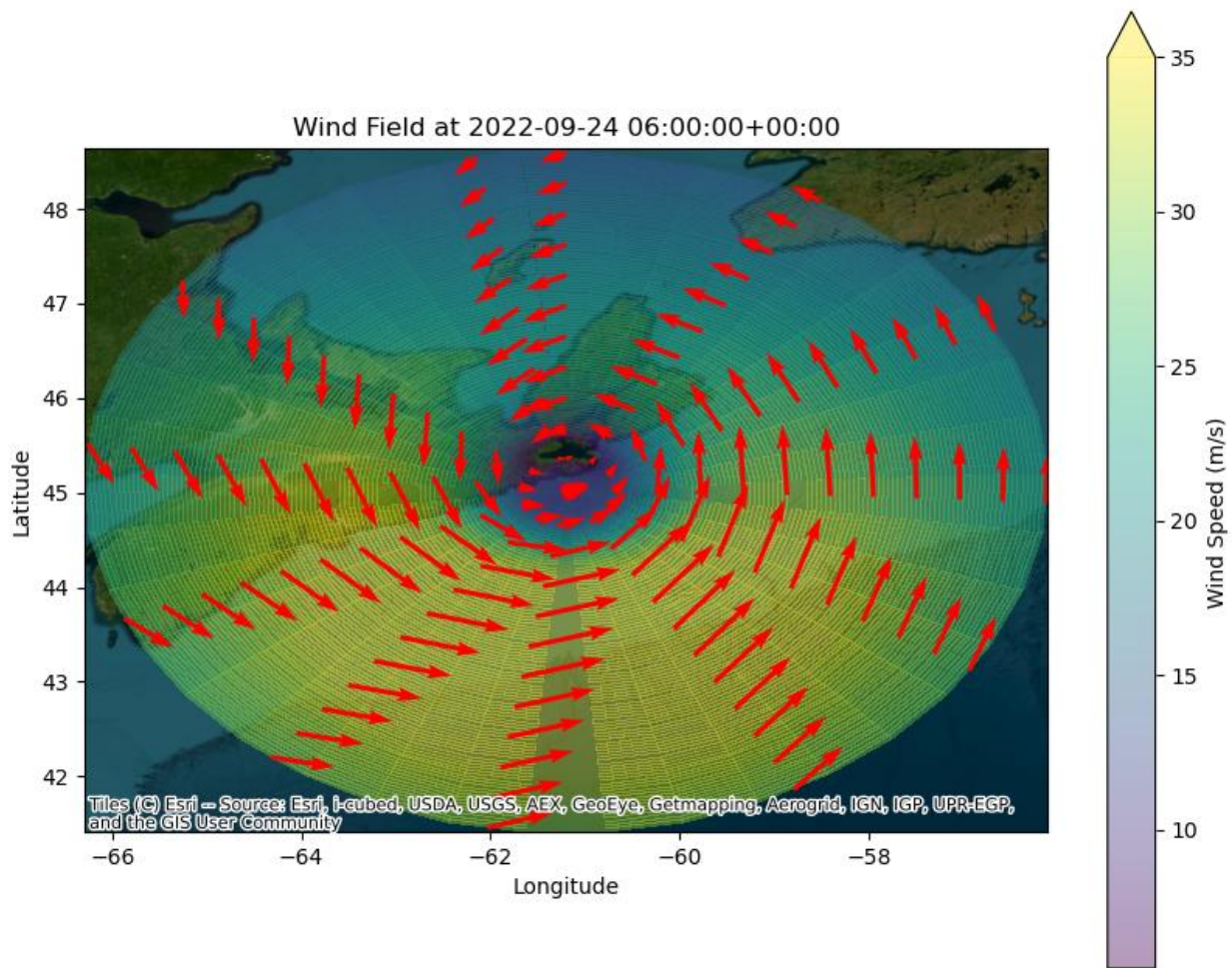


Figure 3-9: Hurricane Fiona's wind field on September 24, 2022, at 6:00 UTC, generated using the Holland parametric model.

3.3.2.3 Regional Hurricane Modelling

The historical storm analysis is based on a large-scale, low resolution model suitable to investigate a large number of scenarios from both historical and synthetic tracks. The objective of this exercise was to narrow down the number of scenarios to be simulated with the high-resolution model described in Section 3.2.

Model Description

Large-scale, hurricane-induced storm surges can be modeled using physics-based numerical models such as Super-Fast INundation of CoastS (SFINCS). This recent model solves the simplified momentum and continuity shallow water equations using reduced-physics, allowing it to reduce computation time without significant trade-offs in accuracy when compared to other fully-physics-based models (such as XBeach, Delft3D, or MIKE21).

The SFINCS model was developed using bathymetry data from the GEBCO 2025 grid combined with publicly available nearshore datasets to represent coastal terrain, as shown in Figure 3-10. To balance computational efficiency with spatial detail, an iterative process determined that a

2000 m resolution mesh was reasonable to resolve Chedabucto Bay while maintaining reasonable model runtime.

Model parameters were selected to support stable and efficient simulations while capturing the large-scale surge dynamics relevant to the study area. Friction was represented using Manning's roughness coefficients, applying a simple land-sea partition: dry areas were assigned a value of $0.04 \text{ s/m}^{1/3}$, while submerged areas were assigned $0.02 \text{ s/m}^{1/3}$. The internal timestep was allowed to vary between $1.0 \times 10^{-3} \text{ s}$ and 60 s based on the Courant–Friedrichs–Lewy (CFL) condition, with results stored at 3600 s intervals. A constant eddy viscosity coefficient of 0.01 was applied throughout the domain.

Model suitability was evaluated by benchmarking the Hurricane Fiona surge results against those from a more detailed MIKE21 HD simulation. This comparison showed that the reduced-physics SFINCS setup could capture the large-scale surge dynamics required for the sensitivity assessment of this study. Holland-model-derived wind fields were generated for each member of the historical and synthetic ensembles using the Delft Dashboard toolbox¹⁸.

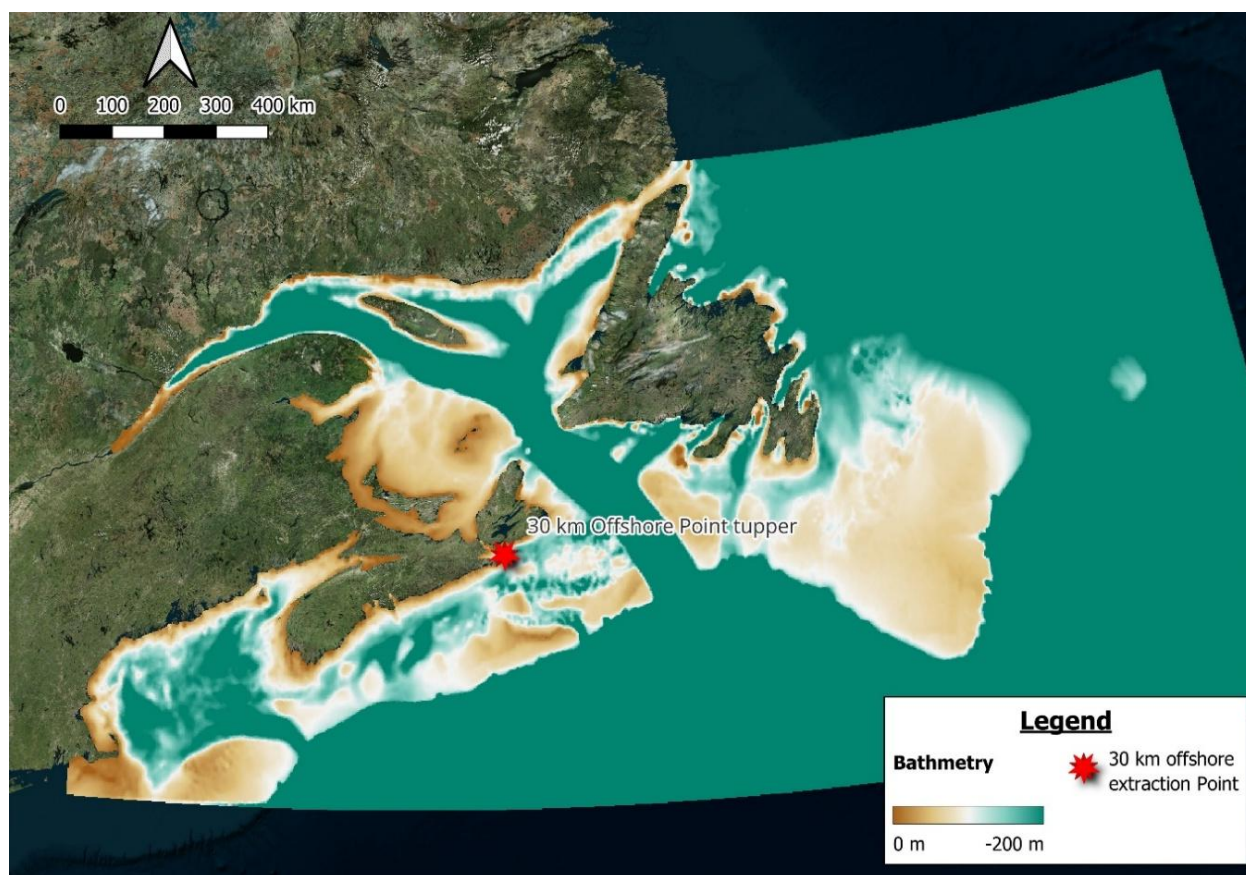


Figure 3-10: SFINCS model extents and bathymetry used in the storm surge analysis.

¹⁸ <https://github.com/Deltares-research/DelftDashboard>

Model Results

Hurricane Fiona was simulated using SFINCS, with a model snapshot presented in Figure 3-11 illustrating the simulated storm surge.



Figure 3-11: Residual storm surge generated by Hurricane Fiona using the SFINCS numerical model. Water level changes in this figure are due to modelled storm surge.

The historical and synthetic wind fields were then used to model hypothetical storm surges in SFINCS. The resulting storm surge levels were extracted for an output location in Chedabucto Bay to the east of Point Tupper (marked by the red star in Figure 3-10). The storm surge timeseries generated by the historical tracks were overlaid, and their maximum storm surges extracted as shown in Figure 3-12. Similarly, the storm surge timeseries generated by the synthetic tracks were overlaid, and their maximum storm surges extracted as shown in Figure 3-13.

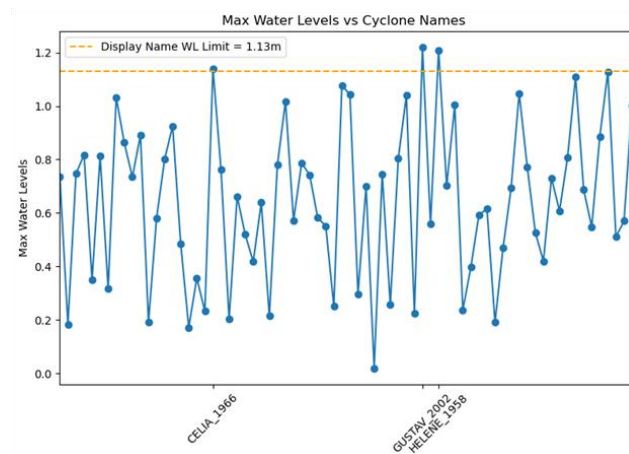
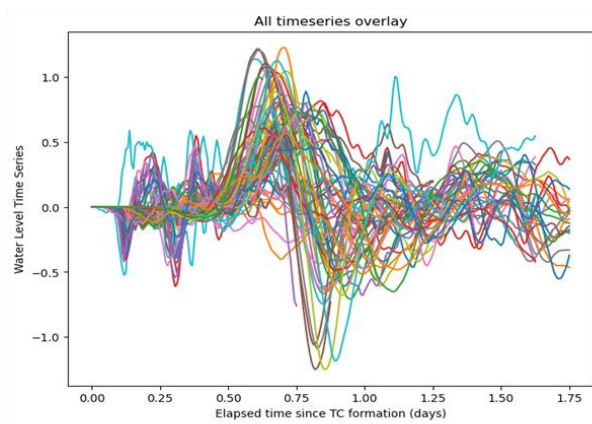


Figure 3-12: Residual storm surge time series from historical tracks (left) and maximum surge per track (right) in Chedabucto Bay. Cyclone names displayed for top 3 storms.

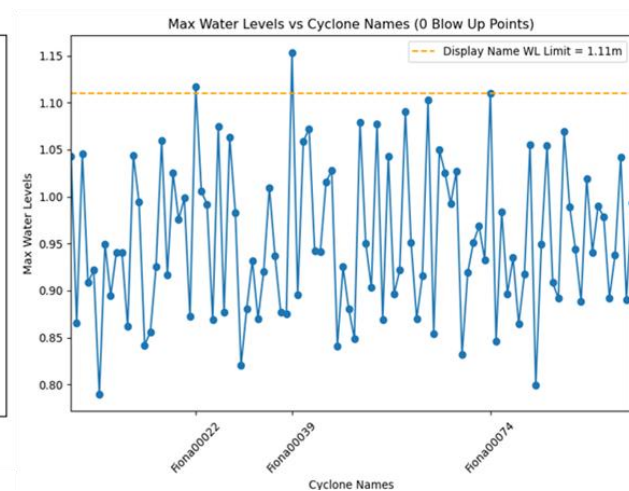
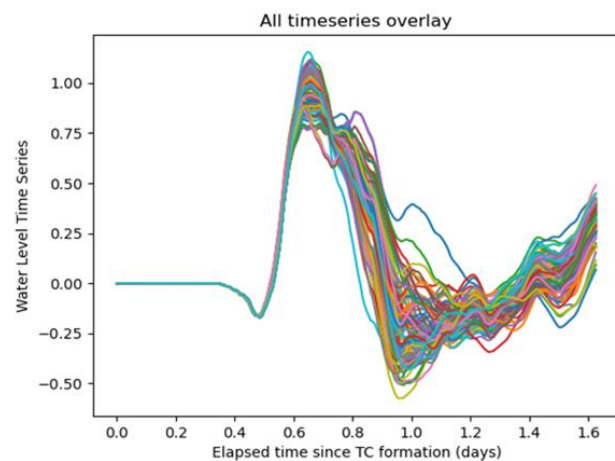


Figure 3-13: Residual storm surge time series from synthetic tracks (left) and maximum surge per track (right) near Point Tupper. Cyclone names displayed for top 3 storms.

The largest storm surge modelled in Chedabucto Bay was obtained with a synthetic track relatively close to that of the actual storm, with Hurricane Fiona wind speed and pressure fields. This finding was then further investigated with the high resolution model described in 3.2.

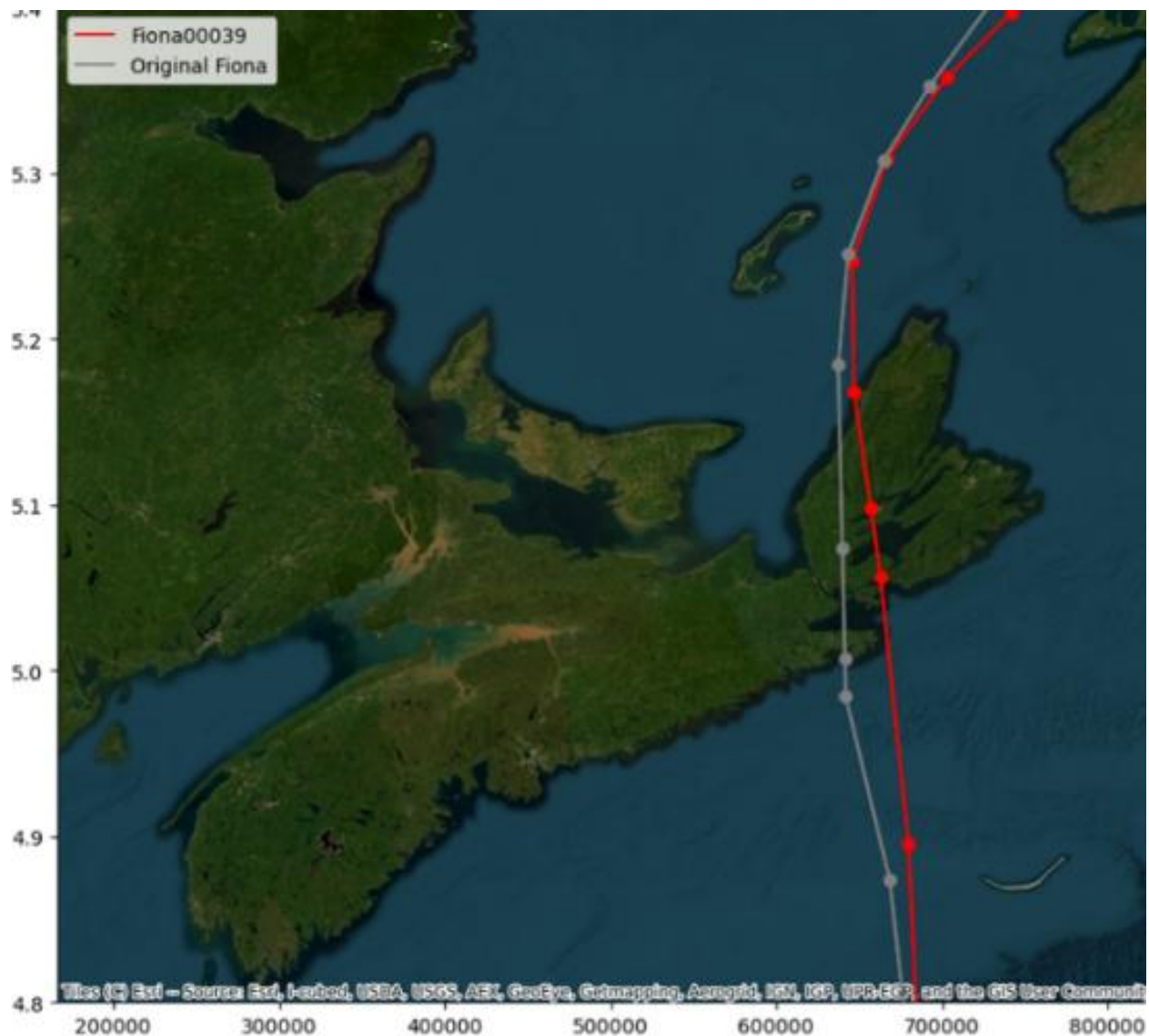


Figure 3-14: Tracks producing the highest modelled residual storm surge near Point Tupper: historical ensemble (left) and synthetic ensemble (right). Red tracks indicate surge-maximizing paths, grey track shows Hurricane Fiona's original path.

3.3.2.4 High-Resolution Hurricane Modelling

The large-scale regional hurricane modelling was followed by higher-resolution modelling that resolves the Strait of Canso, with finer increments of track adjustments in 0.1 degree over the project site.

The MIKE21 model calibrated to Hurricane Fiona¹⁹ was applied to an enhanced Hurricane Fiona scenario with a direct-hit track at high tide as follows:

- ▶ The storm was simulated to occur with the tide at the HAT water level
- ▶ The storm track was shifted to the west by increments of 0.1° longitude (up to a total of 0.4) for a “direct hit” of Point Tupper, after further track sensitivity analyses with MIKE21.

All other model inputs were as described in Section 3.2.



Figure 3-15: Actual Hurricane Fiona track location versus sample shifted track location.

The track causing the highest modelled water level at Point Tupper was Hurricane Fiona’s shifted 0.3 deg to the west, which was adopted as the Enhanced scenario presented next.

3.3.3 Enhanced Hurricane Fiona Scenario

A timeseries of modelled vs tide gauge observations is shown in Figure 3-16. From this figure, we note an approximate 2 m difference in peak water levels between the observed Hurricane Fiona and the modelled enhanced scenario. The primary driver of this difference is the difference in tidal elevation during the enhanced storm scenario (HAT, or +0.78 m CGVD2013) vs the predicted tidal elevation during the storm of -0.92 m CGVD2013, or a difference of 1.70 m.

The difference in increased storm surge level due to the storm’s track accounted for approximately 0.3 m of the difference between the enhanced scenario and the observed water levels.

¹⁹ See Section 3.2.2.3 for model calibration details.

Peak modelled water levels at Point Tupper during the peak of the enhanced scenario are shown in Figure 3-17. Flood maps of this scenario in present-day climate, 2050, and 2100 are shown in Appendix E.

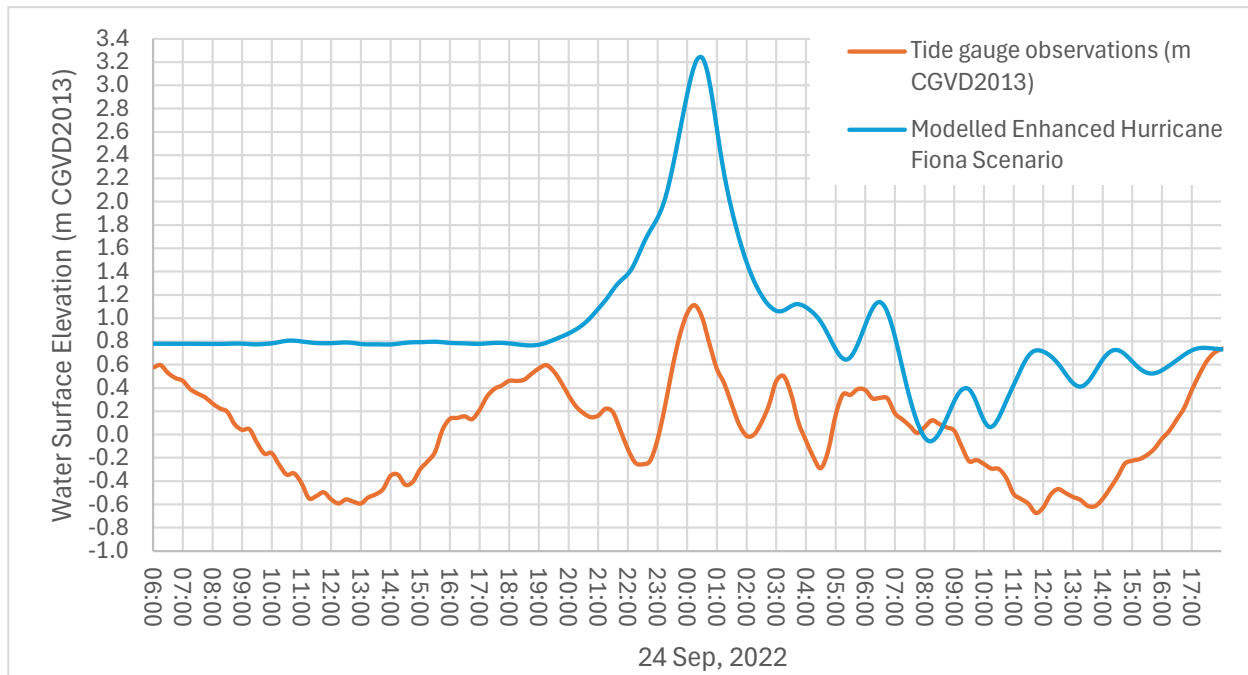


Figure 3-16: Modelled extreme total water levels in Hurricane Fiona Enhanced Scenario compared to CHS tide station observed water levels.

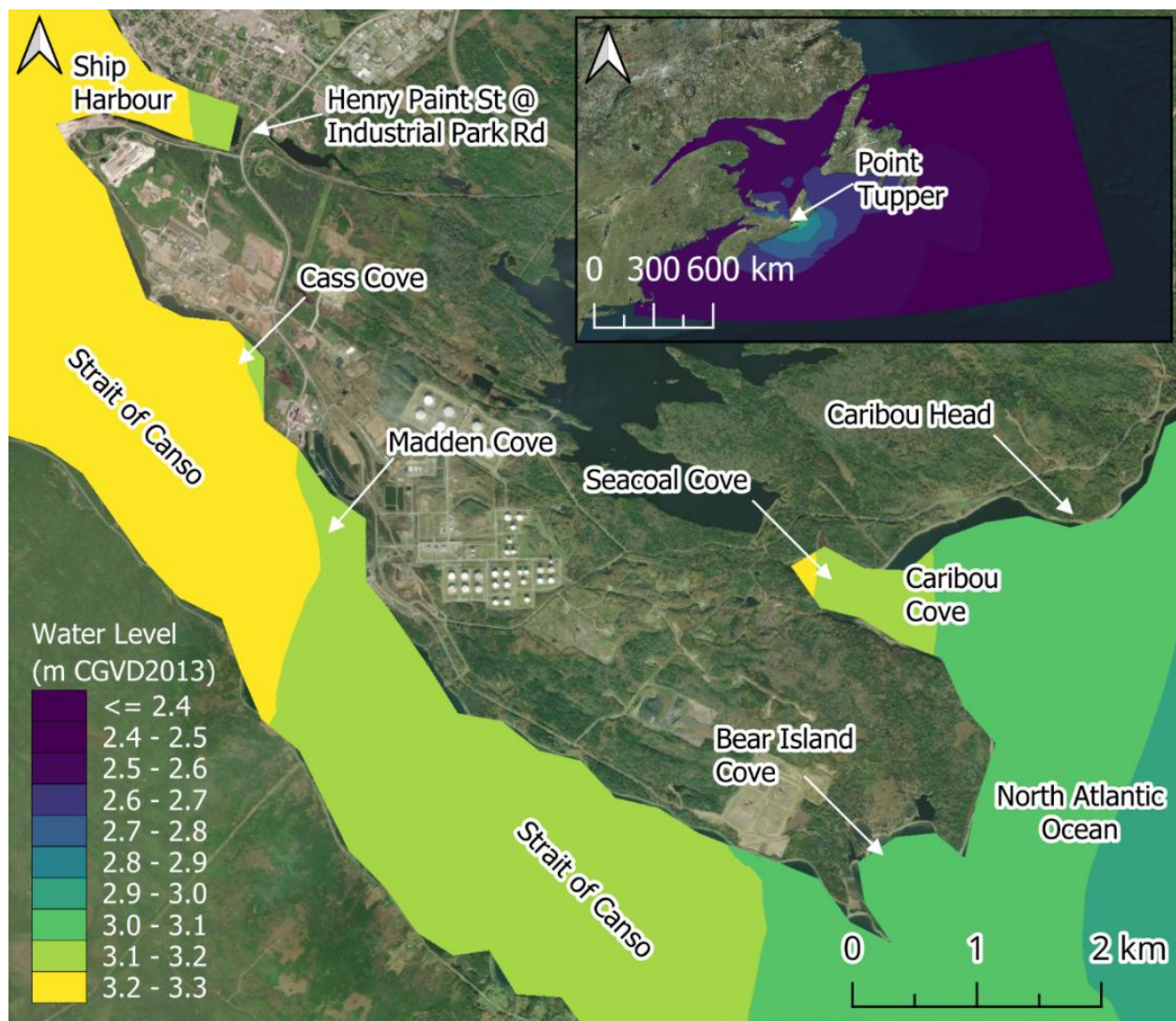


Figure 3-17: Peak modelled water levels during the enhanced Hurricane Fiona scenario.

3.4 Nearshore Wave Modelling

The nearshore wave modelling was completed by transforming extreme offshore wave conditions (as described in Section 2.4.6) to the project site by using the spectral wave model MIKE21 SW. This model is described in detail in CBCL's Eastern Shore Coastal Flood Line Mapping project, under the FHIMP program.

The resulting wave map for the model domain and project site is shown in Figure 3-18, representative of the 100-year return period extreme event from the east.

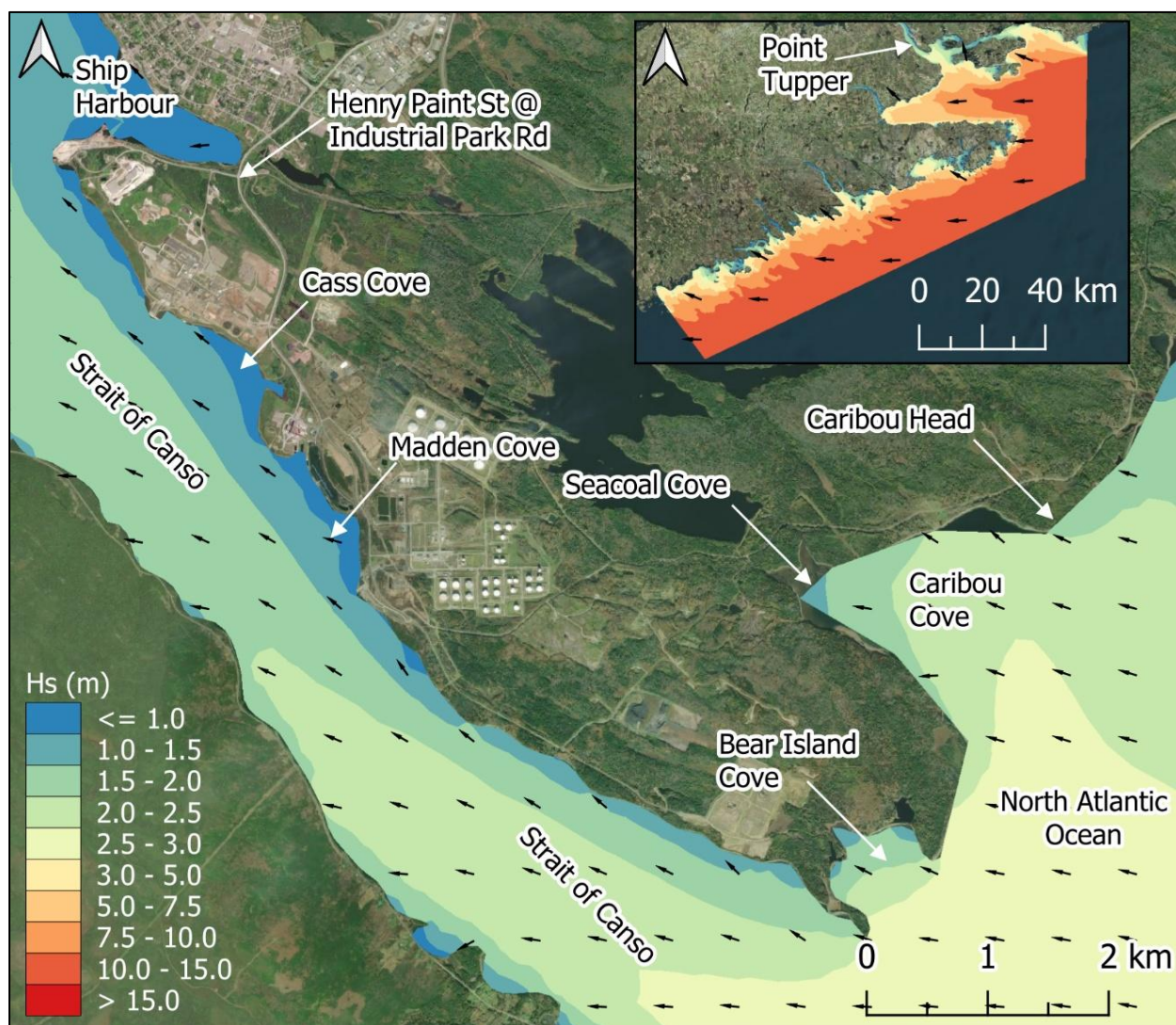


Figure 3-18: Significant wave height for extreme eastern event with 100-year return period modelled in MIKE21 SW. Model domain shown in inset.

The following figure shows results for modelled extreme wave conditions at the project site for waves approaching from the east direction for 20-year return period conditions (Figure 3-19).

The east direction produced the most extreme wave action at the project site, based on MSC50-driven modelling from the areas exposed to the open ocean (south, southeast, east), due to the influence of large offshore waves propagating through Chedabucto Bay and into the Strait of Canso.

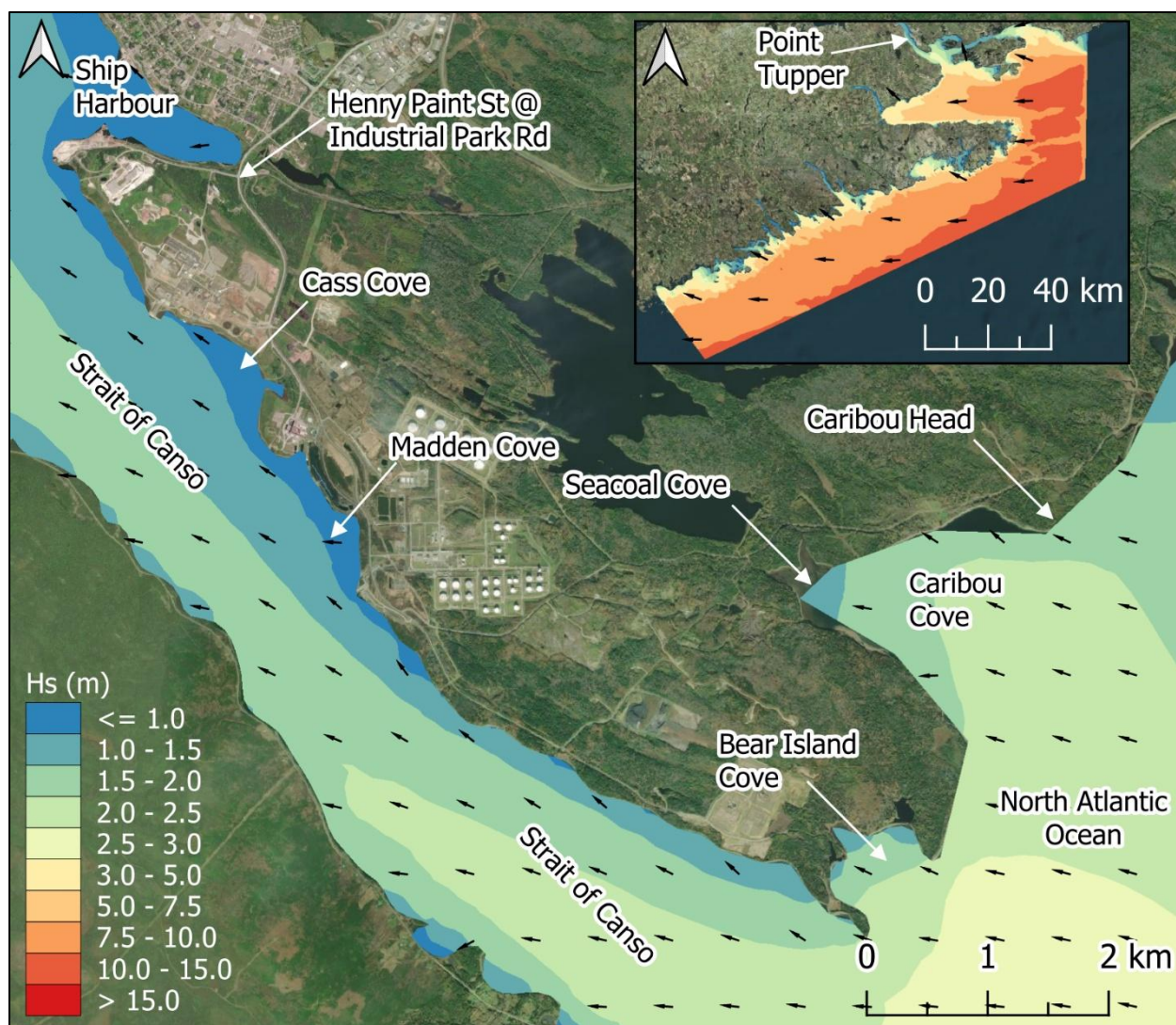


Figure 3-19: Significant wave height for extreme eastern event with 20-year return period modelled in MIKE21 SW. Model domain shown in inset.

Extreme wave parameters for relevant offshore directions for the 20-year and 100-year events are summarized in Table 3-6 and nearshore of the project site in Table 3-7.

Table 3-6: Summary of offshore wave conditions for 20-year and 100-year events.

		Extreme Offshore Conditions		
RP	Direction	Hs (m)	Tp (s)	Wind Speed (m/s)
20	Northeast	7.1	12.3	24.8
100		8.5	13	26.7
20	East	9.6	13	25.7
100		11.8	13.8	28.1
20	Southeast	8.9	12.5	24.5
100		10	13	26.9
20	South	9.5	13.7	23.7
100		11.6	14.7	25.3

Table 3-7: Summary of nearshore wave conditions for 20-year and 100-year events.

RP	Dir	Caribou Cove		Bear Island Cove		Strait of Canso		Madden Cove		Cass Cove		Ship Harbour	
		Hs (m)	Tp (s)	Hs (m)	Tp (s)	Hs (m)	Tp (s)	Hs (m)	Tp (s)	Hs (m)	Tp (s)	Hs (m)	Tp (s)
20	NE	1.3	3.6	1.1	4.2	0.9	2.7	0.9	2.6	0.9	2.6	0.9	2.7
100		1.5	3.9	1.3	4.6	1.0	2.8	1.0	2.8	1.1	2.9	1.0	2.9
20	E	2.1	4.8	1.8	5.3	1.6	4.6	1.2	3.1	1.2	4.2	0.9	3.0
100		2.4	5.1	1.9	5.4	1.8	4.5	1.4	3.5	1.4	4.3	1.1	3.1
20	SE	2.3	5.3	1.9	5.3	1.8	4.6	1.5	4.2	1.5	4.3	0.9	2.9
100		2.6	5.6	2.1	5.5	2.0	4.7	1.7	4.3	1.7	4.5	1.0	3.0
20	S	2.0	5.7	1.5	4.1	1.4	3.8	1.3	3.7	1.4	3.8	0.8	2.5
100		2.2	5.9	1.6	4.2	1.5	3.9	1.4	3.9	1.5	3.9	0.9	2.7

3.5 Wave Run-Up

Using the modelled nearshore wave conditions from the previous section, wave run-up at the project site was modelled using XBeach, a 1D wave propagation model²⁰. This additional model is necessary to examine the behaviour of individual waves, such as the run-up limit, whereas the nearshore model is used for the modelling of wave statistics, representative of a sea state, such as significant wave height or peak period.

The run-up model was applied along ten representative profiles across the project site, chosen as representative of the types of shorelines at the site. Profiles were selected in a coverage to be representative of the shoreline conditions of the site. Profile heights derived from interpolated topography and bathymetry, as described in Section 2.3.

Profiles 1 to 3 are exposed to waves travelling from the North Atlantic through Chedabucto Bay. Profiles 4 to 9 are exposed to waves within the Strait of Canso, and profile 10 is protected within Ship Harbour. The profile locations are shown in Figure 3-20. Incident wave conditions (H_s , T_p) were extracted at the seaward end of the profiles with seafloor elevations as shown in Table 3-8.

Table 3-8: Seafloor elevation at seaward end of profiles.

Profile	1	2	3	4	5	6	7	8	9	10
Seafloor Elevation (m CGVD2013)	-7	-4	-17	-28	-41	-39	-13	-13	-5	-7

²⁰ <https://oss.deltares.nl/web/xbeach/>

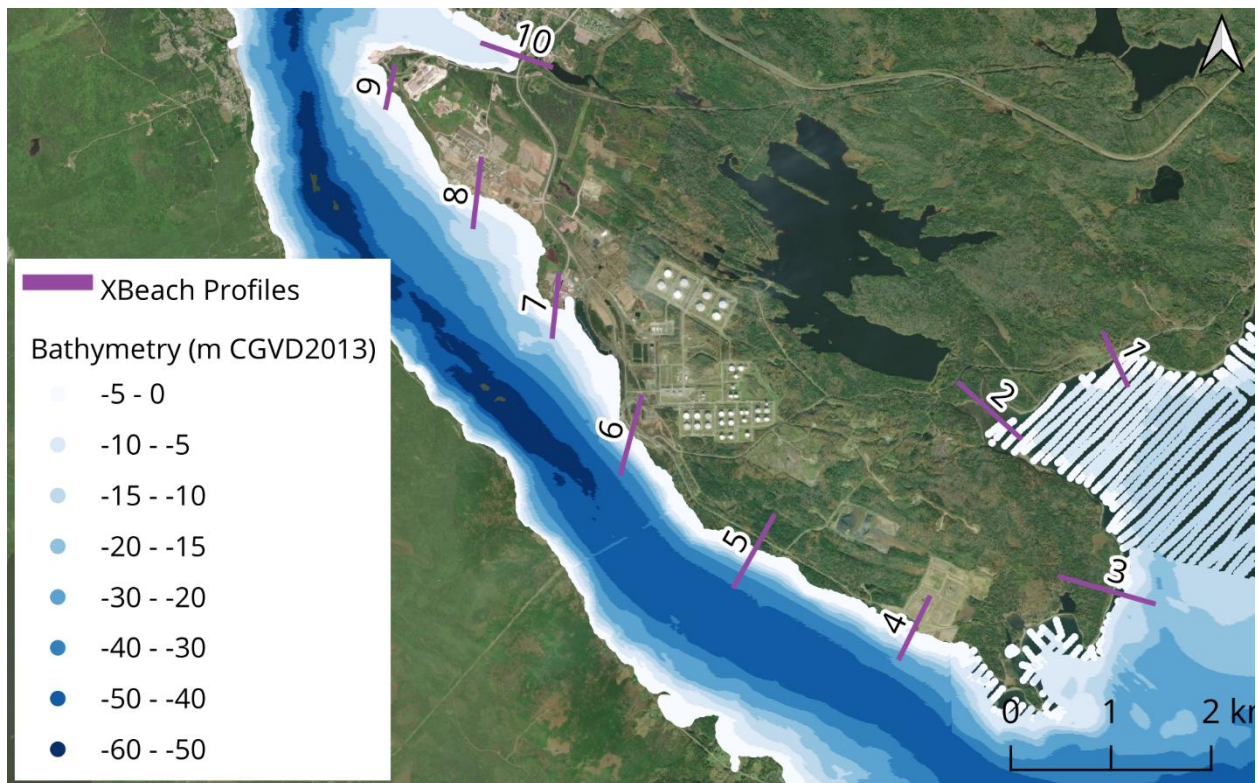


Figure 3-20: Representative profiles for wave run-up computation.

XBeach simulations were run in non-hydrostatic mode with a horizontal resolution of 0.5 m, allowing for individual waves to be simulated over the duration of a synthetic storm event to compute dynamic flood elevations. Simulated storms include the present day 20-year RP and the 100-year RP event for year-2100 sea level rise, to produce a range of modelled run-up values for the assessment scenarios. Example results of the 100-year RP model results are shown for Profile 1, during present-day conditions in Figure 3-21, and for year-2100 SLR conditions in Figure 3-22. The modelled elevation reached by 2% of the waves, an industry-standard indicator of the limit of wave run-up, $Z_{2\%}$, is shown by the red dotted line.

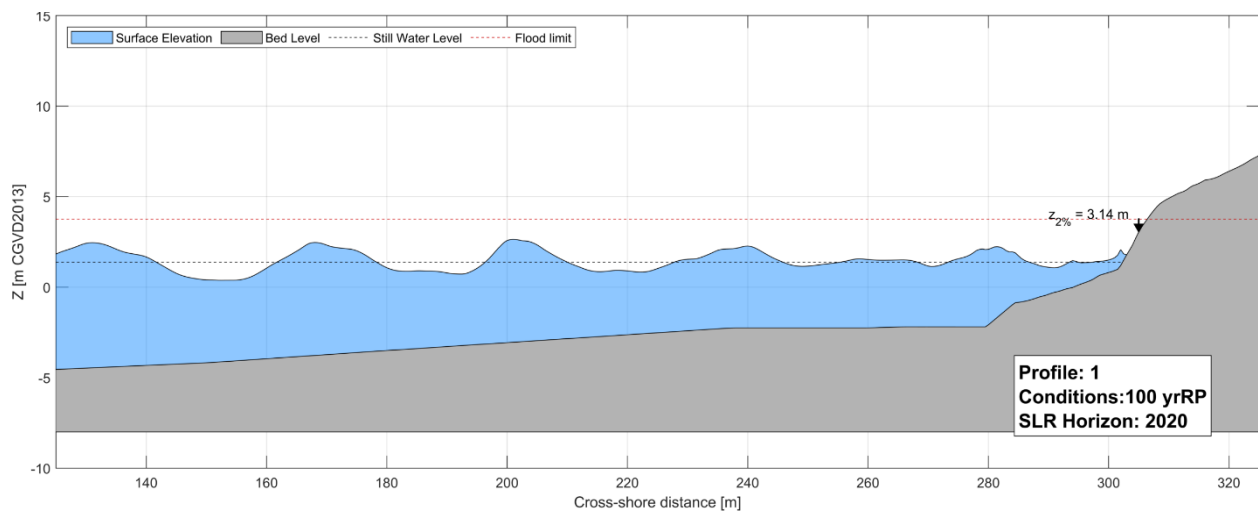


Figure 3-21: Run-up model results snapshot for 100-year return period, present climate conditions, Profile 1.

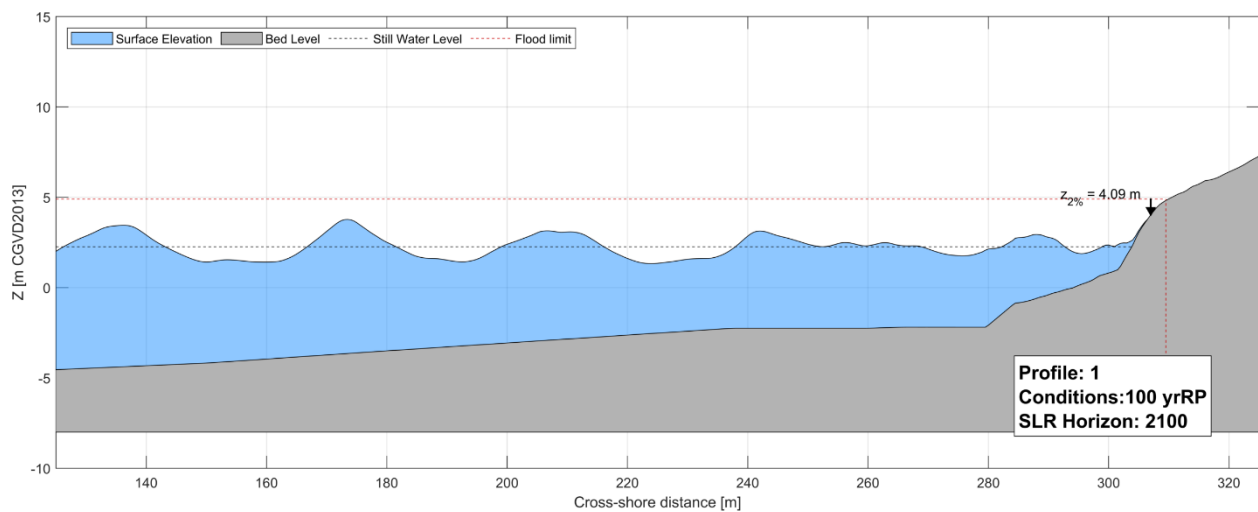


Figure 3-22: Run-up model results snapshot for 100-year return period, 2100 climate conditions, Profile 1.

Due to the relatively sheltered profile locations, the offshore wave conditions are generally small compared to regions of open ocean within Chedabucto Bay. The topographic features at the project site tends to be characterized by steep banks, particularly in the southern portion of the site where wave exposure is higher, limiting the horizontal distance covered by an increase in wave run-up.

Calculations of $Z_{2\%}$ were computed and mapped for each profile. Results for each profile and each scenario were aggregated and interpolated to contour lines representing a spatially-varying $Z_{2\%}$ surface for the project area. This spatially varying surface was then intersected with the DTM to extract a line showing the limit computed by the wave run-up simulations. Results of the $Z_{2\%}$ simulation for 100-year, present climate conditions are shown in Figure 3-23. A table of calculated run-up elevations on the assessed profiles is presented in Appendix D. Due to the depth of the water, incident waves at the seaside end of the model profiles are assumed to be

similar in future climate conditions, though mean sea level will change. The wave run-up lines are shown in the flood maps in Appendix E.

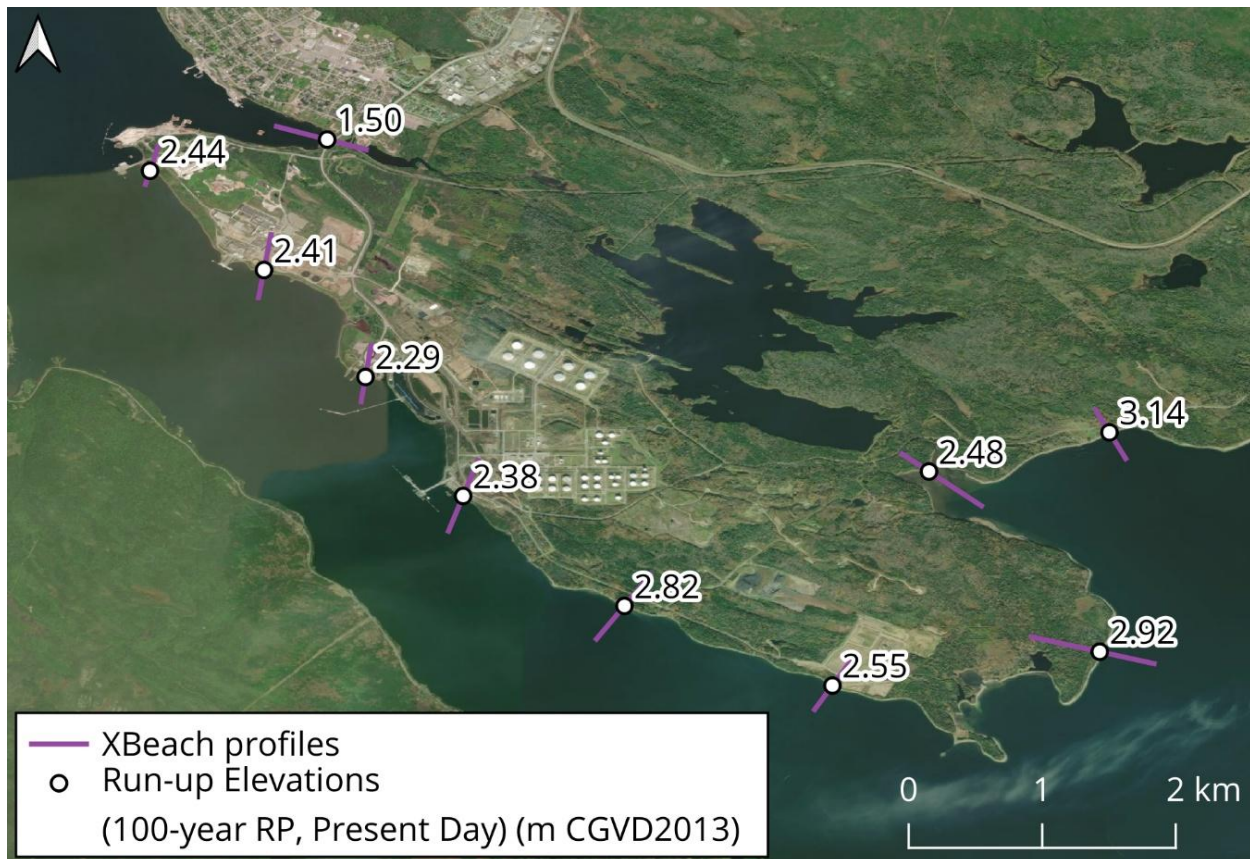


Figure 3-23: Wave run-up elevations ($Z_{2\%}$) of the 100-year return period event, in present climate conditions.

3.6 Compound Flooding Sensitivity Analysis

This analysis investigated the potential for flooding resulting from a combination of high coastal water levels and heavy precipitation. **It was found that extreme coastal water levels do not significantly affect inland flooding, and that extreme precipitation does not significantly affect coastal flooding at the Point Tupper site, both for present-day conditions and future climate conditions.**

Details of the analysis are found below.

3.6.1 Hydrological and Hydraulic Model

A hydrological and hydraulic model was developed to simulate the impact of heavy rainfall (Appendix B). The purpose was to estimate watershed runoff as well as channel routing from Peebles Pond to Ship Harbour and from Landrie Lake to Seacoal Cove. These flows form the basis for examining how runoff from extreme rainfall events may coincide with elevated coastal conditions to produce compound flooding.

The model was developed using PCSWMM, a platform built on Version 5 of the US EPA's Storm Water Management Model (SWMM). PCSWMM is well suited for assessing compound flooding because it simulates how rainfall-driven runoff within the watershed interacts with tidal and storm-surge conditions at the downstream coastal boundary.

Subcatchments were delineated using high-resolution LiDAR topography and are shown in Figure 3-24. Land-surface roughness and infiltration characteristics were assigned based on land cover mapping and soil data, and lakes and ponded areas were represented as storages to capture attenuation effects. Stream channels and hydraulic structures were defined using a combination of LiDAR data and targeted field surveys. The model was calibrated using a representative regional flow gauge and historical rainfall event, providing a first-order calibration suitable for assessing compound flooding.

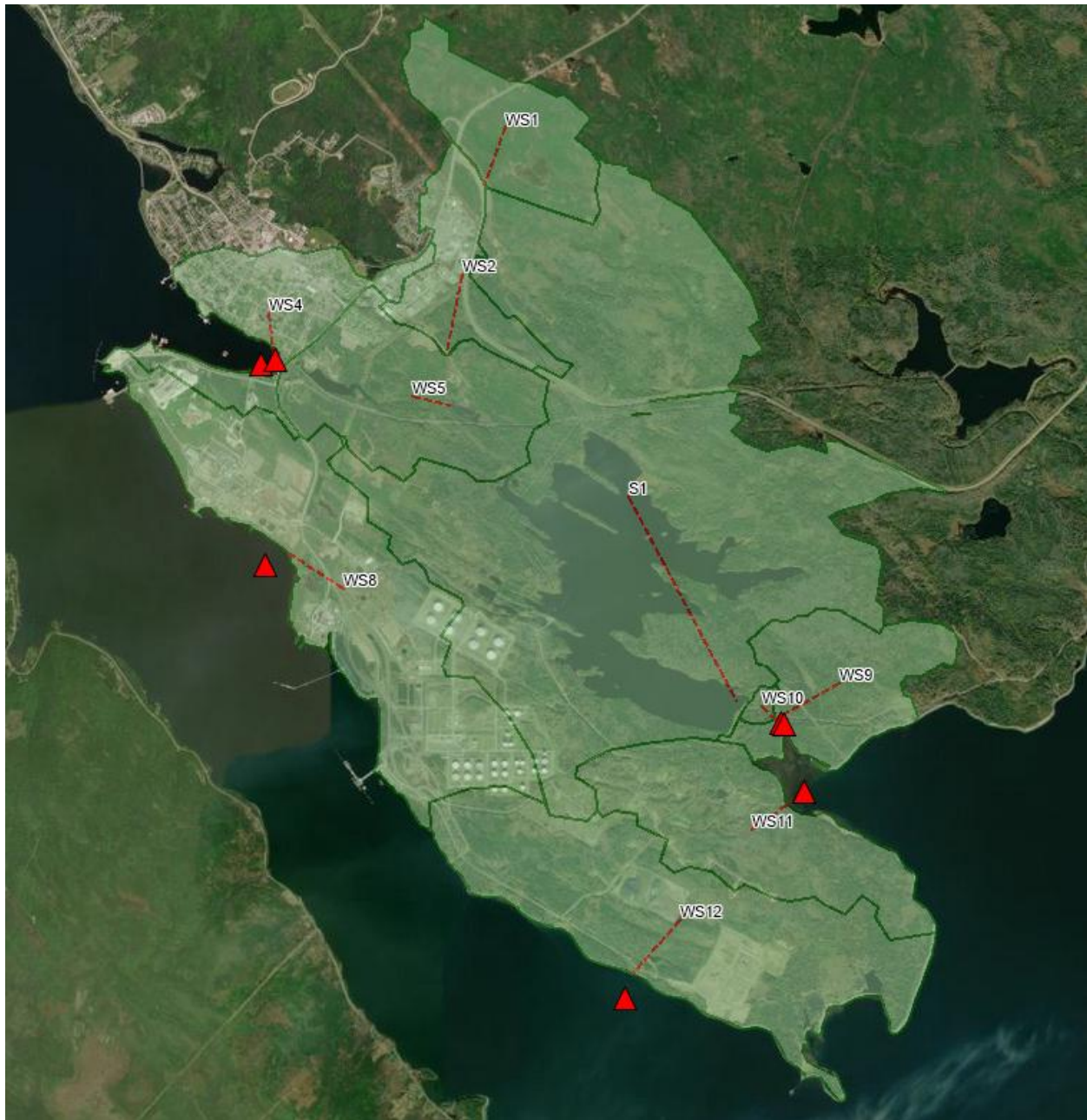


Figure 3-24: Hydrological model layout for study area watersheds. Red triangles indicate locations where flow time series are generated to serve as inputs for the coastal model (see Section 3.6.4).

3.6.2 Climate Change Impact on Precipitation Intensity

Future changes in extreme precipitation were incorporated by applying climate-change scaling factors to historical data using the Clausius–Clapeyron relationship, which assumes an approximate 7% increase in rainfall intensity per degree of warming. Scaling factors were derived from the Sixth Coupled Model Intercomparison Projection (CMIP6) model ensemble under a high-emissions scenario (SSP5-8.5), using the median projection for the late-century period (2071–2100) relative to a 1981–2010 baseline. Bias-corrected temperature projections

(CanDCS-M6 dataset) were used to calculate temperature changes at the site, resulting in an overall estimated increase of approximately 45% in extreme precipitation by end-of-century. These increases were applied to the design storm hyetographs used in the hydrological model to represent future precipitation conditions.

3.6.3 Impact of Coastal Water Levels on Inland Drainage.

To assess whether elevated coastal water levels could contribute to flooding in inland areas, coastal water levels from the coastal analysis (Section 2.4.5) were applied as downstream boundary conditions in the PCSWMM model. These boundary conditions account for the combined effects of tides, storm surge, and sea-level rise. These high-water level scenarios were compared to low tide scenarios as well as a scenario replacing the Industrial Road culvert with an open channel.

PCSWMM model results demonstrate that compound flooding is not an important influence on inland drainage upstream of the Industrial Road culvert (Figure 3-25). Water levels in this area are primarily controlled by flow restriction at the culvert, while tidal and storm-surge conditions have a negligible (less than 5 cm) contribution to peak water levels and do not affect drainage duration.

Under future climate conditions, increased precipitation intensity has a greater influence on peak inland water levels than does sea-level rise (see Appendix B). Other upstream structures are sufficiently distant from the coast that their water levels are governed by rainfall-driven runoff rather than coastal boundary conditions. Overall, the results indicate that compound flooding is not a significant driver of inland flooding in this project area under existing infrastructure conditions.

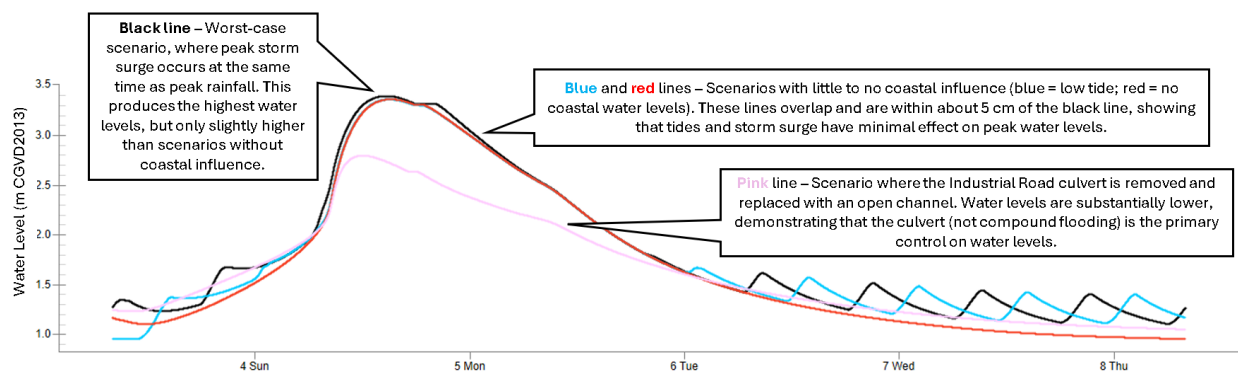


Figure 3-25: Modelled water levels upstream of the Industrial Road culvert under alternative outlet and coastal boundary conditions, showing that flow restriction at the Industrial Road culvert is the dominant control on upstream water levels.

3.6.4 Impact of Rainfall Runoff on Coastal Flooding

PCSWMM-generated flow timeseries were also used as inputs to a MIKE21 HD storm surge model to investigate how heavy rainfall (20-year RP and 100-year RP) may influence coastal flood extents. Offshore coastal boundary conditions for this modelling were a tidal water level boundary sinusoidally oscillating between HHWLT and LLWT with a 100-year extreme water

level coinciding with HHWLT to propagate a surge within the model. The generated surge and rainfall are assumed to be from the same event and therefore coincide in time.

The results of this analysis are shown for the most extreme assessed scenario in Figure 3-26. This shows the difference between the peak of the 100-year RP storm surge coinciding with a 100-year RP rainfall event, and the same event without rainfall. This is for the year-2100 climate conditions, which have the most calculated discharge and would have the most impact.

Downstream of the hydraulic structures, there is **no reasonably discernable difference between the coastal water levels with and without heavy rain inputs**. In very localized areas around the outfalls themselves, there is a difference visible in the model results in the magnitude of 0.01 m or less. This small difference is not enough to be visible when plotted on a flood map, and so the results for the storm surge flood mapping for each scenario are also indicative of the storm surge flood mapping with coinciding heavy rain for the site. For less extreme return period events, such as the 20-year RP, the modelled effect is even smaller.

In terms of the effect on coastal flooding seaward of the hydraulic structures, the effects of coinciding heavy rainfall are negligible.

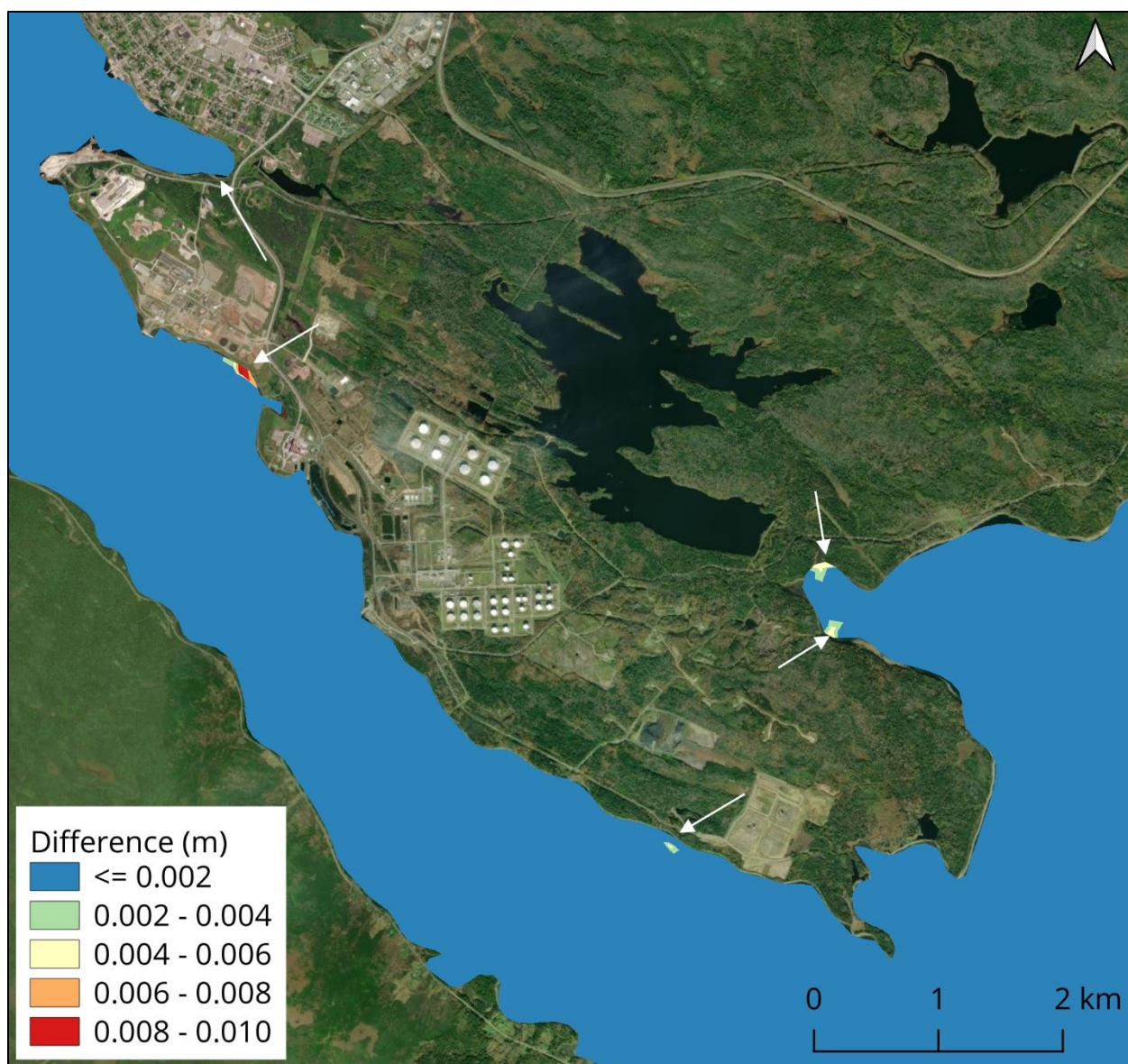


Figure 3-26: Impact of runoff on coastal flooding. 100-year RP storm surge event coinciding with 100-year RP rainfall event with results of no rainfall scenario subtracted. 2100 climate conditions. Outfall locations shown with arrows.

4 Coastal Flood Mapping

Static extreme water levels were computed for HAT, Hurricane Fiona, an enhanced Hurricane Fiona scenario, 20-year RP EWL, and 100-year RP EWL, and projected to year-2050 and year-2100 SLR levels (Section 2.4). Dynamic water levels that include the effects of wave run-up were computed for 20-year and 100-year RP events.

Flood maps for the site were created by extracting the static flood elevation's contour from the DTM (Section 2.1) uniformly throughout the project area. Dynamic, spatially varying, flood mapping was performed for scenarios that included wave run-up. This run-up line was computed by applying the run-up elevation at each computation profile and extrapolating its elevation to nearby similar coastline. These elevation points were interpolated to a grid, which was then intersected with the DTM, forming the continuous wave run-up line.

Flood mapping of extents and depths are included in Appendix E. Associated GIS files have been submitted alongside this report showing flood extents, flood depths, and wave run-up extent.

For demonstration purposes, three scenarios are included within the body of this report: the 100-year RP (year-2100 SLR) extreme water level, Hurricane Fiona as measured by the CHS tide gauge, and the modelled enhanced Hurricane Fiona scenario projected to year-2100. The other maps, including flood depths, are found in Appendix E. Each of the maps displays the HAT contour line for reference to high tide.

Inset maps (Figure 4-1) show details where flooding is projected to occur. Figure 4-2 and Figure 4-3 show the 100-year RP (year-2100 SLR) scenario. Figure 4-4 and Figure 4-5 show Hurricane Fiona. Figure 4-6 and Figure 4-7 show the enhanced Hurricane Fiona model results projected to year-2100.

From these figures, and accompanying GIS shapefiles, it is possible to identify the extent of flooding that would be anticipated from extreme coastal water levels.

Most of the flooding predicted by this static water level analysis is in coastal wetlands, such as in Ship Harbour or Bear Island cove, with Bear Island itself isolated from land. Additionally, there are wharf areas that may be inundated in extreme events by late century. The breakwater structures at Point Tupper Generating Station are also projected to be completely inundated during an extreme late century event.

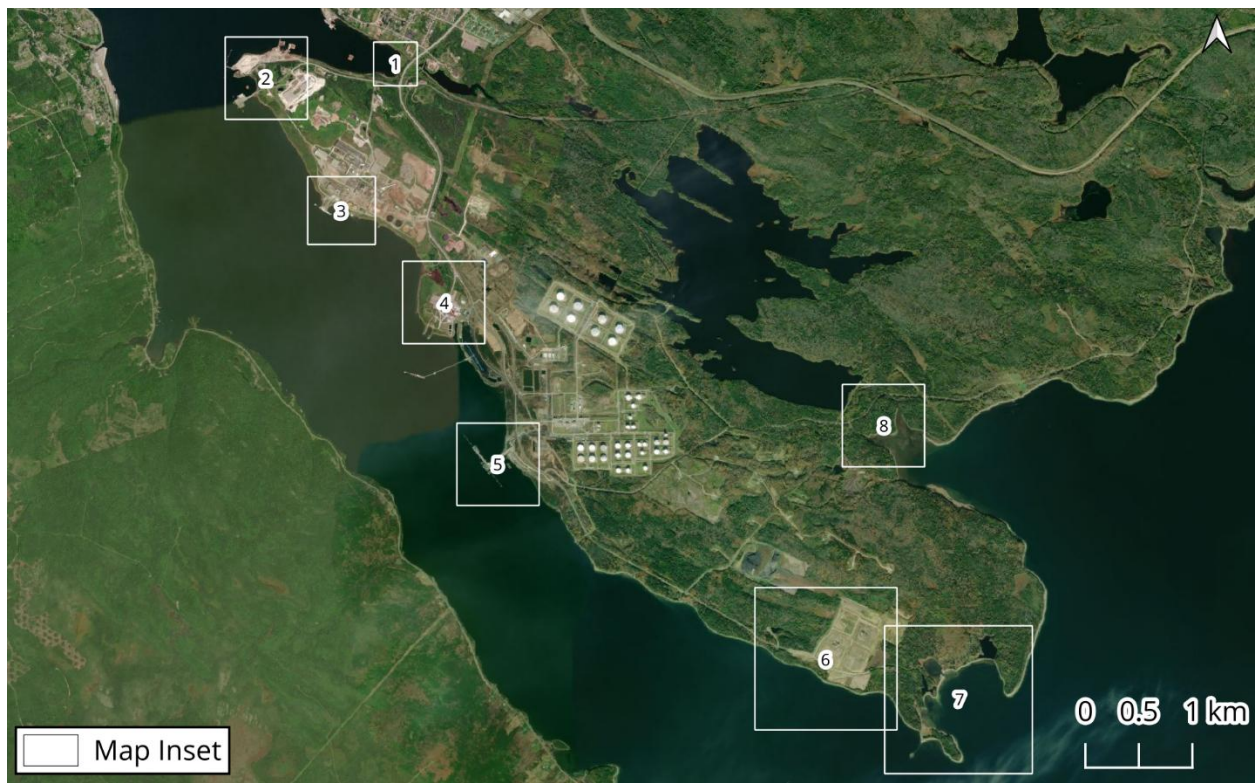


Figure 4-1: Map inset locations.

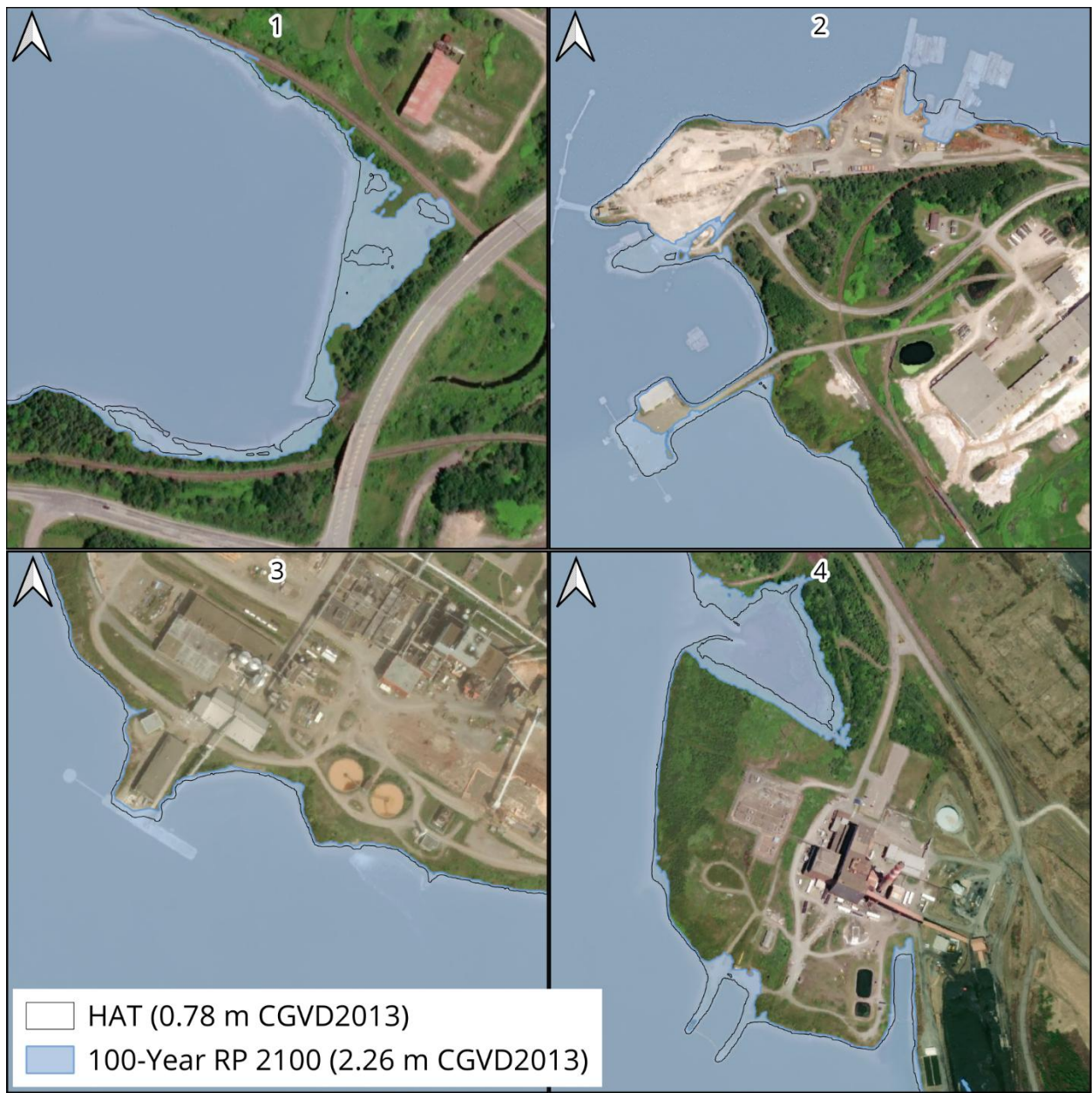


Figure 4-2: Flood extents in the project area for 100-year RP static flood elevations (2100 SLR), showing flooding details in key areas.

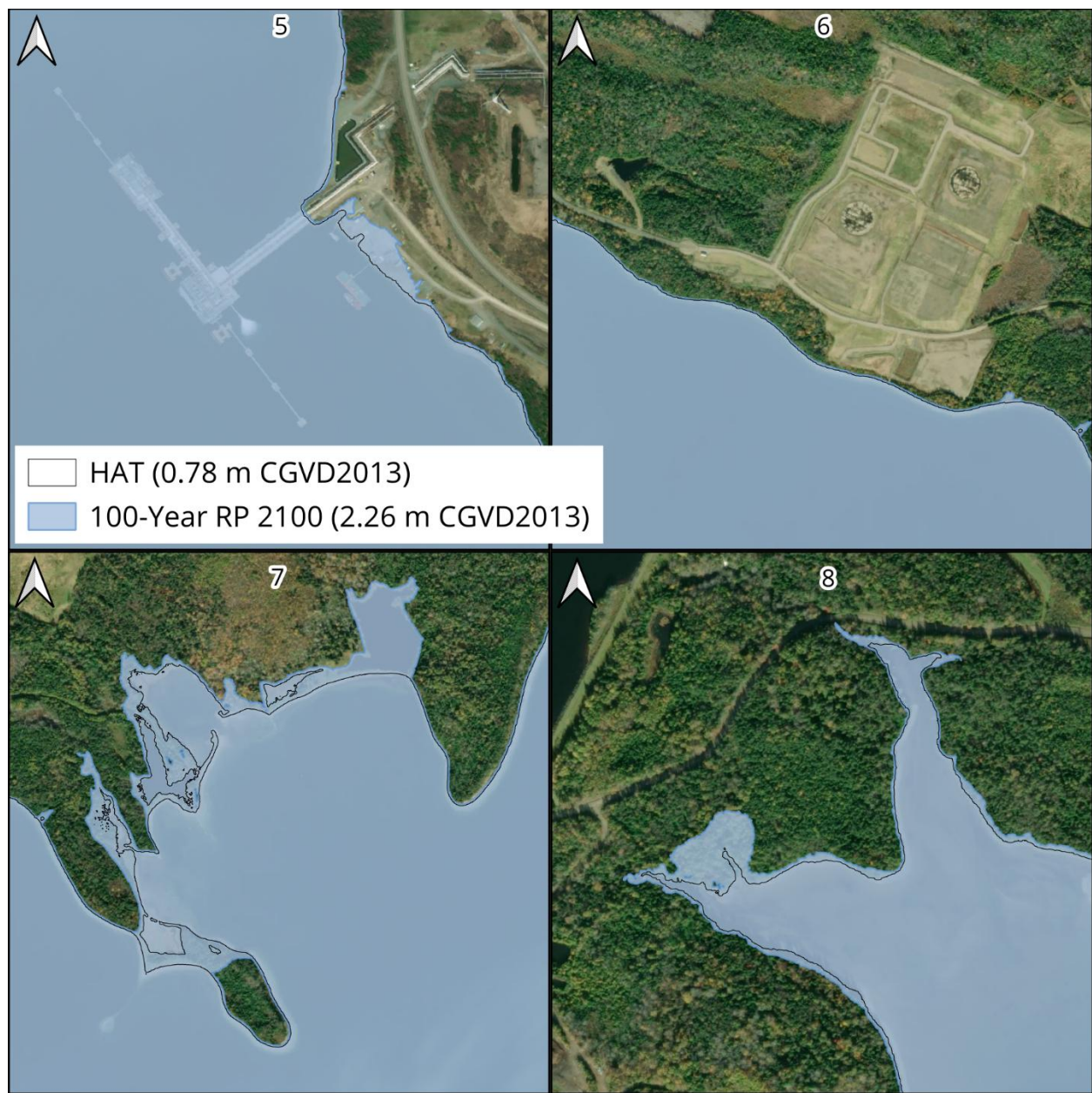


Figure 4-3: Flood extents in the project area for 100-year RP static flood elevations (2100 SLR), showing flooding details in key areas.



Figure 4-4: Flood extents in the project area for Hurricane Fiona static flood elevations. Tidal elevation as occurred during storm event. Figure shows flooding details in key areas.

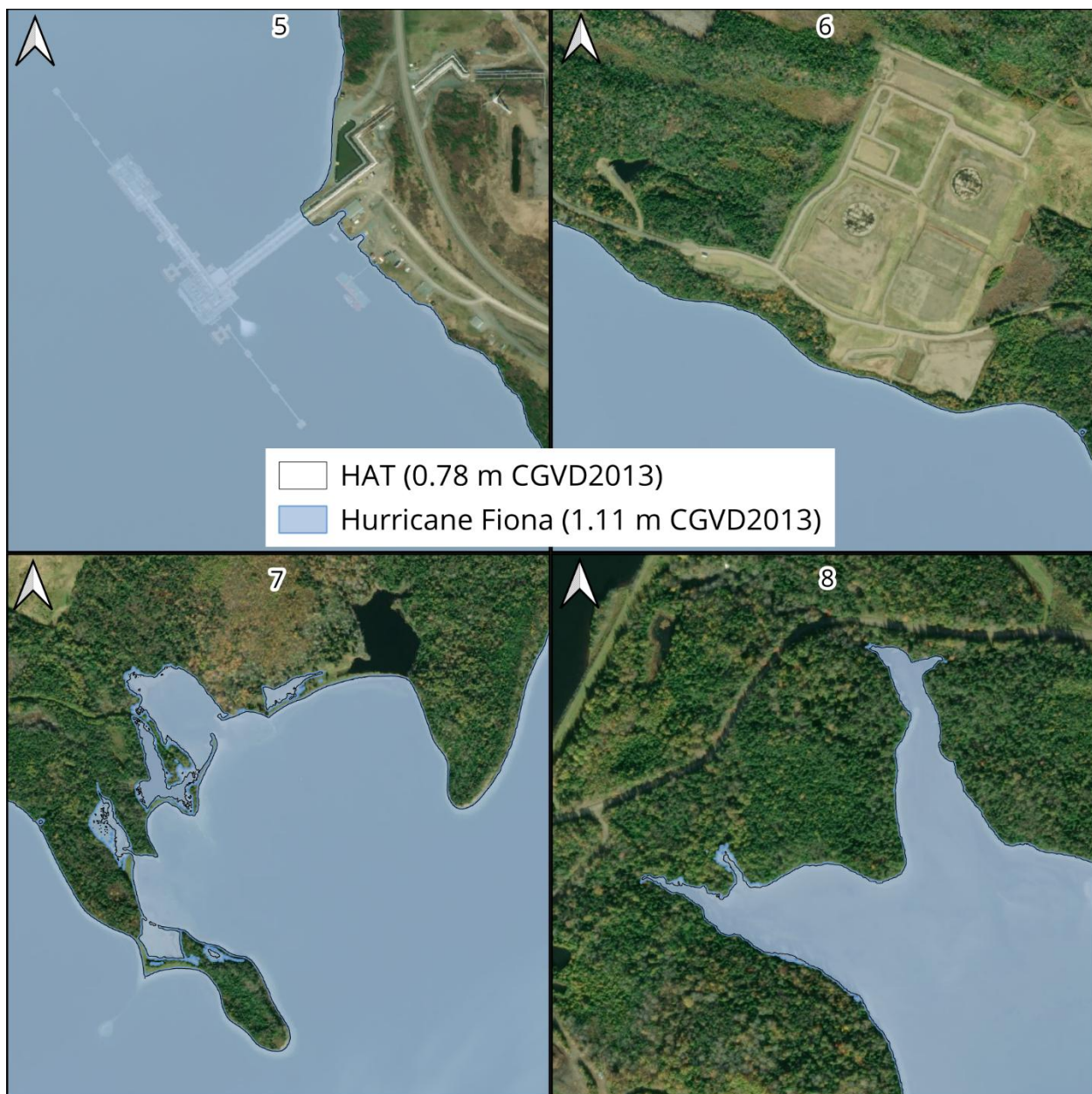


Figure 4-5: Flood extents in the project area for Hurricane Fiona static flood elevations. Tidal elevation as occurred during storm event. Figure shows flooding details in key areas.

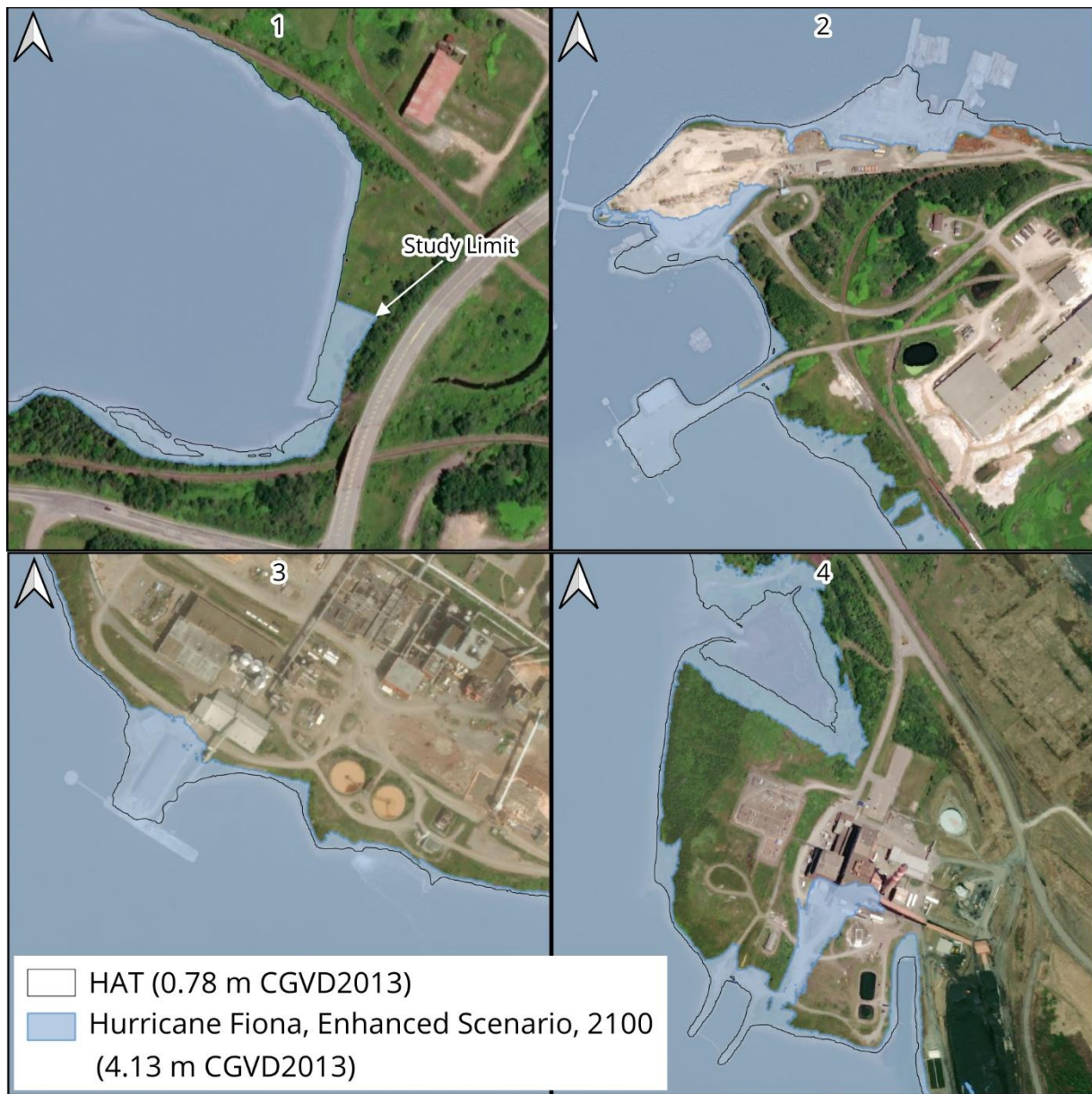


Figure 4-6: Flood extents in the project area for the enhanced Hurricane Fiona scenario static flood elevations, in year-2100. Figure shows flooding details in key areas.

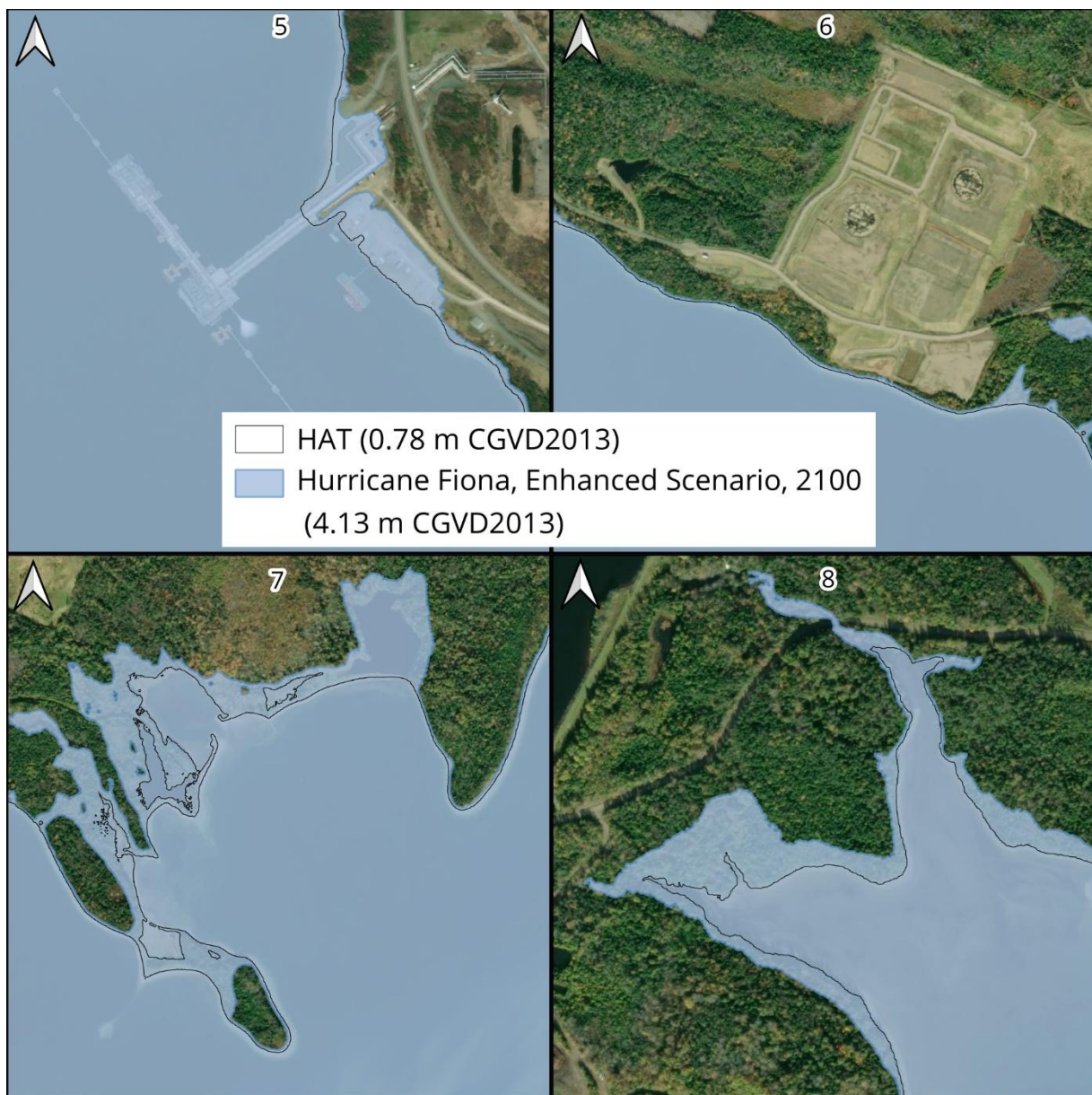


Figure 4-7: Flood extents in the project area for the enhanced Hurricane Fiona scenario static flood elevations, in year-2100. Figure shows flooding details in key areas.

5 Key Findings, Next Steps, and Limitations

5.1 Key Findings

Project-specific scenarios tailored to site conditions and MOCR project requirements included combining the following key elements:

- ▶ 20- and 100-year return period scenarios
- ▶ Scenarios based on Hurricane Fiona, with alternative enhanced conditions related to storm track and timing relative to the high tide
- ▶ 2050 and 2100 horizons for sea level rise projections

Analysis was performed of existing data, such as bathymetry and topography, water level measurements at the nearby Canadian Hydrographic Services (CHS) tide gauge, Hurricane Fiona intensity data, and future sea level rise (SLR) projections. Using this data, a series of analyses and numerical models were used to investigate extreme water levels at the project site.

- ▶ Tidal elevations assessed from published CHS values,
- ▶ 20-year and 100-year storm surge assessed by extreme value analysis (EVA) of CHS tide gauge data,
- ▶ Hurricane Fiona water levels assessed from measurements from CHS tide gauge,
- ▶ Enhanced Hurricane Fiona simulations performed with calibrated MIKE21 HDSW hurricane model,
- ▶ Rainfall events assessed with PCSWMM storm water management model,
- ▶ Wave run-up assessed with 1-D XBeach non-hydrostatic wave propagation model,
- ▶ For year-2050 and year-2100 projections, SLR added to XBeach model inputs, and for remaining scenarios SLR was added to model outputs.

Findings show the following.

- ▶ The site is primarily protected from coastal flooding due to two geographical features: the topography of the site is generally high above the coastal water levels and steep, and Point Tupper is relatively well protected from offshore swell wave penetration.
- ▶ The water surface elevation during Hurricane Fiona did not cause extensive flooding at Point Tupper due to the low tidal elevation during the peak of the storm surge.
- ▶ An extremely unlikely enhanced Hurricane Fiona scenario, investigating alternate tidal elevations and storm tracks produced modelled extreme water levels 1.85 m higher than those measured during the storm.

- ▶ The impacts of heavy rainfall on the coastal flooding downstream of the hydraulic structures (e.g. culverts) is negligible.
- ▶ Modelling indicates that the impacts to inland flooding, via hydraulic structure such as culvert, due to coastal water levels is negligible.
- ▶ The flooding due to wave run-up varies across the site, with larger waves expected at the south of the site. In the south of the site, the shoreline topology is steep and there is little difference in expected flooding with and without waves.
- ▶ Coastal flooding during extreme events is expected to affect wharves and wharf infrastructure on the Point Tupper coast by end of century, such as those operated by McNally, Everwind, and Port Hawkesbury Paper. Jetty structures at the Point Tupper generating station are also expected to be affected by coastal flooding during extreme events by end of century.
- ▶ Wetland areas such as Ship Harbour, Bear Island Cove, and Bear Island are expected to experience inundation during extreme events.

5.2 Next Steps

The contents of this report are concerned primarily with the production of flood lines for various scenarios in the present and projected into the future. A recommended next step would be to conduct an infrastructure risk assessment using the flood lines produced under this project. Such a risk assessment would typically entail the careful selection of infrastructure assets, such as buildings, wharves, roads, etc., that are relevant for MOCR decision-makers and stakeholders and assigning to each a likelihood score of coastal flooding. These scores can then be combined with scores representing the consequences of flooding, either scored categorically or individually, to compute a risk score. The results of such risk assessments may be integrated into MOCR's general risk planning framework.

5.3 Limitations

This report has been prepared based on a specific scope of work, and it should be read in its entirety. The findings and recommendations are based on information collected to date at the time of writing, and on simplified mathematical formulations of complex dynamic natural processes. While the modelling effort incorporated as much relevant data as possible within the study schedule and budget, uncertainties associated with data gaps and modelling approximations are inherent to this type of study. Results should be interpreted with caution and actual conditions encountered in the future may vary from predictions. We recommend that results be revisited by MOCR as new information, such as updates to sea level rise projections, becomes available.

This document was prepared for the party indicated herein. The material and information in the document reflect CBCL Limited's opinion and best judgment based on the information available at the time of preparation. Any use of this document or reliance on its content by third parties is the responsibility of the third party. CBCL Limited accepts no responsibility for any damages suffered as a result of third-party use of this document.

6 References

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APPENDIX A

Offshore Wind and Wave Hindcast Analyses

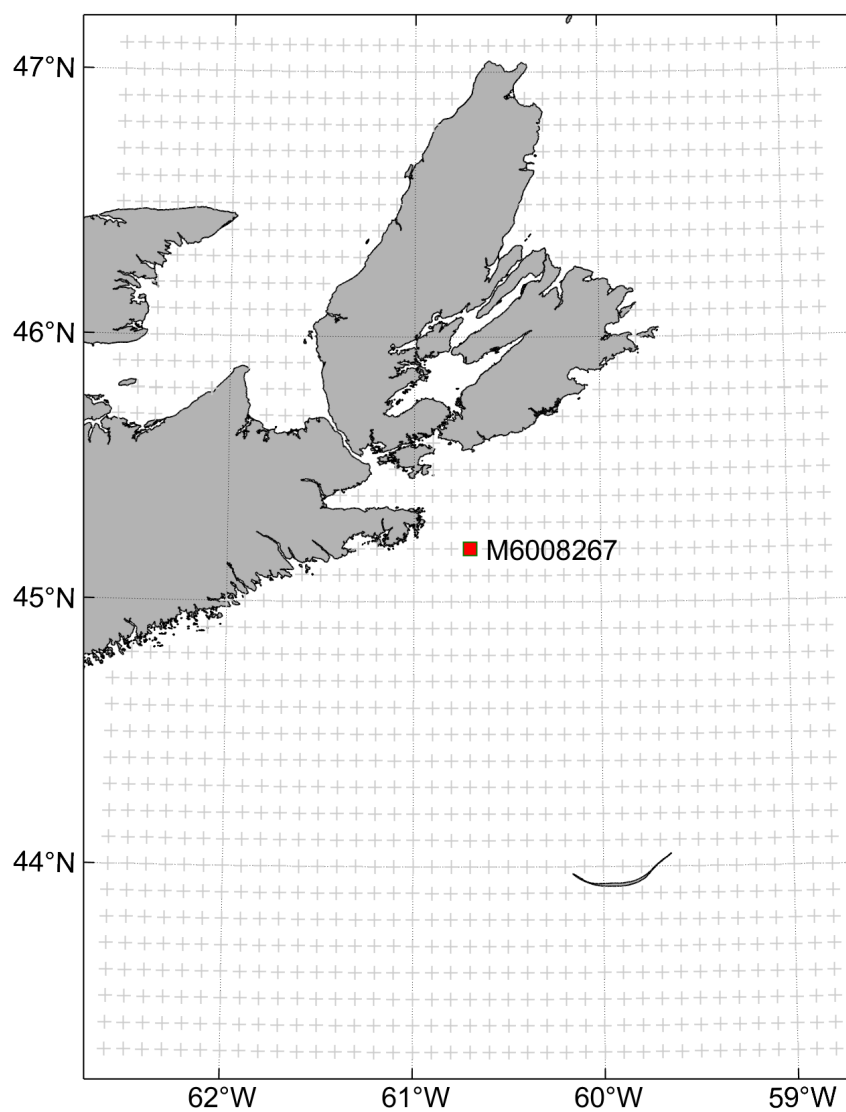


Figure 1: Study Area and Selected MSC50 Grid Point.

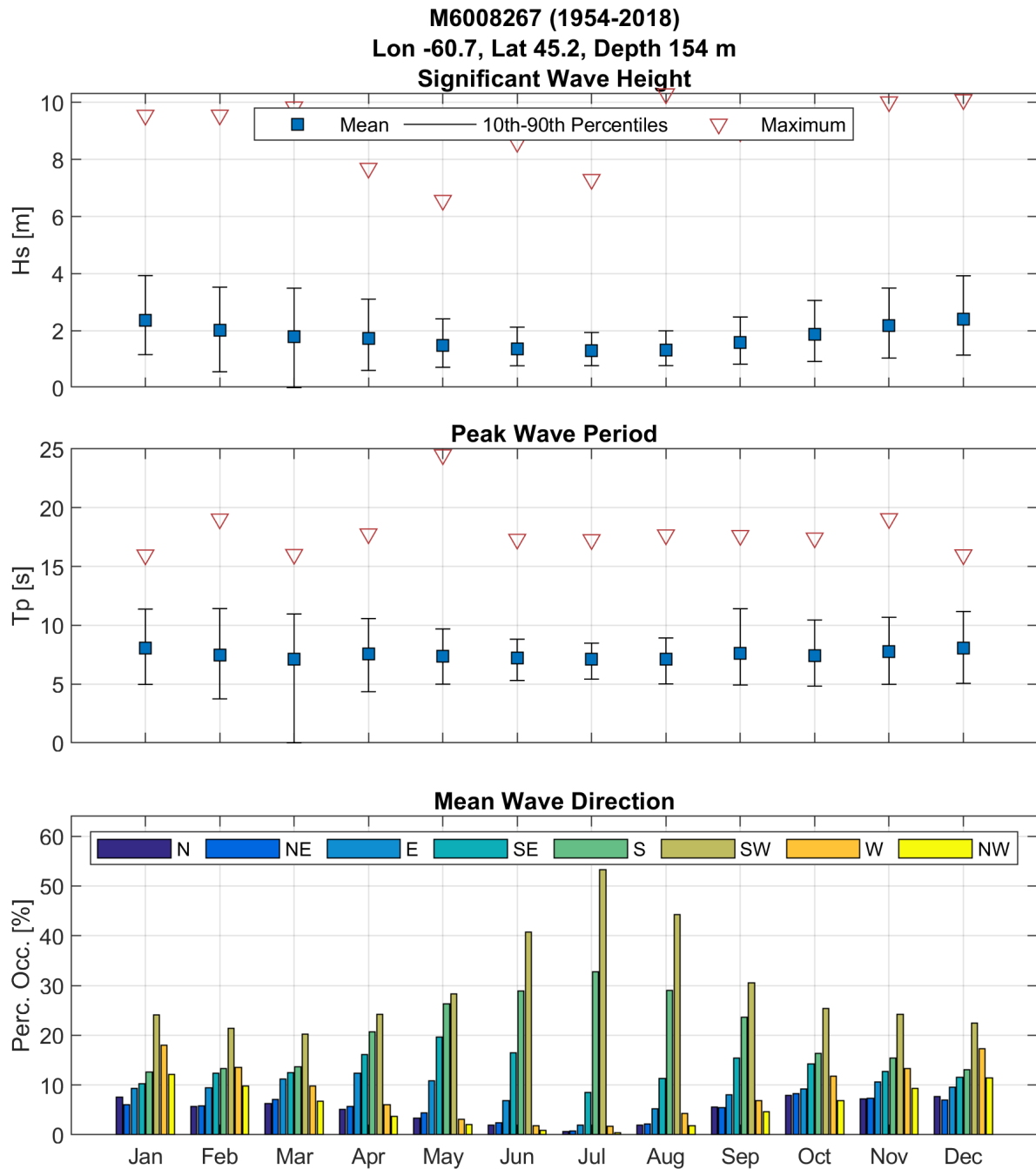
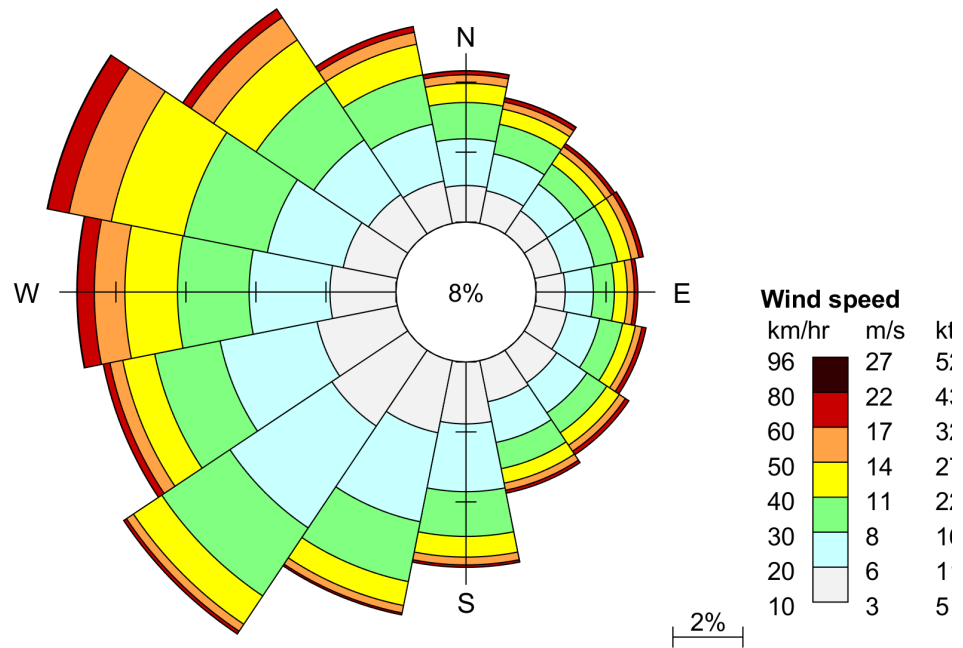
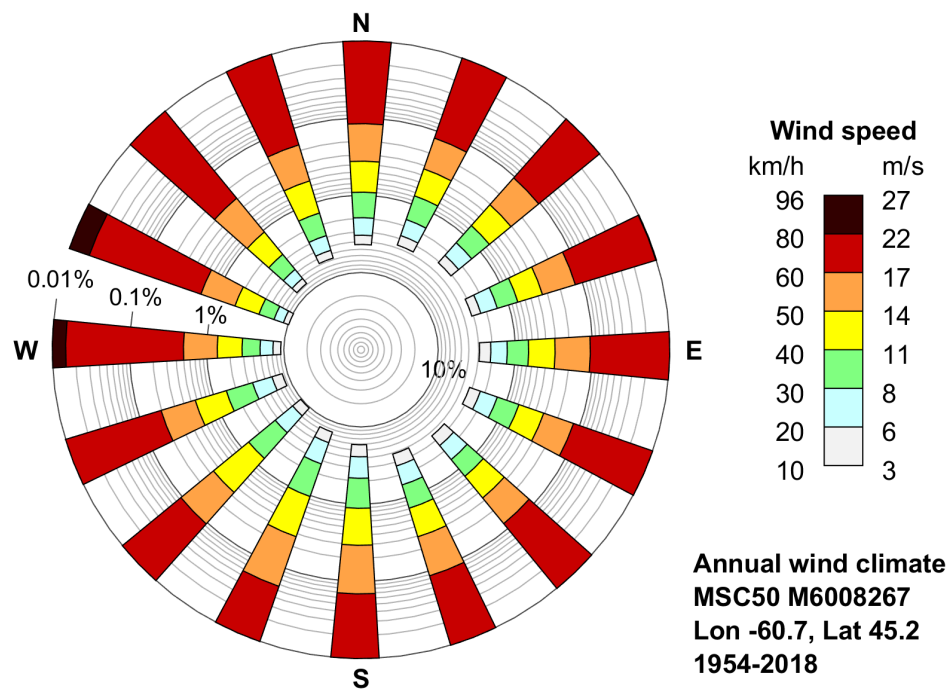


Figure 2: Monthly Variability of Wave Conditions.

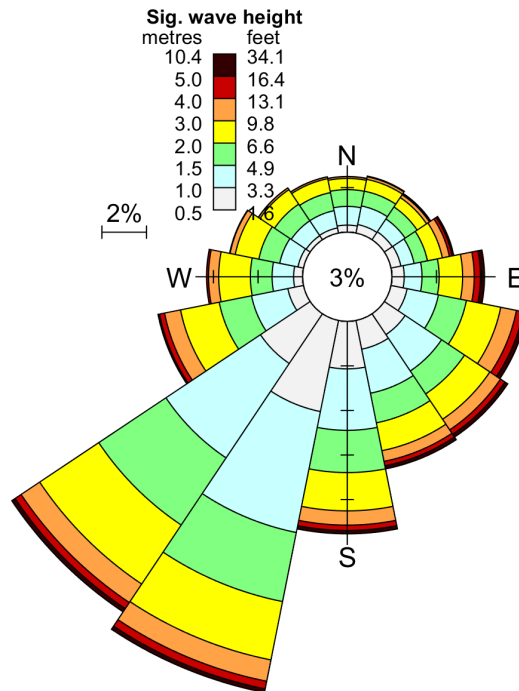


(a) Linear Scale

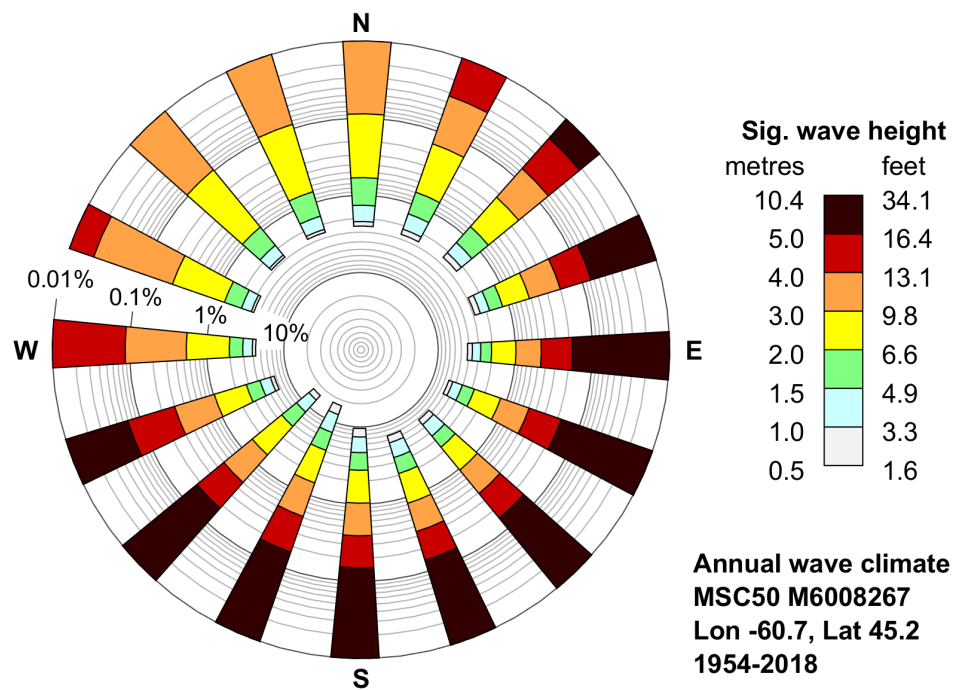


(b) Logarithmic Scale

Figure 3: Wind Rose - Joint Occurrence of Wind Speed and Wind Direction.



(a) Linear Scale



(b) Logarithmic Scale

Figure 4: Wave Rose - Joint Occurrence of Significant Wave Height (Hs) and Mean Wave Direction.

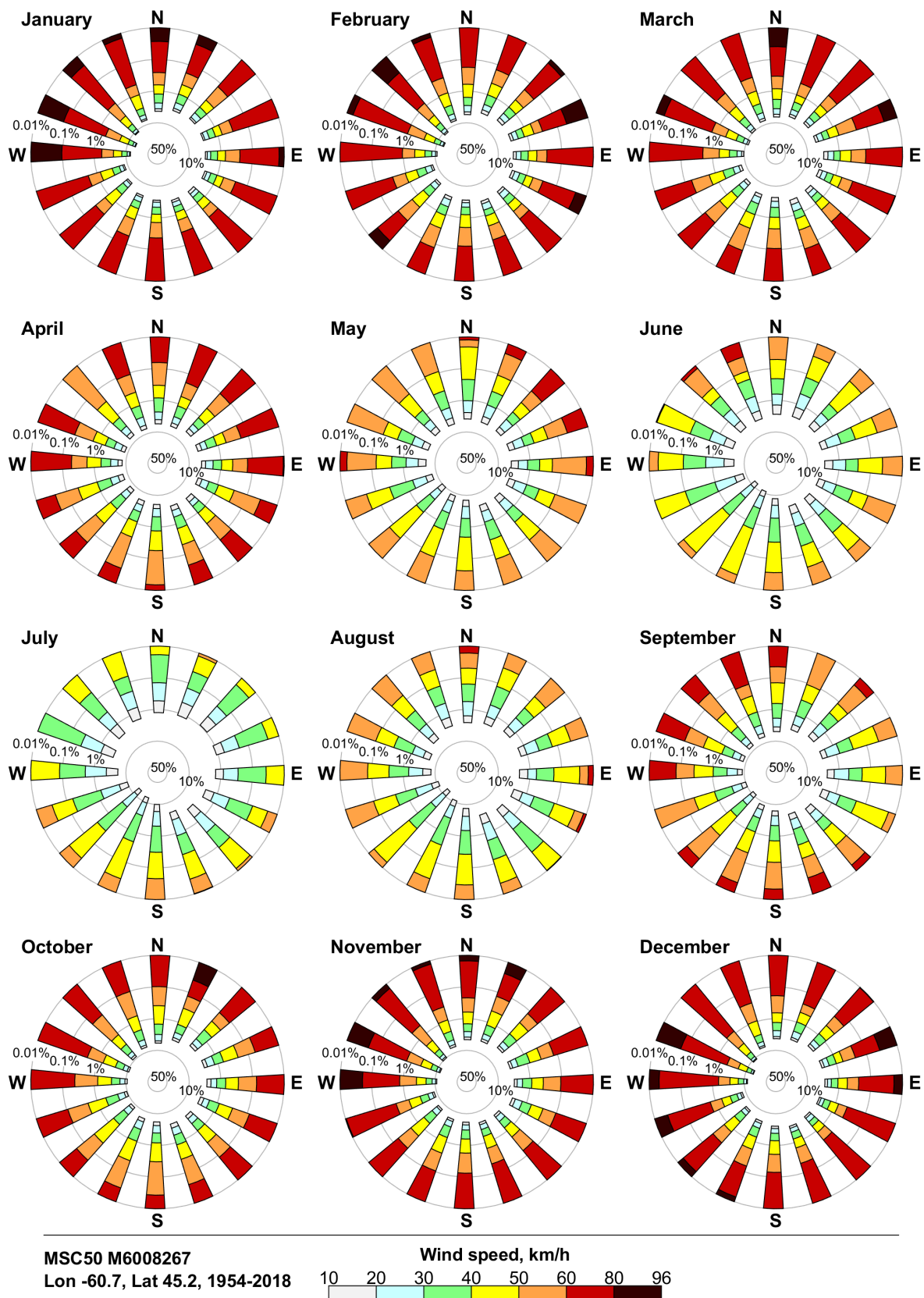


Figure 5: Wind Rose - Monthly Logarithmic Joint Occurrence of Wind Speed and Wind Direction.

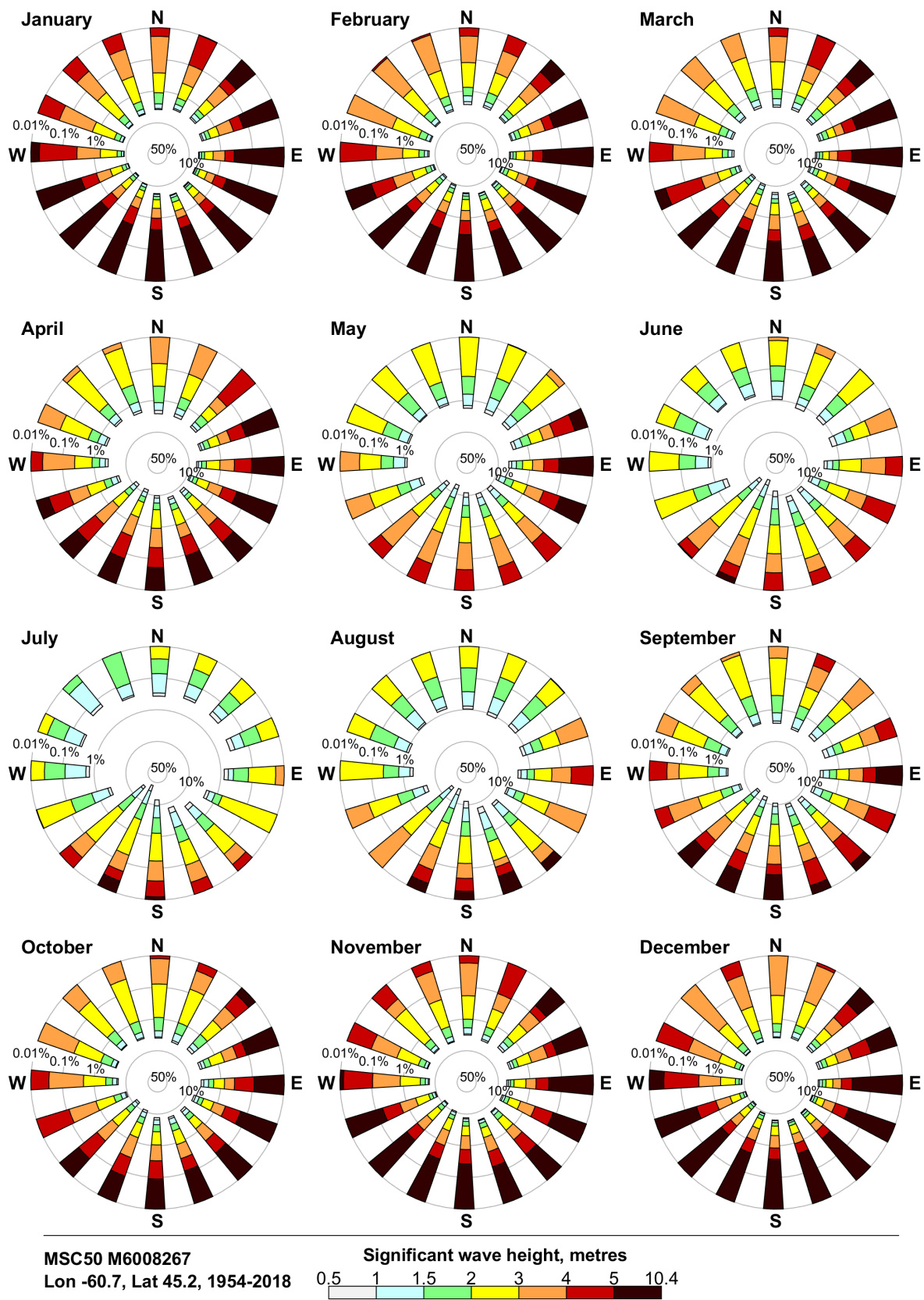


Figure 6: Wave Rose - Monthly Joint Occurrence of Significant Wave Height (H_s) and Mean Wave Direction.

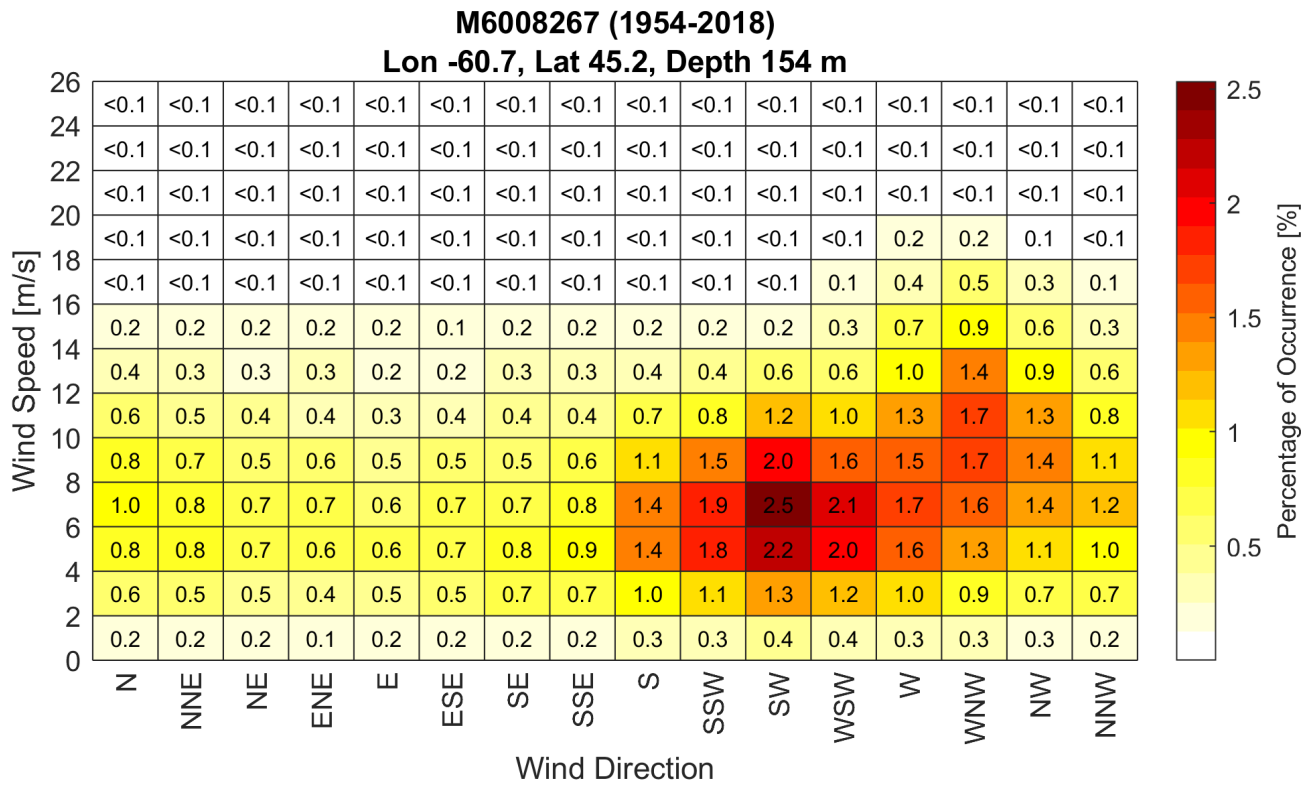


Figure 7: Joint Occurrence of Wind Speed and Direction.

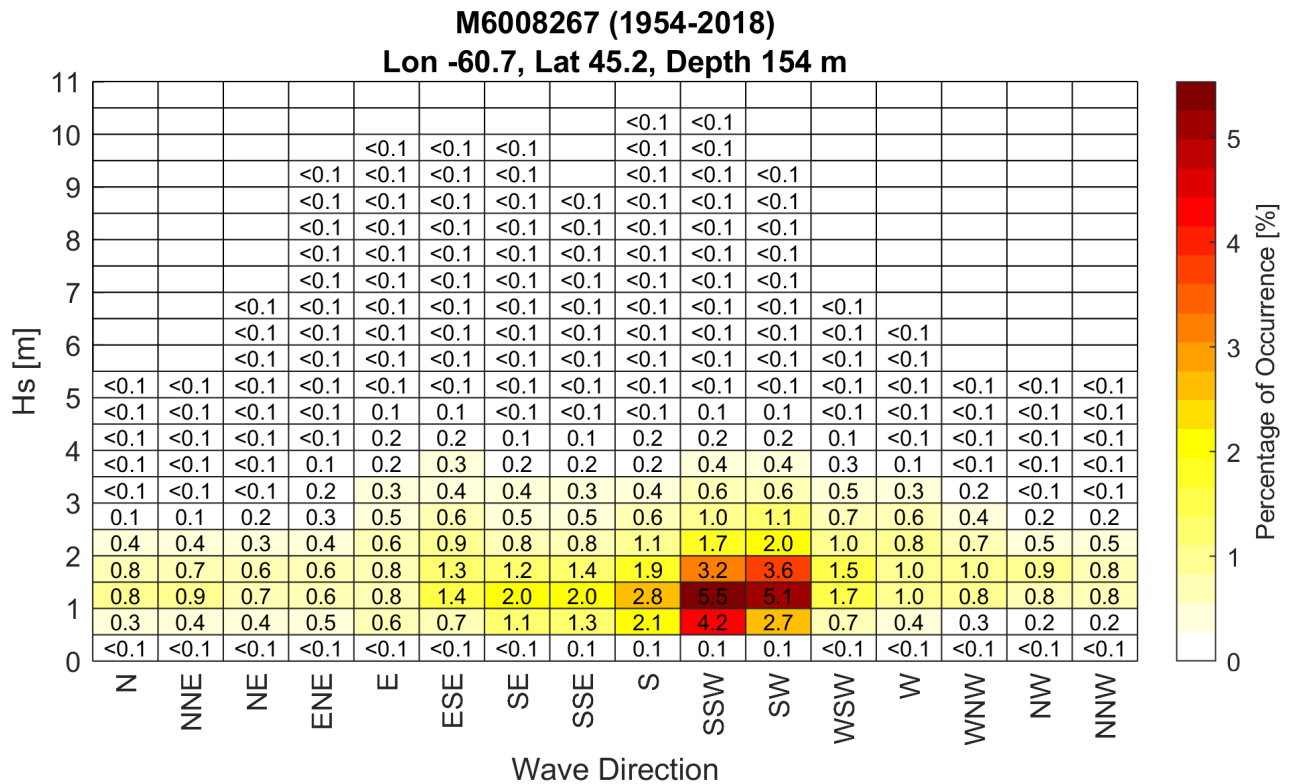


Figure 8: Joint Occurrence of Significant Wave Height (Hs) and Mean Wave Direction.

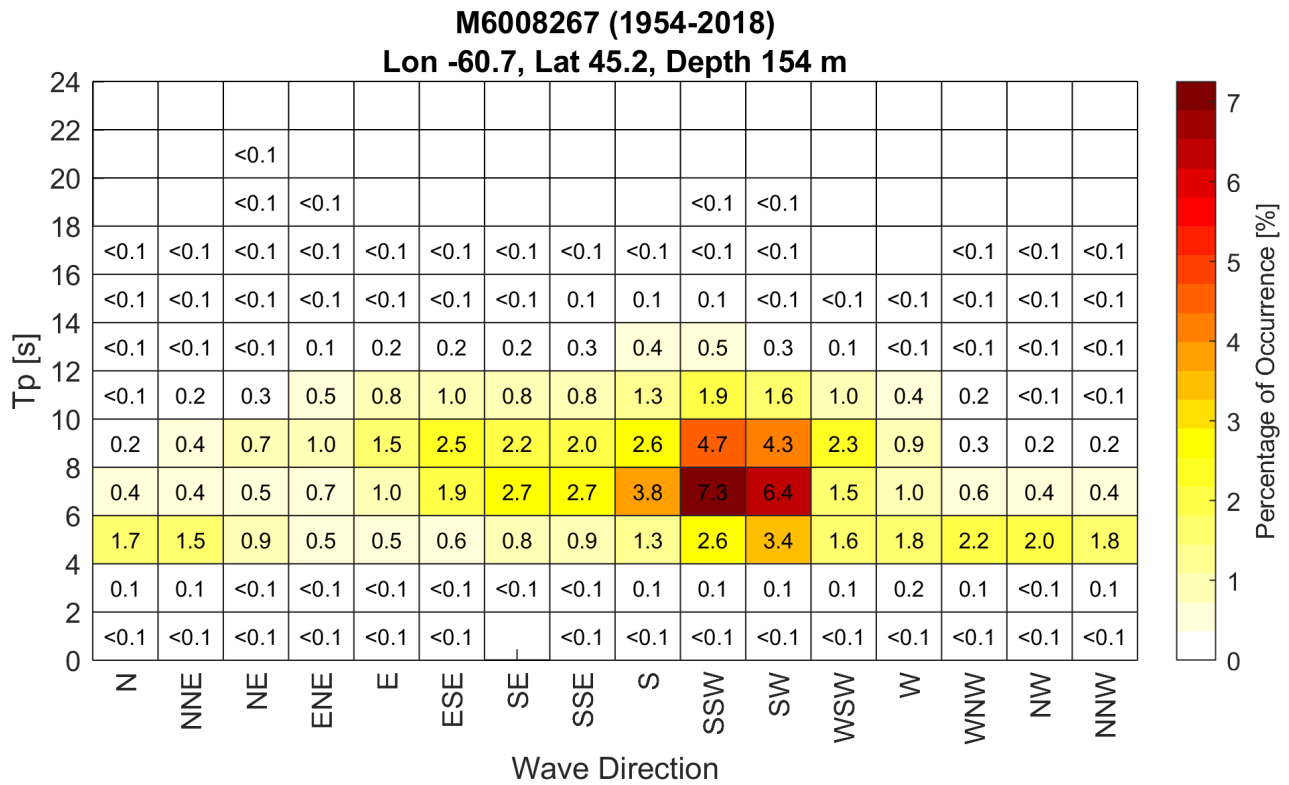


Figure 9: Joint Occurrence of Peak Wave Period (Tp) and Mean Wave Direction.

APPENDIX B

Hydrological and Hydraulic Assessment

B.1 Introduction

The hydrological and hydraulic assessment forms part of the project's "Compound Flooding" task, aimed at determining whether rainfall and storm surge combine in ways that increase flood severity. The goal is to assess compound flooding in two ways.

- ▶ Impact of coastal water levels on inland drainage.
- ▶ Impact of runoff on coastal flooding.

A hydrological and hydraulic model was developed for the study area using PCSWMM, a platform built on Version 5 of the US EPA's Storm Water Management Model (SWMM). The software was used to simulate watershed hydrology (rainfall interception, Green-Ampt infiltration, and runoff generation) and channel hydraulics (dynamic flow routing through river reaches and hydraulic structures). PCSWMM is well suited for assessing compound flooding because it simulates how rainfall-driven runoff within the watershed interacts with tidal and storm-surge conditions at the downstream coastal boundary. Results are focused on two key reaches: from Peebles Pond to Ship Harbour, and from Landrie Reservoir to Seacoal Cove.

B.2 Subcatchment Delineation

The 2019 provincial 1-meter topographic LiDAR Digital Elevation Model (DEM) from GeoNOVA was used to delineate subcatchments in GIS software using a series of tools, including flow accumulation and direction, combined with manual verification. The DTM was also used as the basis for assigning physical subcatchment parameters such as slope and maximum overland flow length.

A total of 10 subcatchments were delineated, over a total drainage area of 35 km². As shown in Figure B-1, the delineated areas extend beyond the Point Tupper Industrial Area to ensure that upstream contributing watersheds are fully captured.



Figure B-1: Hydrological model layout for study area watersheds. Red triangles indicate locations where flow time series are generated to serve as inputs for the coastal model.

B.3 Land Cover, Soils, and Lakes

Key subcatchment characteristics required to represent overland flow and infiltration include land-surface roughness and soil infiltration.

Land-surface roughness values were derived from Natural Resources Canada's National Land Cover Mapping (Table B-1). Roughness coefficients for shallow overland flow were assigned to the NRCan land-cover classes present in the study area and prorated by area for each subcatchment. The overall landscape is dominated by forest (nearly 70% when combining forest sub-types), followed by urban land (approximately 13%). Barren ground, grasslands, and wetlands each occupy less than 5%, with the remainder composed of open water (primarily the Landrie Reservoir).

Table B-1: NRCAN land cover types and roughness values.

Land Cover Type	Subcatchment Roughness Value	Percentage of Study Area
Urban (roads / built up area)	0.013	13%
Barren lands	0.05	3%
Temperate or sub-polar grassland	0.24	4%
Mixed forest	0.4	20%
Temperate broadleaf deciduous forest	0.4	11%
Temperate needleleaf forest	0.8	35%
Temperate shrubland	0.4	2%
Water	0.011	9%
Wetland	0.24	3%

Infiltration parameters were informed by provincial soil survey data from Agriculture and Agri-Food Canada (2013). Hydraulic conductivity and suction head values were assigned to the soil drainage classes mapped in the study area and prorated for each subcatchment by area. Poorly drained clay loam is the predominant soil type (about 70%), followed by better drained sandy loam (roughly 20%), with the remaining 10% represented by open water. These provide a representative starting point from which to estimate hydraulic conductivity, which can be further adjusted during model calibration.

Landrie Reservoir, Peebles Pond, and other areas with ponded water were incorporated into the model using LiDAR data and aerial imagery. PCSWMM routed flows through these features to account for their storage and attenuation effects on downstream flows.

B.4 Stream Reaches

Stream reaches were digitized from LiDAR DTM following the rivers' thalwegs and dominant flow path. The LiDAR data (above water surface) was merged with surveyed cross-sections to better represent channel morphology, especially below the water surface. Survey data were available immediately upstream and downstream of structures, so the intervening reaches were interpolated based on these known cross-sections by subtracting the measured channel depth at the nearest surveyed cross-section from the LiDAR-derived cross-section.

Because cross-sections were only collected upstream and downstream of hydraulic structures, spacing varies throughout the model and is greater in some reaches. This introduces uncertainty in channel morphology, particularly in ponded areas where LiDAR provides limited information below the water surface. However, this uncertainty is not expected to materially affect the overall modelling results, including conclusions regarding the negligible influence of compound flooding upstream of the Industrial Road culvert and the negligible influence of runoff on coastal water levels.

Cross-section lines were manually drawn perpendicular to the flow path and extended far enough left and right to contain all flows up to the most extreme event with future climate conditions. They were placed to capture changes in slope, channel or floodplain area, obstructions, and land cover type.

Manning's roughness values for the channel were assigned based on photographs taken during field work or from satellite imagery (most had lower values of 0.03, with some having values of 0.04 or 0.05). Floodplain roughness was assigned based on land cover mapping, shown in Table B-1.

B.5 Hydraulic Structures

Hydraulic structures such as bridges, culverts, and dams can strongly influence upstream water levels and downstream flows. Seven structures were field-inspected and incorporated into the model (Figure B-2). Bridge and culvert dimensions and characteristics (including geometry, roughness, and inlet and outlet conditions) were measured during CBCL's field surveys (Appendix C) and integrated into the PCSWMM model.

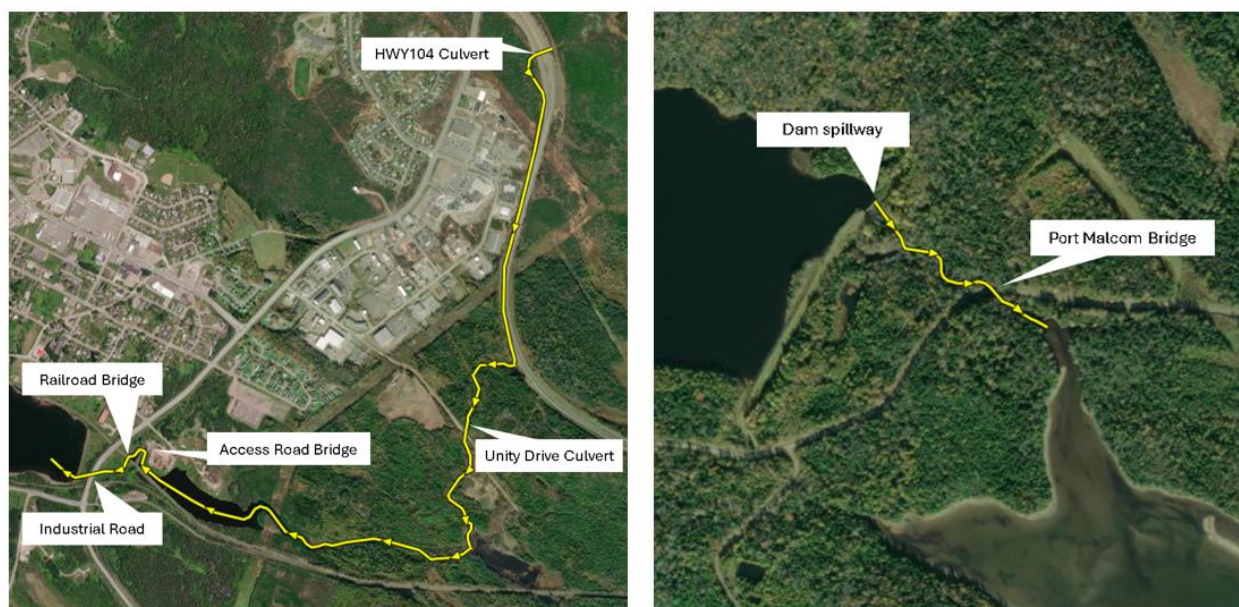


Figure B-2: Location of channels and structures in PCSWMM model.

B.6 Calibration

Model calibration involves adjusting parameters within reasonable bounds so the model can reproduce observed flows from past flood events. Because no flow measurements are available within the study area, flows from a nearby Water Survey of Canada (WSC) gauge were used as a proxy. This was a hydrologic, rather than hydraulic, calibration. Hydraulic calibration requires site-specific downstream flow or water-level data, which cannot be reliably transferred from another subcatchment with different channels and structures.

Flow gauge 01FG001 was selected along with rainfall data from the Port Hawkesbury climate station, using the event of 2021-04-04. Measured flows at this gauge were compared to

modelled flows at the Industrial Road Culvert entering Ship Harbour, a sub-area chosen because it does not include the dampening effects of Landrie Reservoir. The gauge was selected amongst nearby WSC stations based on its proximity and its similarity to the study subcatchment in size, slope, land cover, and soils, as well as for capturing a substantial flow event coinciding with a major rainfall recorded at a nearby rain gauge. While no gauge is a perfect match, 01FG001 was considered the closest proxy for calibration purposes. It should be noted that Hurricane Fiona (2022) was considered as a calibration event, but April 2021 was prioritized because it showed a better correspondence between measured precipitation and flows.

With the gauge and event selected, calibration focused on three parameters: subcatchment width, hydraulic conductivity, and percent imperviousness. These parameters are usually selected for calibration because they carry substantial uncertainty. For example, percent imperviousness can be estimated from land-use data and aerial imagery, but in reality, varies locally with soil compaction, rock outcrops, and landscaping. The percentage changes in parameters obtained from calibrating the Industrial Road Culvert sub-area were applied across the full study area. The resulting runoff coefficients ranged from 0.2 to 0.7, which is within expected bounds (Table B-2).

Table B-2: Calibration event and subcatchment runoff coefficients.

Flood Event Date	Storm Precipitation (mm)	Recorded Peak Flow Rate (m ³ /s)	Modelled Peak Flow Rate (m ³ /s)	Runoff Coefficient Ratio		
				Avg	Max	Min
2021-04-04	84	7.2	7.3	0.64	0.82	0.18

Overall, this represents a first-order calibration. It could be expanded with multiple events, use of more than one flow gauge, sensitivity testing of antecedent conditions, and flow-frequency analysis. However, the selected 2021 event is considered adequate for the present scope and purpose, which is to identify where compound flooding may occur at the site.

B.7 Scenarios

Once the PCSWMM model was calibrated, it was used to run scenarios assessing both the impact of coastal water levels on inland drainage and the effect of subcatchment runoff on coastal flooding.

To maintain a manageable number of scenarios within the scope of this study, scenarios from the Municipal Flood Line Mapping Program such as the winter rainfall on frozen ground were not implemented here. Although the precipitation design events were 48 hours in duration, the model was simulated over a 5-day period to capture multiple tidal cycles and to adequately represent the filling and draining of ponded areas.

To assess the impact of coastal water levels on inland drainage, several boundary condition scenarios were tested, including low tide and free outfall conditions, as well as replacing the Industrial Road culvert with an open channel (at its current elevation and at a lower elevation).

Additional runs isolated individual climate change components (precipitation intensity alone and sea-level rise alone).

To evaluate how subcatchment runoff affects coastal flooding, the scenarios listed in Section 1.3.1 were applied. These consisted of 1-in-20-year and 1-in-100-year precipitation events under both present-day and future climate conditions (four scenarios total). Multiple timing combinations were tested to identify the worst-case overlap between rainfall and coastal water levels (e.g., surge coincident with peak rainfall, low tide at peak rainfall, surge aligned with maximum water levels, and surge occurring before peak rainfall). The configuration that produced the largest flows was a surge occurring three hours before peak rainfall, as this allowed the storage area to fill and then release both rainfall and surge volumes during peak flow.

B.8 Rainfall Analysis

Rainfall Intensity-Duration-Frequency (IDF) data is the result of statistical analysis of historical rainfall intensities. Environment and Climate Change Canada (ECCC) is the primary organization that publishes IDF data in Canada. The IDF data can be used to generate synthetic hyetographs (e.g., the Chicago storm distribution) that represent specific exceedance probability storm events (i.e., return periods).

ECCC climate stations with published IDF data near the study area were reviewed to identify suitable sources for generating storm hyetographs. The station selected was 8205702 in Sydney, NS, which has records dating back to 1961. Although this station is 120 km from the study area, it was considered the best choice that does not require interpolation between IDF stations, which is outside the scope of the present study. Given the sparse IDF network in Nova Scotia, this station is commonly used in hydrologic studies across Cape Breton. Closer stations, such as Eddie Point and Tracadie, were not used because their records are too short for reliable statistical analysis of extreme rainfall events (13 years each).

B.9 Climate Change Projections

To account for future changes in extreme precipitation, historical IDF data were adjusted using climate change scaling factors. The Clausius-Clapeyron approach was applied, which assumes an approximate 7% increase in precipitation intensity per degree of warming. This method is considered scientifically defensible and aligns with federal guidance (CSA PLUS 4013:19; Cannon et al., 2020).

For consistency with the coastal assessment, projections were derived from the Sixth Coupled Model Intercomparison Project (CMIP6) model ensemble under Shared Socioeconomic Pathway (SSP) 5-8.5. The 50th percentile of the model ensemble was used, and projection horizons for 2100 were based on the 30-year period 2071–2100. A baseline of 1981–2010 was adopted, even though the coastal baseline was 2020, because this baseline is commonly used in climatology and better reflects the historical climate underlying the IDF curves.

Temperature projections for individual bias-corrected CMIP6 models were obtained from PAVICS (CanDCS-M6 dataset). For each model, a temperature delta relative to the baseline was

calculated and the corresponding scaling factor derived. The median scaling factor across all models in the ensemble was then computed.

Based on this approach, precipitation intensities for extreme events are expected to increase by approximately 45% by 2100. These percentage increases was applied directly to historical IDF hyetographs used in the hydrological model.

While the Clausius-Clapeyron relationship provides a robust first-order estimate, the scaling rate may vary around the 7% value (Cannon et al., 2020). Evidence also suggests that shorter-duration events may experience a higher scaling rate, but there is currently no clear guidance for applying this, and it was not considered for this study (CSA, 2019).

B.10 Results

Impact of coastal water levels on inland drainage.

The first set of results focuses on explaining what causes high water levels in the area upstream of the Industrial Road culvert. This “Ponded Area” includes the rail bridge, the small bridge just upstream of it, and the section of channel farther upstream where water consistently pools.

The model shows that water levels in the Ponded Area are almost the same from one end to the other (less than 5 cm difference). The only time we see a noticeable slope in the water levels are in hypothetical scenarios where the Industrial Road culvert is removed.

Overall, the current Industrial Road culvert is the main reason for high water levels in the Ponded Area. Figure B-3 shows a large water level difference between today’s culvert (red) compared to an open channel at the same elevation (pink). On the contrary, adding either a low tide timed with rainfall (blue) or a storm surge timed with rainfall (black), has a small (<5 cm) additional impact on peak water levels, and does not affect how long the Ponded Area takes to drain. This confirms that the culvert, not the tides, is the dominant control on water levels. These model runs all include 2100 climate-change conditions, including sea-level rise and/or increased precipitation intensity due to climate change.

Therefore, with the existing Industrial Road culvert and embankment in place, compound flooding is not a major factor for the Ponded Area. When a scenario was tested where the Industrial Road embankment was removed (replacing the culvert with an open channel and lowering the channel bottom to the lowest point of the Ponded Area), the influence of extreme coastal water levels increased, since lowering the outlet allows seawater to move farther upstream. At the same time, peak water levels within the Ponded Area decreased overall because water could drain more freely. This shows that the culvert and embankment currently prevent compound flooding; without them, compound flooding would occur, but peak water levels would still be lower than they are with the current configuration.

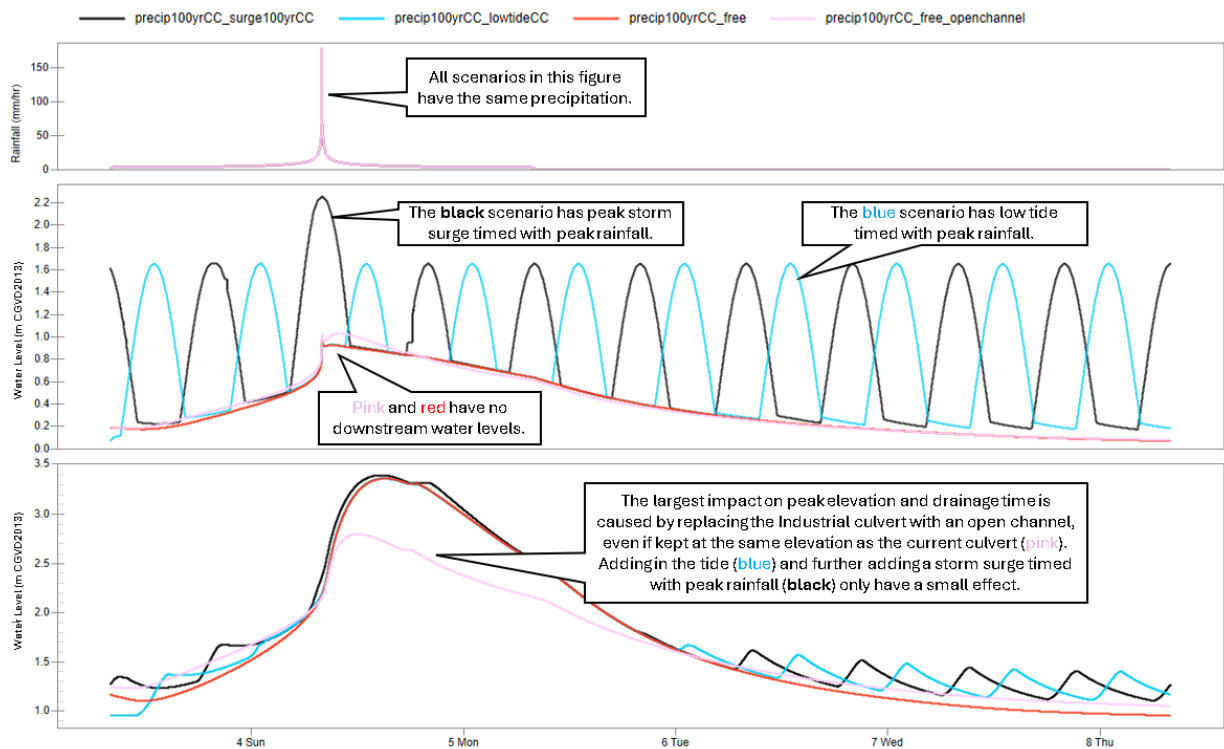


Figure B-3: Model results for causes of peak ponded area water levels.

Figure B-4 shows how different components of climate change contribute to peak water levels in the Pondered Area. The black line is the full climate-change scenario, which includes both higher sea levels and more intense rainfall (the same scenario shown in Figure B-3 above). The other scenarios isolate each component: sea-level rise with current precipitation (green), future precipitation with present-day storm surge (orange), and present-day conditions (purple).

These results show that increased rainfall under future climate conditions has a stronger effect on water levels in the Pondered Area than climate-driven increases in extreme coastal water levels. In other words, future peak levels are more likely to be controlled by heavier precipitation backing up behind the Industrial Road culvert. This aligns with the earlier finding that the existing Industrial Road culvert and embankment prevent compound flooding at the site.

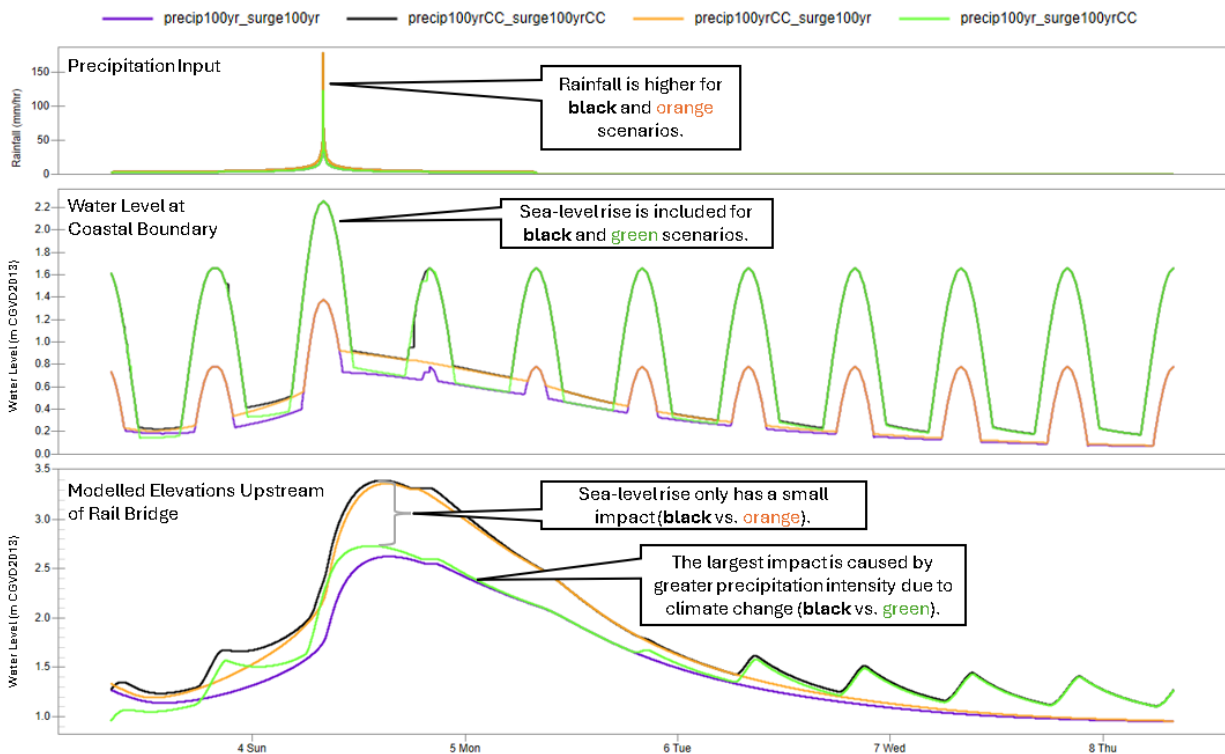


Figure B-4: Model results for impacts of climate change on ponded area water levels.

For the other structures in the study area, model results show that they are far enough upstream for coastal water levels to have a negligible effect (less than 5 cm), meaning they are not subject to compound flooding. Their water levels are instead controlled by present-day and future-climate precipitation-driven flows.

HWY104 – Experiences surcharging during the 1-in-100-year precipitation event under both present-day and future climates. With climate change, overtopping occurs by only a few centimeters for roughly six hours, which remains within the model’s uncertainty.

Unity Drive – Has adequate capacity for the 1-in-100-year event under current conditions but surcharges under climate-change rainfall.

Dam Spillway – Maximum water depth remains well below the top of the spillway.

Port Malcolm Bridge – Does not overtop, and water does not reach the underside of the bridge, even with climate change increases in precipitation intensity and sea-level rise.

Impact of runoff on coastal flooding

To evaluate how subcatchment runoff affects coastal flooding, time series were extracted at the outfalls marked by red triangles in Figure B-1. Figure B-5 is an example time series for the 1-in-100-year (with and without 2100 climate change) downstream of Industrial Road.

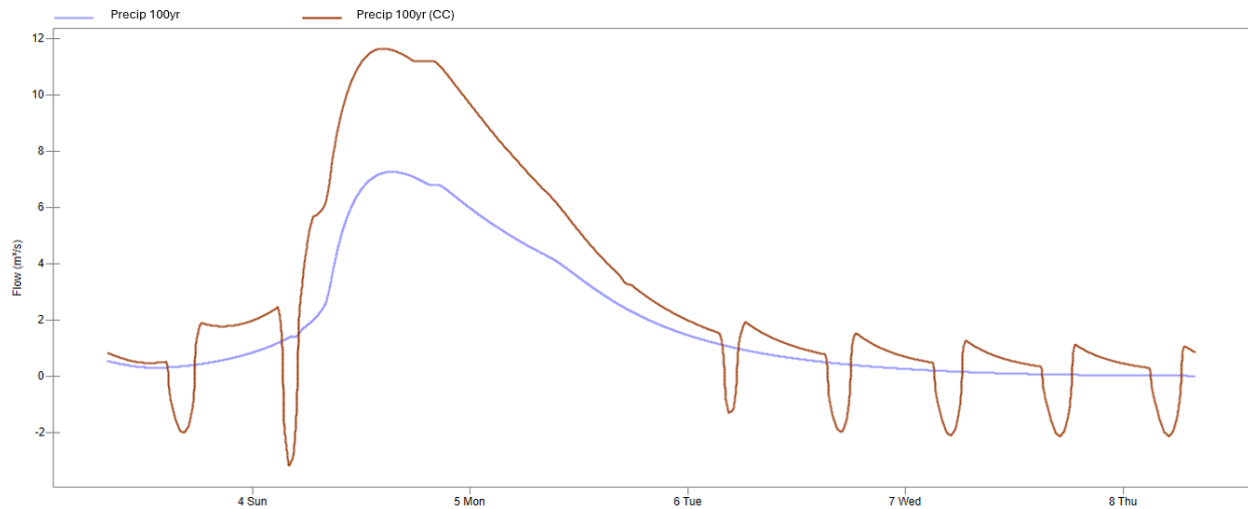


Figure B-5: Example flow timeseries extracted from PCSWMM for input into MIKE (downstream of Industrial Road culvert).

APPENDIX C

Survey Data Sheets

GENERAL

Structure ID: ST-411
 Structure Type: Culvert
 Date of Construction:
 Community: Port Malcolm
 Primary Watershed: 1FD
 Secondary Watershed: 1FD-SD6
 River: Seacoal Brook
 Reach:

Location:



Note: Field notes collected to support survey shots completed.
 Forms may be incomplete where all data collected directly
 with GPS controller.

SURVEY INFORMATION

Inspected: Yes
 Inspector:
 Date of Survey: 7/23/2025 3:00:00 PM

Survey Note:

STRUCTURE INFORMATION

Diameter:
 Span: 3.744 m
 Rise: 2724 mm
 Length: 9.06 m

Shape: Open bottom Arch
 Material: Corrugated HDPE
 Guiderail: Yes

CONDITION

General Condition:
 Inlet Condition: Headwall

Outlet
 Condition: Headwall

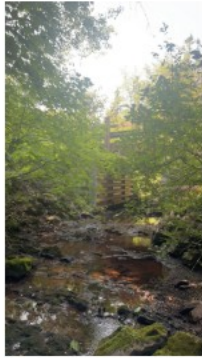
Comment:

Comment:

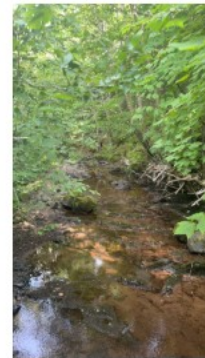
OTHER COMMENTS

Comment:

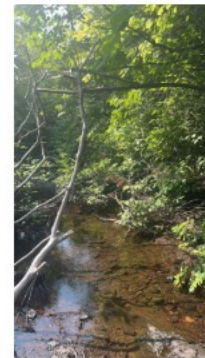
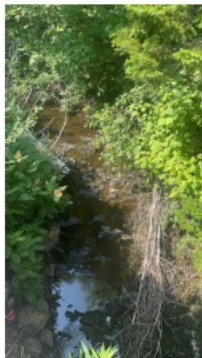
At Downstream looking Upstream at Structure



At Structure looking Downstream



At Structure looking Upstream



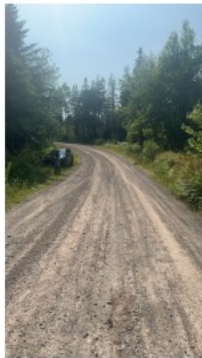
At Structure looking Downstream



At Structure looking up Road (to left)



At Structure looking up Road (to right)



Up Road (left side) looking at Structure



Down Road (right side) looking at



GENERAL

Structure ID: ST-412
 Structure Type: Dam
 Date of Construction:
 Community: Port Malcolm
 Primary Watershed: 1FD
 Secondary Watershed: 1FD-SD6
 River: Seacoal Brook
 Reach:

Location:



Note: Field notes collected to support survey shots completed.
 Forms may be incomplete where all data collected directly
 with GPS controller.

SURVEY INFORMATION

Inspected: Yes
 Inspector: JS
 Date of Survey: 8/12/2025 3:00:00 PM

Survey Note:

STRUCTURE INFORMATION

Diameter:
 Span: 30431 mm
 Rise: 2453 mm
 Length: 25 m
 Shape: Other
 Material: Concrete
 Guiderail: No

CONDITION

General Condition:
 Inlet Condition: Other
 Outlet Condition: Other

Comment:

Comment:

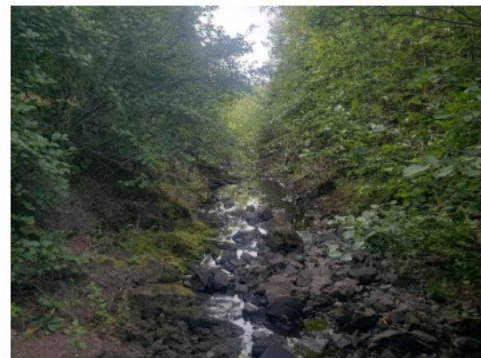
OTHER COMMENTS

Comment:

At Downstream looking Upstream at Structure



At Structure looking Downstream



At Structure looking Upstream



At Structure looking Downstream

No
Photo

No
Photo

At Structure looking up Road (to left)



No
Photo

At Structure looking up Road (to right)



Up Road (left side) looking at Structure

No
Photo

No
Photo

Down Road (right side) looking at



GENERAL

Structure ID:	ST-414	Location:	
Structure Type:	Culvert		
Date of Construction:			
Community:	Point Tupper		
Primary Watershed:	1FA		
Secondary Watershed:	1FA-SD7		
River:	Peebles Pond		
Reach:			
Note: Field notes collected to support survey shots completed. Forms may be incomplete where all data collected directly with GPS controller.			

SURVEY INFORMATION

Inspected:	Partial	Survey Note:	No access to US
Inspector:			
Date of Survey:	7/14/2025 3:00:00 PM		

STRUCTURE INFORMATION

Diameter:		Shape:	Ellipse
Span:	200 mm	Material:	Corrugated HDPE
Rise:	165 mm	Guiderail:	
Length:			

CONDITION

General Condition:		Outlet	
Inlet Condition:		Condition:	
Comment:		Comment:	

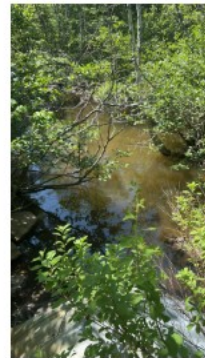
OTHER COMMENTS

Comment:

At Downstream looking Upstream at Structure



At Structure looking Downstream



At Structure looking Upstream

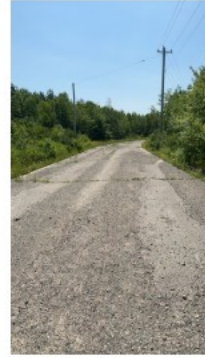
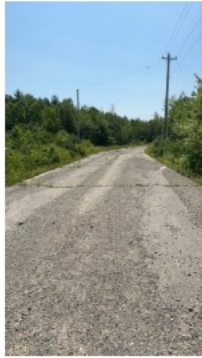


At Structure looking Downstream

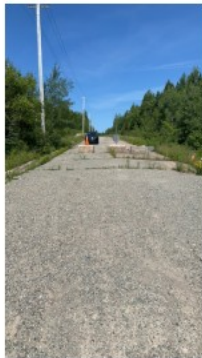
No
Photo

No
Photo

At Structure looking up Road (to left)



At Structure looking up Road (to right)



Up Road (left side) looking at Structure



Down Road (right side) looking at



GENERAL

Structure ID: ST-417
 Structure Type: Culvert
 Date of Construction:
 Community: Point Tupper
 Primary Watershed: 1FA
 Secondary Watershed: 1FA-SD7
 River: Peebles Pond
 Reach:

Location:



Note: Field notes collected to support survey shots completed.
 Forms may be incomplete where all data collected directly
 with GPS controller.

SURVEY INFORMATION

Inspected: Yes
 Inspector:
 Date of Survey: 7/14/2025 3:00:00 PM

Survey Note:

STRUCTURE INFORMATION

Diameter:
 Span: 250 mm
 Rise: 185 mm
 Length:
 Shape: Box
 Material: Concrete
 Guiderail:

CONDITION

General Condition:
 Inlet Condition:
 Comment:
 Outlet Condition: Wing wall, Square edge with Headwall
 Comment:

OTHER COMMENTS

Comment: Couldn't access US or road

At Downstream looking Upstream at Structure



At Structure looking Downstream



At Structure looking Upstream

No
Photo

No
Photo

At Structure looking Downstream

No
Photo

No
Photo



Structure Data Sheet - Photos

<u>At Structure looking up Road (to left)</u>	
No Photo	No Photo
<u>At Structure looking up Road (to right)</u>	
No Photo	No Photo
<u>Up Road (left side) looking at Structure</u>	
No Photo	No Photo
<u>Down Road (right side) looking at</u>	
No Photo	No Photo

GENERAL

Structure ID: ST-419
 Structure Type: Culvert
 Date of Construction:
 Community: Melville
 Primary Watershed: 1FA
 Secondary Watershed: 1FA-SD7
 River: Peebles Pond
 Reach:

Location:



Note: Field notes collected to support survey shots completed.
 Forms may be incomplete where all data collected directly
 with GPS controller.

SURVEY INFORMATION

Inspected: Yes
 Inspector: AB
 Date of Survey: 7/14/2025 3:00:00 PM

Survey Note: one single culvert under road

STRUCTURE INFORMATION

Diameter: 130 mm
 Span:
 Rise:
 Length:

Shape: Circular
 Material: Concrete
 Guiderail: No

CONDITION

General Condition:
 Inlet Condition:

Outlet
 Condition: Groove end projecting

Comment:

Comment:

OTHER COMMENTS

Comment: Secondary Culvert: 135mm Concrete, Invert Elevation 58.997m

At Downstream looking Upstream at Structure



At Structure looking Downstream



At Structure looking Upstream



At Structure looking Downstream





Structure Data Sheet - Photos

<u>At Structure looking up Road (to left)</u>	
No Photo	No Photo
<u>At Structure looking up Road (to right)</u>	
No Photo	No Photo
<u>Up Road (left side) looking at Structure</u>	
No Photo	No Photo
<u>Down Road (right side) looking at</u>	
No Photo	No Photo

GENERAL

Structure ID:	ST-415	Location:	
Structure Type:	Bridge		
Date of Construction:			
Community:	Port Hawkesbury		
Primary Watershed:	1FA		
Secondary Watershed:	1FA-SD7		
River:	Peebles Pond		
Reach:			
Note: Field notes collected to support survey shots completed. Forms may be incomplete where all data collected directly with GPS controller.			

SURVEY INFORMATION

Inspected:	Yes	Survey Note:
Inspector:	AB	
Date of Survey:	July 14, 2025	

STRUCTURE INFORMATION

Span:	11.84 m	Number of Piers:	0
Height:	0.857 m	Width of Pier:	
Length:	9.15 m	Pier Spacing:	
Top of Deck Elev.:	2.999 m	Type of Pier:	
Underside of Deck Elev.:	2.293 m		

CONDITION

General Condition:	Poor	Outlet	
Inlet Condition:	Vertical Abutments	Condition:	Vertical Abutments
Comment:		Comment:	

OTHER COMMENTS

Comment:

At Downstream looking Upstream at Structure

No
Photo

No
Photo

At Structure looking Downstream



At Structure looking Upstream



At Structure looking Downstream

No
Photo

No
Photo

At Structure looking up Road (to left)



At Structure looking up Road (to right)



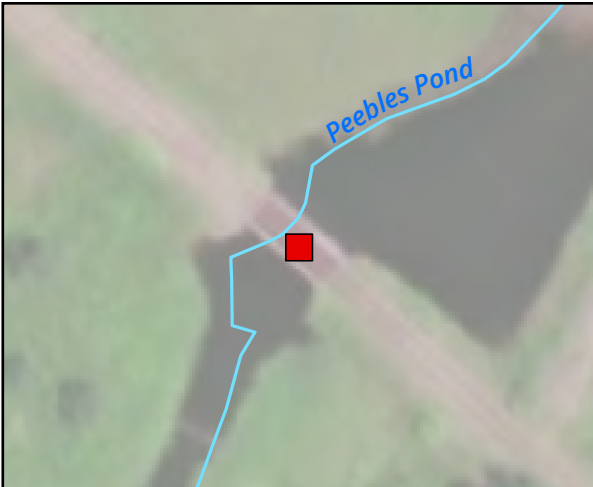
Up Road (left side) looking at Structure



Down Road (right side) looking at



GENERAL

Structure ID:	ST-416	Location:	
Structure Type:	Bridge		
Date of Construction:			
Community:	Port Hawkesbury		
Primary Watershed:	1FA		
Secondary Watershed:	1FA-SD7		
River:	Peebles Pond		
Reach:			
Note: Field notes collected to support survey shots completed. Forms may be incomplete where all data collected directly with GPS controller.			

SURVEY INFORMATION

Inspected:	Yes	Survey Note:
Inspector:	AB	
Date of Survey:	July 14, 2025	

STRUCTURE INFORMATION

Span:	12.6 m	Number of Piers:	0
Height:	1.68 m	Width of Pier:	
Length:	3.69 m	Pier Spacing:	
Top of Deck Elev.:	3.542 m	Type of Pier:	
Underside of Deck Elev.:	3.092 m		

CONDITION

General Condition:	Good	Outlet	
Inlet Condition:	Wing Walls	Condition:	Wing Walls
Comment:		Comment:	

OTHER COMMENTS

Comment:

At Downstream looking Upstream at Structure



At Structure looking Downstream



At Structure looking Upstream



At Structure looking Downstream



At Structure looking up Road (to left)



At Structure looking up Road (to right)



Up Road (left side) looking at Structure



Down Road (right side) looking at



APPENDIX D

Run-up Modelling Results

Scenario			Location of Modelled Wave Run-up Extent		
Profile ID	Return Period (Years)	SLR Horizon (Year)	Z2% (m CGVD2013)	x (m UTM 20)	y (UTM 20)
1	20	Present Day	2.73	634362.9	5048766.4
1	100	Present Day	3.14	634362.9	5048766.4
1	20	2050	3.04	634362.9	5048766.4
1	100	2050	3.33	634362.4	5048767.4
1	20	2100	3.71	634362.4	5048767.4
1	100	2100	4.09	634362.0	5048768.4
2	20	Present Day	2.25	633022.6	5048318.8
2	100	Present Day	2.48	633020.6	5048320.6
2	20	2050	2.53	633019.6	5048321.5
2	100	2050	2.68	633016.6	5048324.1
2	20	2100	3.04	633012.6	5048327.7
2	100	2100	3.21	633010.6	5048329.5
3	20	Present Day	2.61	634340.2	5046428.2
3	100	Present Day	2.92	634340.2	5046428.2
3	20	2050	2.88	634340.2	5046428.2
3	100	2050	3.2	634339.2	5046428.5
3	20	2100	3.71	634339.2	5046428.5
3	100	2100	4.13	634338.2	5046428.8
4	20	Present Day	2.34	632346.4	5046026.7
4	100	Present Day	2.55	632345.9	5046025.7
4	20	2050	2.59	632346.4	5046026.7
4	100	2050	2.85	632346.9	5046027.7
4	20	2100	3.32	632346.9	5046027.7
4	100	2100	3.57	632347.4	5046028.7
5	20	Present Day	2.53	630770.3	5046841.3
5	100	Present Day	2.82	630770.3	5046841.3
5	20	2050	2.82	630770.3	5046841.3
5	100	2050	3.05	630770.3	5046841.3

Scenario			Location of Modelled Wave Run-up Extent		
5	20	2100	3.57	630770.3	5046841.3
5	100	2100	3.89	630770.9	5046842.3
6	20	Present Day	2.24	629538.3	5047986.9
6	100		2.38	629538.3	5047986.9
6	20	2050	2.51	629538.6	5047987.9
6	100	2050	2.62	629538.6	5047987.9
6	20	2100	3.23	629541.0	5047996.9
6	100	2100	3.29	629541.3	5047997.9
7	20	Present Day	2.11	628781.2	5049239.8
7	100	Present Day	2.29	628781.2	5049239.8
7	20	2050	2.27	628781.2	5049239.8
7	100	2050	2.67	628781.2	5049239.8
7	20	2100	2.94	628781.2	5049239.8
7	100	2100	3.23	628781.3	5049240.8
8	20	Present Day	2.21	627998.0	5050362.1
8	100	Present Day	2.41	627998.1	5050363.1
8	20	2050	2.41	627998.1	5050363.1
8	100	2050	2.69	627998.1	5050363.1
8	20	2100	3.08	627998.1	5050363.1
8	100	2100	3.38	627998.3	5050364.1
9	20	Present Day	2.17	627123.3	5051401.2
9	100	Present Day	2.44	627123.5	5051402.2
9	20	2050	2.44	627123.5	5051402.2
9	100	2050	2.57	627123.5	5051402.2
9	20	2100	2.97	627126.9	5051418.2
9	100	2100	3.15	627127.1	5051419.2
10	20	Present Day	1.49	628442.3	5051762.2
10	100	Present Day	1.5	628442.3	5051762.2
10	20	2050	1.56	628442.3	5051762.2
10	100	2050	1.67	628443.3	5051761.9

Scenario			Location of Modelled Wave Run-up Extent		
10	20	2100	2.17	628449.4	5051759.8
10	100	2100	2.32	628450.4	5051759.4

APPENDIX E

Flood Maps



Solutions today | Tomorrow **IN** mind

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