Impacts of Climate Change and Sea Level Rise on the Mi'kmaq Communities of the Bras d'Or Lakes

Phase Two Project Report
AANDC Climate Change Adaptation Program

March 2016

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Unama'ki Institute of Natural Resources

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1. Background

The Unama'ki Institute of Natural Resources (UINR) is an organization that represents the five Mi'kmaq communities of Unama'ki (Cape Breton Island, Nova Scotia) on natural resources issues. UINR contributes to an understanding and protection of the Bras d'Or Lakes' ecosystem through research, monitoring, education, management, and by integrating Mi'kmaq and conventional ways of understanding, known as Two-Eyed Seeing. Four of our five communities (Potlotek, Eskasoni, Wagmatcook and We'koqma'q) are located on the Bras d'Or Lakes. A sixth community, Malagawatch, which is owned jointly by the five communities, is also located on the Bras d'Or.

Coastal communities are susceptible to erosion that results from the increased storm surges and lack of ice coverage due to climate change. First Nation communities are particularly affected by these threats due to their limited infrastructure funding and land base. This project will provide the Unama'ki communities with a powerful tool for the community development and adaptation planning needed to face the pending challenges that will arise due to Climate Change.

Our Unama'ki communities will be engaged in discussion on the cause and effects of climate change, vulnerabilities of their communities and some options on moving forward for mitigation and adaptation. Meetings will be held with each community to present the results of our research and inform them of the potential threats that are posed both to their own communities and the shared community of Malakowej'k.

In year two, UINR will facilitate a series of meetings with the seasonal residents of Malakowej'k and Potlotek to share the results of the study and engage them in the development of a strategy for adaptation. In years one and two UINR will engage community Elders to gather traditional knowledge on storm surges to compliment the scientific work to be done on storm surge modeling. The completed study will then be shared with the Elders to show them how their knowledge has contributed to the study. The project will also be communicated broadly to Unama'ki community members through UINR's quarterly newsletters and website www.uinr.ca . The information resulting from these discussions will then be shared with the Chief and Council members contributing to an increased knowledge of the causes and impacts of climate change and their community's vulnerabilities to these changes. This will empower the communities to adapt to the identified changes and challenges. Capacity will also be developed in the communities through the inclusion of band administration staff including public works, housing and lands officers throughout the project.

The communities will have access to a valuable tool which will inform their community plans and decision making processes including land use development, future infrastructure needs, protection of cultural and historic significant area

2. Link to Climate Change

The coastlines of the Bras d'Or Lakes, due to their proximity to the North Atlantic Ocean, are frequently exposed to the devastating effects of extreme storms, including post-tropical hurricanes, resulting in storm-surge events that flood low lying sections of the Mi'kmaq communities. The strong winds that accompany these storms generate significant wave action (particularly along the longer southwest-northeast wind fetch axes) that eat away sections of coastline thereby impacting on infrastructure, ecosystems and historically and recreationally significant sites (e.g., graveyards and Aboriginal burial sites).

Climate change is expected to exacerbate these impacts by producing more frequent storm surge events through a combination of more intense and possibly more frequent storms, stronger winds and sea levels that are expected to rise by nearly one metre by year 2100 through a combination of Global Sea Level Rise and Regional Coastal Subsidence (IPCC Fifth Assessment Report, Sep 2013). It is also expected that North Atlantic hurricanes would not dissipate as quickly south of Nova Scotia due to the presence of warmer ocean temperatures, thereby contributing to higher storm surge damages.

It has been demonstrated that present day, one in hundred year rare flooding events could increase in frequency to near annual events, given a rise in sea levels of one metre (Richards, W., Daigle, R., 2011, Scenarios and Guidance for Adaptation to Climate Change and Sea-Level Rise – NS and PEI Municipalities).

The direct impact climate change has had on the Unama'ki communities is evident. A report prepared by W.F. Baird and Associates in 2009, Erosion Mitigation Assessment for Malagawatch Grave Yard, indicted that the shore line is rapidly eroding due to wave attack during severe storms putting roads, cabins and cultural resources at risk. A report prepared by Jens Jensen HMJ consulting in 2007 for Wagmatcook identified the community's wharf to be at risk due to storm surges and community infrastructure vulnerable to flooding due to their proximity to a flood plain. A planning meeting was held by UINR with community members on September 12, 2013 in Eskasoni to discuss concerns around the Potlotek mission site. A number of concerns were raised regarding the effect of storm surges and sea-level rise on the seasonal residences. The majority of cabins on the island are built along the shoreline and more than a dozen have been lost in the last two to three years due to erosion. A need was identified for engaging the cabin owners on climate change adaptation and land use planning to prevent further losses.

3. Project Outcomes

The project outcomes are hereby summarized in this section according to the Objectives outlined in the Project Proposal

3.1 Objective 1: LiDAR elevation and photographic data for each community

3.1.1 Methodology:

Collection of LiDAR elevation and imagery data for each community was completed in year one (2014-2015). Leading Edge Geomatics Ltd completed the LiDAR and imagery for the Mi'kmaq communities of Potlotek, Eskasoni, Wagmatcook, We'koqma'q and Malagawatch. Aerial photography has also been collected for each community.

3.2 Objective 2: Storm-surge flooding statistics and Traditional Ecological Knowledge (TEK) on storm-surge flooding for the Bras d'Or Lakes with emphasis on each community.

3.2.1 Methodology:

Storm-surge flooding statistics were prepared for the Bras d'Or Lakes in phase one of the study. A water level database of the Bras d'Or Lakes made available by the Science Branch Maritimes Region of Fisheries and Oceans Canada allowed for the detection of important storm surge events that would have taken place since 2009 thereby allowing a comparison with the Fisheries and Oceans Canada North Sydney tide gauge database. This data was complimented by TEK about the behaviour of storms in the Bras d'Or Lakes and local community measurements of storms during the life of the project. This approach is described in the Impacts of Climate Change and Sea Level Rise on the Mi'kmaq Communities of the Bras d'Or – Phase One Report.

3.2.1.1 TEK Method

TEK on climate change events was collected to compliment the scientific research on storm surge modeling. UINR engaged Mi'kmaq Elders from the five Unama'ki communities on their knowledge of storm surge frequency, duration and effects, seasonal changes and changes in natural patterns in nature. UINR has developed a protocol for the collection and use of TEK with our Unama'ki Elders. The preferred methodology of engaging Elders is through a workshop format. This provides a forum for Elders to engage with one another on specific issues in a way that encourages participation and provides opportunity for clarification and validation of their knowledge.

In this way it is a collective knowledge that we are obtaining. Elders were selected with the assistance of UINR's Elder Advisor who has an extensive network in the communities and an awareness of whom within the communities holds knowledge most relevant to the issue we are discussing. The meetings were held in Mi'kmaq and facilitated by one of the Elders.

UINR hosted a meeting of Elders and resource users on September 25th, 2014 in Eskasoni. There were 15 Elders in attendance representing the five Mi'kmaw communities of Unama'ki. Discussions focused on frequency, duration and intensity of storm surges, observations in seasonal changes and changes in the natural patterns observed in nature. A knowledge review session was held on December 14th, 2015 with the Elders to ensure that the knowledge shared was captured accurately. The proceedings from this session are in Appendix C.

3.3 Objective 3: Flooding scenarios for each community

3.3.1 Methodology

An initial set of storm-surge flooding scenario contours and maps were prepared in Year 1 of the UINR Project for the Bras D'Or Lakes Mi'kmaq communities. These scenarios were based on limited available water level data obtained the Department of Fisheries and Oceans. The scenarios have now been updated in collaboration with Coldwater Consulting Limited, resulting in so-called Hazard Maps that represent the flooding that would occur with the 100-Year event, an event with a 1% annual probability of occurrence. Coldwater Consulting Limited have in fact concluded that the major flooding event of December 2010 around the Bras D'Or Lakes was indeed representative of the 100-Year event.

3.3.1.1 Baseline Water Levels

In Year 1 of this project flooding scenarios were developed using a traditional baseline water level of Higher High Water at Larger Tides (HHWLT). The HHWLT baseline is representative of the average of the highest predicted astronomical tide over an 18.6-year tidal cycle, and is hence somewhat higher than a more normal Mean Sea Level (MSL), which is representative of the average between high and low tides in a given location. With a tide range of only approximately 10 cm within the Bras D'Or Lakes (Drozdowski, A, et al., 2014), the difference between HHWLT and MSL for the Bras D'Or Lakes is hence minimal (0.4m CGVD28 for HHWLT vs 0.3 m CGVD28 for MSL). Based on precision elevation measurements by Coldwater Consulting Limited in June 2015, it was decided to use the MSL value of 0.3 m CGVD28 as a 2015 baseline water level value for sea-level rise and associated storm-surge flooding scenarios.

3.3.1.2 Sea-Level Rise Estimates

As for Year-1 of this project, the regional sea-level rise projections for the Bras D'Or Lakes were extracted from a recent report entitled "Relative Sea-level Projections in Canada and the Adjacent Mainland United States, (James et al., 2014)". This report has taken the Intergovernmental Panel on Climate Change Fifth Assessment Report global sea-level rise predictions and “downscaled” results to a regional level that includes relative contributions of global sea-level rise, detailed crustal subsidence estimates, impacts of ocean dynamics changes associated with a weakening Gulf Stream circulation and the impacts of ice sheet meltwater distribution (fingerprinting).

The relative sea-level rise projections for the communities of Eskasoni, Potlotek, Malagawatch, Waycobh and Wagmatcook were taken directly from the Baddeck projections in the above-noted publication. The projections in Year-2 of this project have however been limited to years 2040 (25-year projection from 2015) and 2100 (85-year projection from 2015). These values are respectively 0.18 m and 0.82 m above the the 2015 baseline MSL value of 0.3 m CGVD28, hence MSL projections of 0.48 m in 2040 and 1.12 m in 2100.

3.3.1.3 Flooding Scenarios

Flooding scenario contours and associated Flood Hazard maps have been prepared by Coldwater Consulting Limited for 2015 (baseline), 2040 and 2100. The flood hazard has been defined as the 1 in 100-Year storm surge event (hence 1% probability of occurrence annually). Of interest, the major storm surge flooding event of December 2010 has been found to be representative of the 1 in 100-Year flooding event. In accordance with expected climate change impacts, the storm surge calculations for 2040 and 2100 have taken into account an increased intensity of storms (stronger winds and reduced atmospheric pressure) and the absence of winter ice cover over the Bras D’Or Lakes

The flooding scenario contours (shapefile format) and flood maps (PDF format) are provided in electronic format.

3.4 Objective 4: 2014 coastal mapping for each community; Erosion assessment for two (2) sites: the Malagawatch ancestral cemetery and the Chapel Island ceremonial grounds; and the Year 2100 shoreline projection scenario for the two sites.

Mapping of the coastline for each community and evaluation of coastal erosion patterns for two (2) sites: the Malagawatch ancestral cemetery and the Chapel Island ceremonial grounds were completed in 2014. The completed results are contained in the Impacts of Climate Change and Sea Level Rise on the Mi'kmaq Communities of the Bras d'Or – Phase One Report.

3.5 Objective 5: Provide knowledge and tools for the integration of climate change adaptation into community plan.

3.5.1 Overview

The Bras D'Or Lakes are connected to Sydney Bight and the Atlantic Ocean through the Great Bras D'Or Channel and the Little Bras D'Or Channel (as well as by St. Peter's Canal to the south). Water levels in the Bras D'Or Lakes are influenced by winds, tides and storm surges which flow into the lake through these channels.

Five First Nations communities, Potlotek, Eskasoni, Wagmatcook, We'koqma'q and Malikewe'j, have lands that border the Bras d'Or Lakes. The land and infrastructure of these communities are presently at risk from coastal erosion and flooding. These risks are expected to worsen in the future because of the effects of climate change, specifically:

- relative rise in the water levels of Bras d'Or Lakes (combined effects of sea-level rise and vertical movement of the land);
- reduction in the duration of ice cover, and;
- increased storminess (frequency and/or intensity of storms).

This report presents a risk-based assessment of coastal flooding hazards affecting the five communities prepared by Coldwater Consulting Ltd. under contract to the Unama'ki Institute of Natural Resources (UINR).

Coastal flooding in Bras d'Or Lakes is the result of a number of factors that occur over a range of scales. Although there are measureable tidal fluctuations on a twice daily basis, by far the most important factor is storm surge which can raise water levels across the entire Bras d'Or Lakes for periods ranging from a single day to over a week. In addition, strong winds can push water across the lake, driving up levels at one end and dropping them at the other. Uprush (run-up) from wind waves can further add to flooding risks.

The report builds on earlier work undertaken by the Unama'ki Institute of Natural Resources and gives an updated, and more detailed, assessment of flooding processes along the shores of the Bras d'Or Lakes. It also evaluates the possible measures that can be taken to address these risks now and into the future.

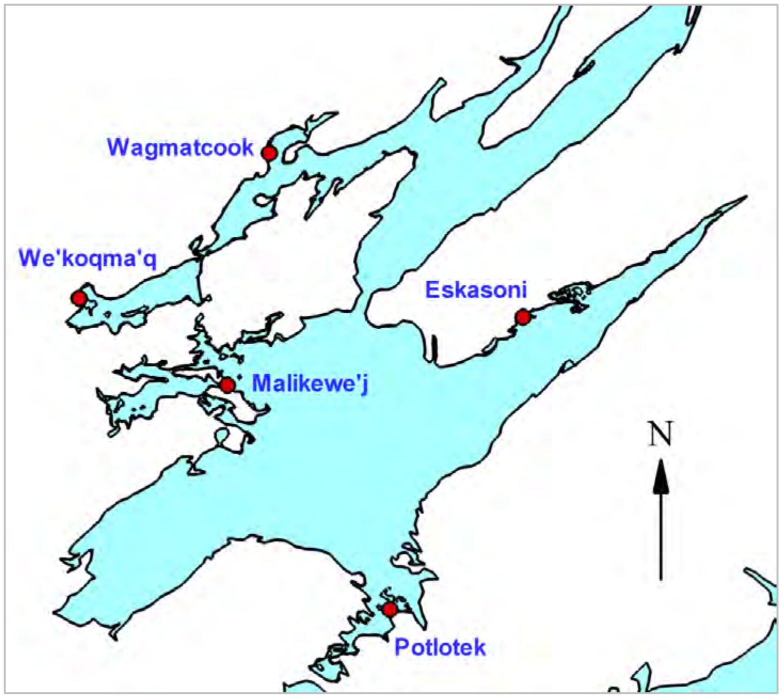

Figure 1 Unama'ki coastal communities of the Bras d'Or Lakes

The analysis presented in this report includes:

1) Met-Ocean Assessment – this is an evaluation of the combined weather (meteorological) and oceanographic conditions that influence water levels and wave conditions throughout the Bras d'Or Lakes. This work involves:

    a. Detailed modelling and analysis of water levels throughout the Bras d'Or Lakes. This analysis uses computer models of the Atlantic Ocean, Sydney Harbour and the Bras d'Or Lakes to predict how tides, storm surge, winds and waves can combine to create flooding conditions, and;

    b. Using these computer models to evaluate how climate change will affect flood risks in coming years – this analysis considers sea level rise, a shortened ice season, and increased storminess.

2) Vulnerability Assessment – this involves using predictions of present-day and future storm conditions to assess the vulnerability of coastal communities to flood and erosion damage. This stage of the work results in maps of flood risk that identify those lands which are vulnerable to storm damage now and in the future.

3) Adaptation Strategies – this is an evaluation of measures that can be taken to protect communities from storm damage. Such measures include planning and land-use regulation, as well as shore protection works.

3.5.1.1 Storm conditions in the Bras d'Or Lakes

Analysis of the effects of storms and tides on water levels in the Bras d'Or lakes has shown that the lakes have quite a unique response to extreme water level events. The restricted opening provided by the Great Bras d'Or Channel is too narrow to allow full tidal exchange; as a result, the tidal range within the Bras d'Or lakes is much smaller than in the adjacent waters of Sydney Harbour (see Figure 2 which shows typical tidal conditions at Sydney and Baddeck).

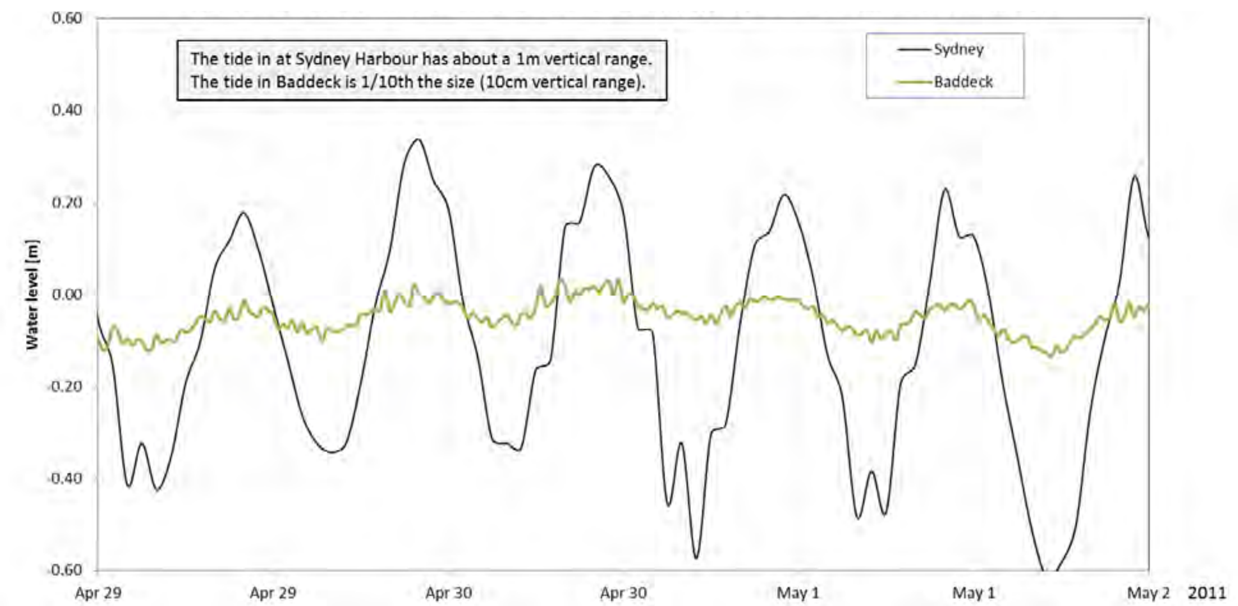

Figure 2 Comparison of typical tidal conditions at Sydney (open Atlantic Ocean) and at Baddeck.

It takes a long time for the tide to push its way through the narrow Great Bras d'Or channel, meaning that by the time the tide in the ocean has finished rising and starts to fall again, the level of the Bras d'Or Lakes has barely risen at all. In the six hours it takes for the ocean to go from low tide to high tide, the flow through the Great Bras d'Or Channel is only enough to raise the Bras d'Or Lakes level by 5 to 10 cm. This response time is critical to water levels in the lakes: long duration storm events, particularly those from the Northeast can cause much larger variations in water levels than those caused by tides. An illustration of this process is the storm of December 2010, which resulted in sustained high water levels over a period of 7 days with water levels as much as 80cm above normal. The following plot of measured water levels during the December 2010 storm shows that storms lasting several days can result in water levels rising 50 to 80 cm and staying well above normal for almost a week.

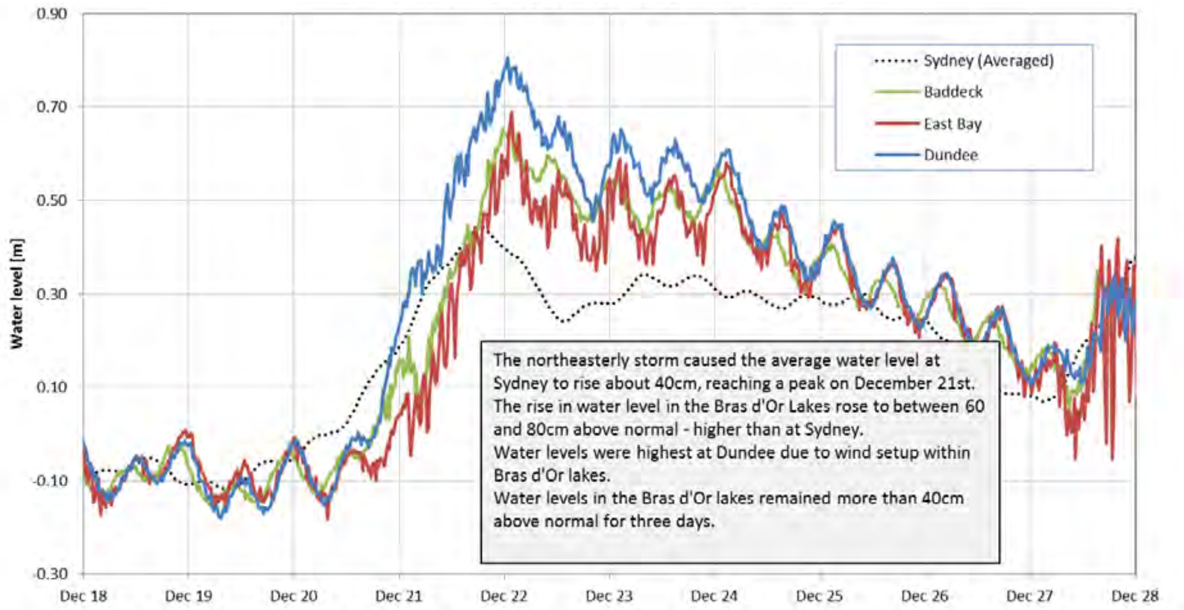

Figure 3 Measured water levels during the December 2010 storm.

Water levels along the shores of the Bras d'Or Lakes are influenced by the following factors:

- *storm surge* – the raising of the overall Bras d'Or Lakes water level by wind and pressure effects of large-scale storms and the underlying tidal fluctuations;
- *wind setup* – the local raising of water levels in one part of the lake because of local winds, and;
- *wave run-up* – the maximum water level at a particular site caused by wave action at the shore.

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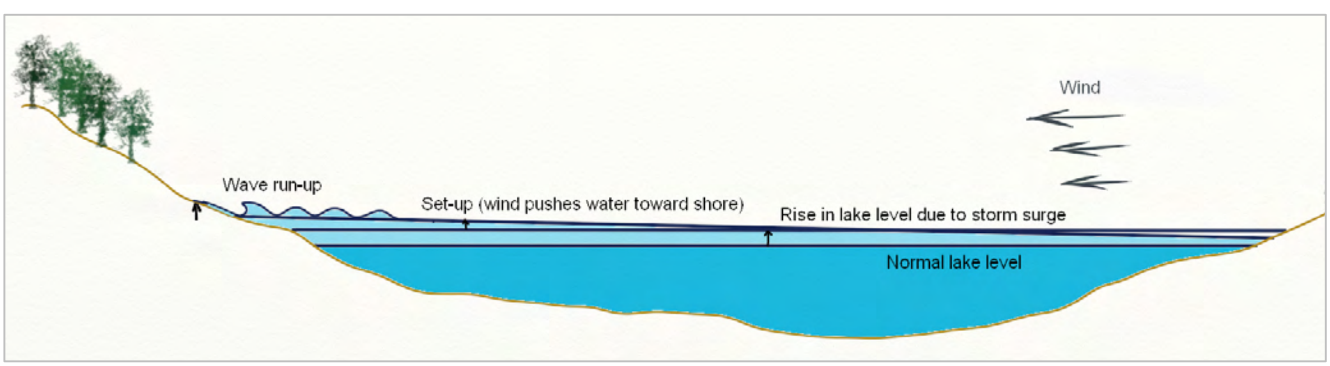


Figure 4 Processes affecting lake levels

The vertical extent of wave run-up depends somewhat on the shape of the shoreline. For the same wave conditions, wave run-up on a vertical structure will be much higher than on a gently sloping beach. Flood hazard elevations (the elevation that storm waters can reach) have been defined for the study area for two shoreline geometries: A relatively steep armour stone revetment; and a gently sloping beach.

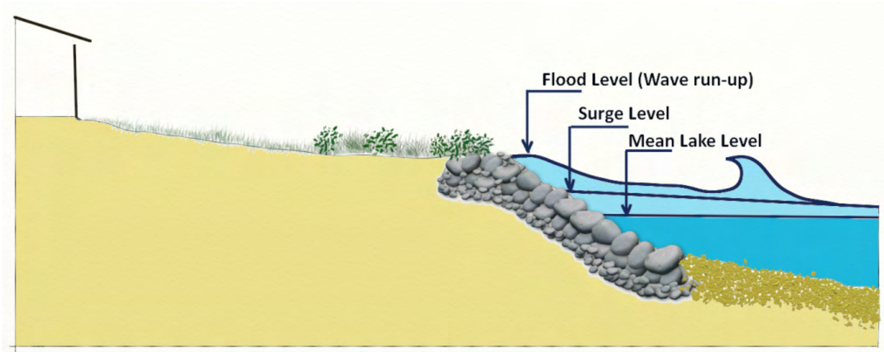


Figure 5 Flood levels (wave run-up) for amour-stone revetment

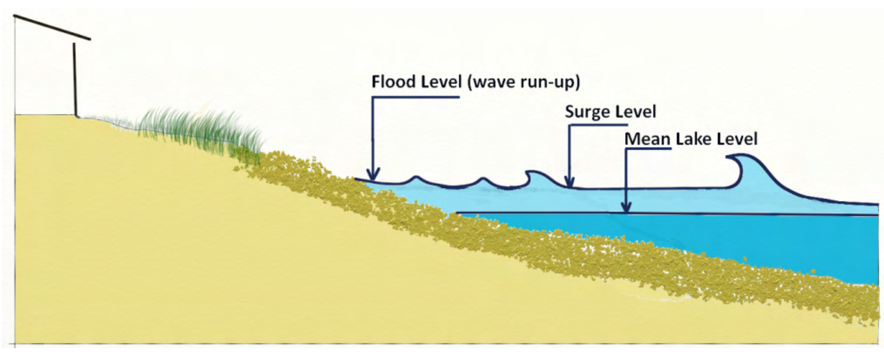


Figure 6 Flood levels (wave run-up) for gently sloping beach

3.5.1.2 Storm water levels in the Bras d'Or Lakes

Flood elevations vary around the lake since some sites are exposed to larger open water fetches resulting in increased set-up and wave run-up.

In this study we have used computer models on tides, winds, surges and waves to create a comprehensive analysis of flooding conditions around the Bras d'Or Lakes. We have used these models to calculate, on an hour-by-hour basis, what the water levels and wave conditions would be along the shorelines of all 5 Unama'ki communities. This was performed as a 'hindcast' – using measured weather conditions from 1953-2005 to create a prediction of storm conditions. Statistical analysis of the results of this 'hindcast' allow an assessment of the frequency and severity of coastal flooding along all the shorelines.

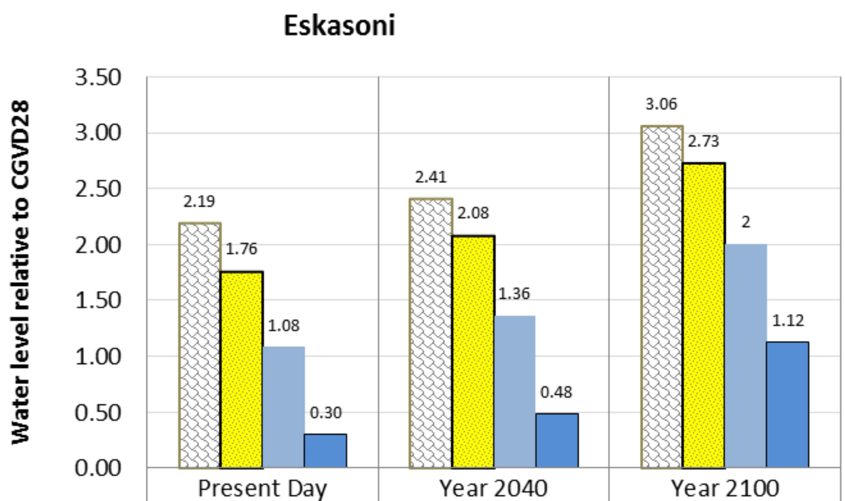
The predicted 100-year return period surge and flood levels (surge + wave run-up) for each community are presented in the following table. The surge level results vary between a low of 0.63 m above MSL at Wagmatcook to a high of 0.89 m above MSL at Potlotek. The flood levels show a different pattern because of the differences in wave action at the various communities; the highest beach flood elevation is 1.55 m above MSL at Malikewe'j whereas the lowest is 0.88 m above MSL at We'koqma'q.

Community	Relative to 2015 MSL (m)			Relative to CGVD28 (m)		
	Surge Level	Flood Level		Surge Level	Flood Level	
		Beach	Revetment		Beach	Revetment
Potlotek	0.89	1.30	2.18	1.19	1.60	2.48
Malikewe'j	0.81	1.55	2.25	1.11	1.85	2.55
We'koqma'q	0.68	0.88	1.11	0.98	1.18	1.41
Wagmatcook	0.63	0.90	1.33	0.93	1.20	1.63
Eskasoni	0.78	1.46	1.89	1.08	1.76	2.19

The previous table gives information about the risks for the communities today; however, the climate is changing, and conditions are expected to worsen in the future, further endangering the infrastructure and lands of the five communities. Sea level, and consequently the level of the Bras d'Or Lakes, is expected to increase significantly, and a warming climate may lead to more open water and increased storminess. Under these conditions, the likelihood of a damaging surge increases dramatically. The following table illustrates how the probability of encountering a damaging surge event of 1.2 m CGVD28 increases over time. At Potlotek, this event has only about a 1% chance of occurring today, but by 2040 it will have a 62% chance of occurring. By 2100, these will occur annually. Worryingly, surges of this magnitude will likely become common at all of the five communities by 2100.

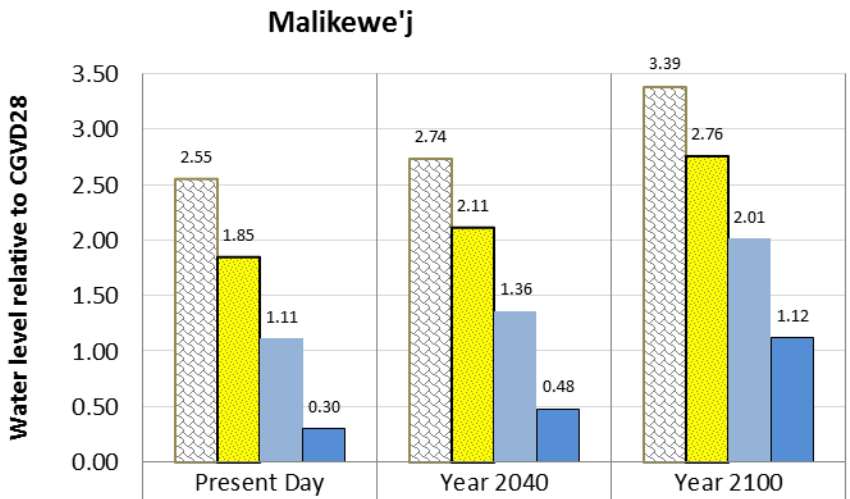
Community	Probability of encountering a surge event of 1.2 m CGVD28		
	2015	2040	2100
Potlotek	1%	62%	> 99%
Malikewe'j	< 1%	14%	> 99%
We'koqma'q	< 0.1%	1%	> 99%
Wagmatcook	< 0.1%	1%	> 99%
Eskasoni	< 0.1%	13%	> 99%

The following graphs present the predicted flood elevations for various locations around the lake for present-day sea level (2015-16), as well as for future sea levels in the years 2040 and 2100. These future sea levels are based on estimates developed by Natural Resources Canada under the assumption of the RCP8.5 climate scenario. All elevations are expressed relative to the CGVD28 National Geodetic Datum. These flood elevations are based on a statistical analysis of hourly conditions over the lake from 1953 through to 2005. This technique of 'hindcasting' wave and water level conditions takes into account the combined probabilities of storm intensity, direction and duration.



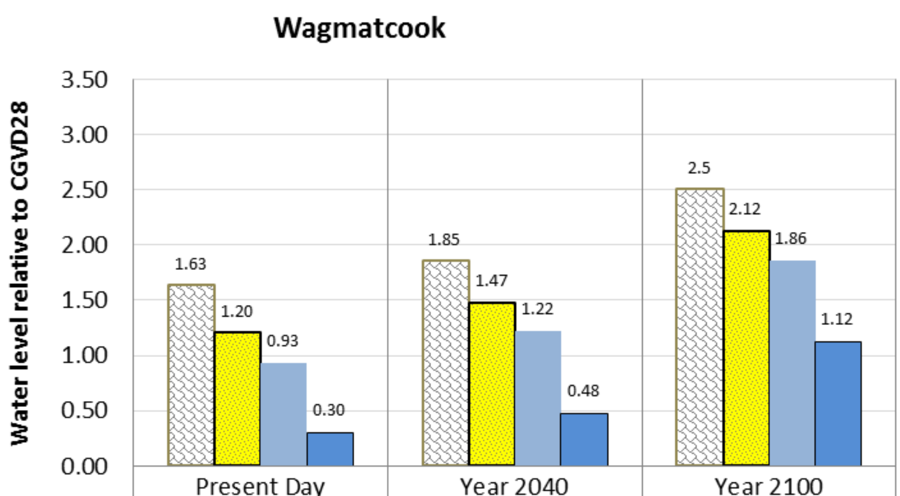
	Present Day	Year 2040	Year 2100
Flood Level: Revetment	2.19	2.41	3.06
Flood Level: Beach	1.76	2.08	2.73
Surge Level	1.08	1.36	2
Mean Lake Level	0.30	0.48	1.12

Figure 7 1% annual chance of exceedance water levels - Eskasoni



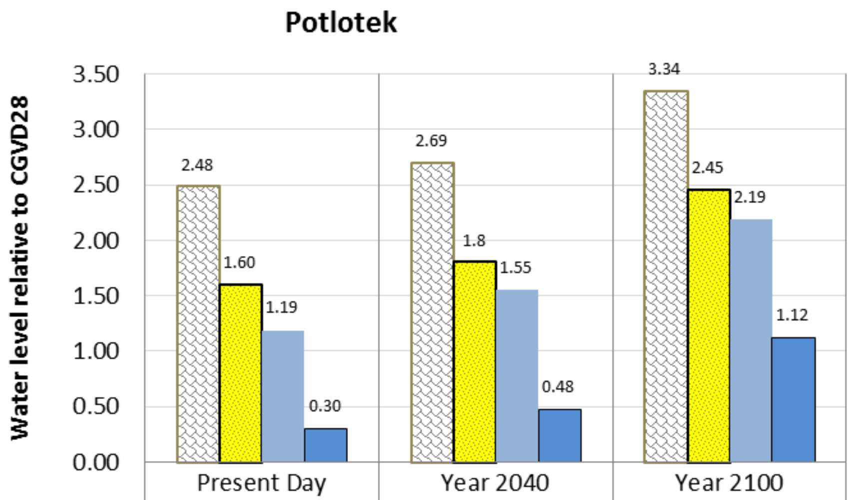
	Present Day	Year 2040	Year 2100
Flood Level: Revetment	2.55	2.74	3.39
Flood Level: Beach	1.85	2.11	2.76
Surge Level	1.11	1.36	2.01
Mean Lake Level	0.30	0.48	1.12

Figure 8 1% annual chance of exceedance water levels – Malikewe'j



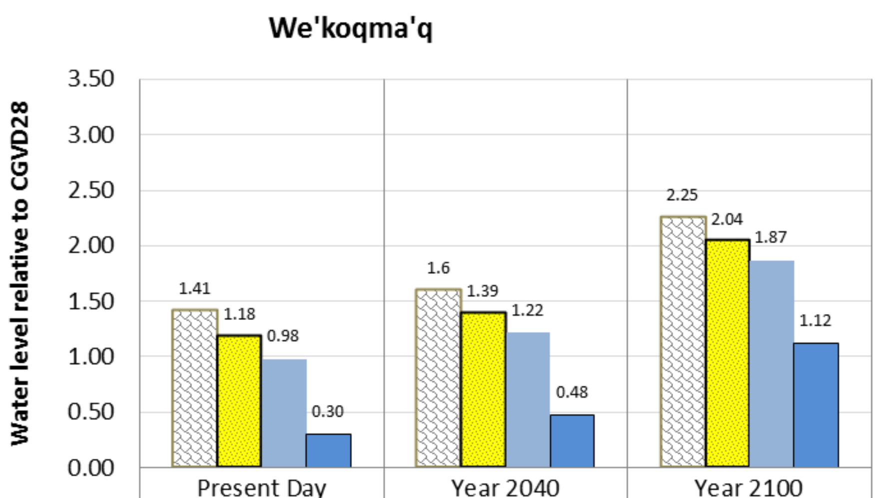
	Present Day	Year 2040	Year 2100
Flood Level: Revetment	1.63	1.85	2.5
Flood Level: Beach	1.20	1.47	2.12
Surge Level	0.93	1.22	1.86
Mean Lake Level	0.30	0.48	1.12

Figure 9 1% annual chance of exceedance water levels - Wagmatcook



	Present Day	Year 2040	Year 2100
Flood Level: Revetment	2.48	2.69	3.34
Flood Level: Beach	1.60	1.8	2.45
Surge Level	1.19	1.55	2.19
Mean Lake Level	0.30	0.48	1.12

Figure 101% annual chance of exceedance water levels - Potlotek



	Present Day	Year 2040	Year 2100
Flood Level: Revetment	1.41	1.6	2.25
Flood Level: Beach	1.18	1.39	2.04
Surge Level	0.98	1.22	1.87
Mean Lake Level	0.30	0.48	1.12

Figure 11 1% annual chance of exceedance water levels – We’koqma’q

The results of this analysis are presented in much greater technical detail in the Technical Analysis section of this report and in Appendix A. Updated flood hazard mapping is presented in Appendix B.

3.5.1.3 Adaptation Strategies

A review of coastal hazards (flooding and erosion), the effects of climate change, and the role of shore protection and other adaptation measures for Atlantic Canada is presented in the report "Climate Change and Shore Protection" (Davies, 2011). Broadly the approaches for addressing coastal hazards are as follows:

1) **Avoidance** Hazard delineation, land-use planning and development regulations are used to ensure that buildings and infrastructure are located out of harm's way. This can involve the use of development setbacks, or managed coastal retreat (such as rolling easements) which allow some nearshore development, but stipulate that land use must revert to natural spaces once flooding and/or erosion have progressed to a certain level.

2) **Retreat** Assets that are exposed to a significant risk of damage are moved back from the shore and relocated out of harm's way.

3) **Protection** This broadly refers to providing protection against storm damage. This can be done through shore protection and/or flood-proofing.

4) **Restoration** Re-establish natural shoreline features such as dunes, beaches, shoals and nearshore/intertidal reef, pool and habitat structures. In this way the shoreline can be re-established either in its existing location or somewhat further offshore-creating, stabilizing and improving habitat while at the same time providing the required protection against storm attack.

There is no single approach that will work everywhere. While retreat and restoration are often the best answers in the long-term; the pragmatic realities of existing development, the economic realities of the value of coastal property, and the costs of abandonment and re-location often lead to a decision to protect.

Many shoreline management policies in Canada (Ontario, PEI, New Brunswick, BC, and Halifax, for example) use coastal setbacks as their main measure for preventing development too close to the water's edge. This approach is generally adapted from flood hazard regulation for rivers. For flood-prone properties along a river or waterway; a hazard zone can be clearly defined. For example, lands lying within the 100-yr return period flood level can be identified as lying within the flood hazard and development there can be banned or restricted. This type of flood hazard regulation is appropriate for a system where there is a small chance that flood waters will reach a certain point of land within a given timeframe. Typically, such a flood event would be a passing phenomenon; after the flood waters recede, life returns to normal and the future risk of flooding is no worse than it was before: A property located at the edge of a river's 100-yr return period floodplain will face the same risk of flooding the day it is developed as it will many years into the future.

For coastlines with eroding shorelines and rising sea levels, the setback strategy has very different implications. Erosion and rising waters march progressively inland as time goes on. If a house or development is positioned sufficiently back from the shoreline that it is safe from erosion for 50 years, say, will find itself at the water's edge in 50 years' time (see Figure 12). Similarly, for coastal flooding; a property with a 1% annual risk of flooding when it's constructed will see its risk of flood damage steadily increase with each passing year as sea levels rise. In the long run you end up with a row of houses at the water's edge requiring protection works or relocation – the use of the regulatory setback only delays the inevitable!

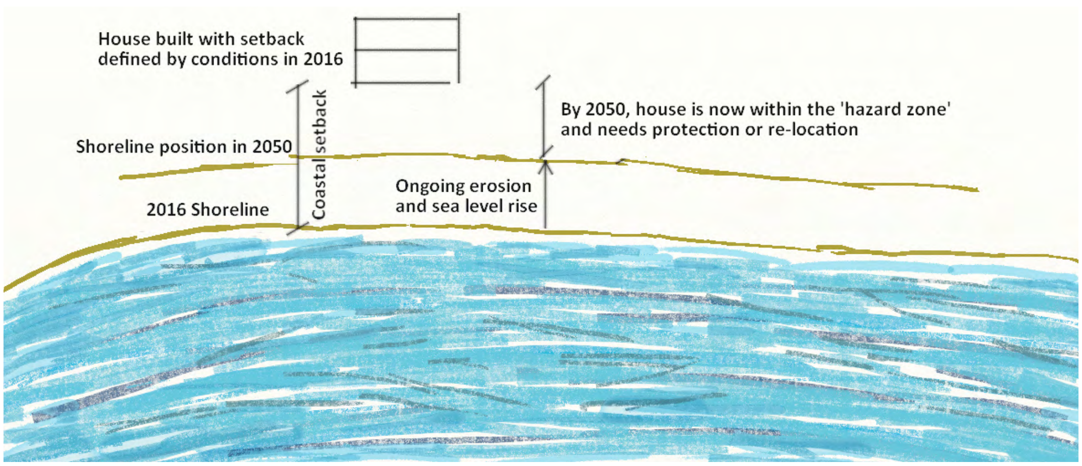


Figure 12 The problem with setbacks

GeoLittoral (2015) has analyzed shoreline erosion at Potlotek and Melikewe'j. These erosion assessments along with site visits and community consultations have been used in combination with the technical analysis of storms, water levels and climate change scenarios in order to develop adaptation strategies for each of the five Unama'ki coastal communities. The findings of this work are presented in the following sub-sections.

3.5.1.3.1 Potlotek (Chapel Island)

Chapel Island is one of the most important cultural sites in the region. It has been a traditional gathering place for Mi'kmaq people since long before first encounter, and has been the site of a Catholic chapel since the mid-18th Century. Activities such as the annual Feast of St. Ann draw people from throughout Atlantic Canada, illustrating the importance of the island to the spiritual and cultural lives of the Mi'kmaq people.

Since 2002, Chapel Island has been listed on the Canadian Register of Historic Places as a National Historic Site. The importance of the island is not just St. Ann's church, but includes the entire landscape, across which there are believed to be many archeological remains and unmarked burials. There are also marked graves, a boulder associated with the 18th-century Abbé Maillard, two circular depressions, Stations of the Cross, and dozens of summer cabins.

The erosion hazard analysis conducted by GeoLittoral and the flood hazard analysis presented in the present report both identify significant coastal hazards along the west, south and east shores of Chapel Island. These hazards are largely confined to the southern half of the island, which is also the focal point for most cultural and social activities. The northern half of the island is generally forested, higher land that is not exposed to erosion and flooding.

The following satellite image clearly illustrates how waves from the north carry sands and gravels toward the southern tip of the island.

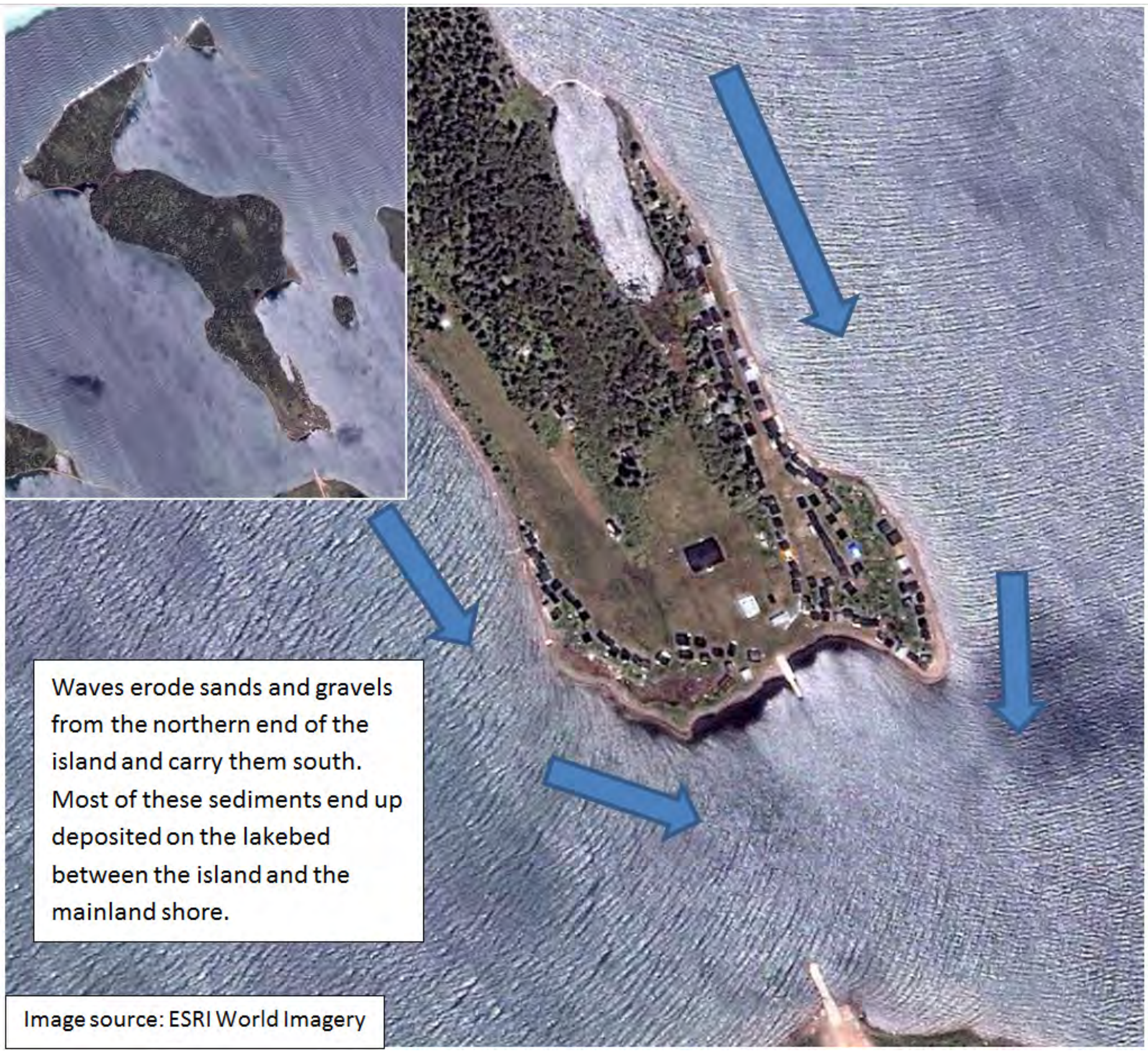


Figure 13 Imagery showing wave patterns around Chapel Island.

The key challenge facing Chapel Island is to preserve the natural state of the island to the maximum extent possible without significant loss of the cultural and social services that the southern end of the island provides.

Within the framework of 'Coastal Adaptation'; adaptation strategies generally range from 'do nothing', wherein nature is left to run its course and development near the shoreline is avoided, to 'protection' wherein revetment and other seawalls are used to hold back the forces of the sea. For Chapel Island, it is hard to envision simply abandoning the southern portion of the island as erosion and climate change gradually erode and flood the shores. This low-lying island is closely connected to its surrounding waters. To encircle it with boulders (shore protection) does not seem suitable for this setting: It would disconnect the land from the lake and, in doing so, would change the cultural and social landscape.

After considerable contemplation and discussion, we have come to the opinion that there may be a third option: By moving the cabin areas back from the water's edge and creating public spaces along the shore. Cabins could be re-located further upland, out of the reach of erosion and flooding, and the shoreline could be re-established as a natural beach feature with a diversity of shoreline features ranging from marshy wetlands to sand and gravel beaches. Public access points, viewing areas, picnic sites and paths could be used to help define the shoreline area and to encourage visitors to share and enjoy the shore. This might also provide the opportunity to re-vitalize the upland facilities on the island to include, perhaps, common kitchen areas, public washroom facilities and communal spaces.

Erosion of the south-east and south-west shorelines has transported sand and gravel southward, off the tip of the island onto the lakebed. We envision small rock reef structures and headlands being built along the nearshore to interrupt this flow of sediments and to help to maintain a wider and more diverse shoreline.

Integral to a redevelopment of the southern end of the island is the improvement of the docks; increasing the available space for safe and secure mooring would be part of a strategy to improve the connection between the island and the mainland and to may even reduce the pressure for cabin space on the island by making it easier to come and go at will.

Many of the specifics of re-imagining the land use and landscape features of the island are beyond the scope of a civil engineering consulting firm such as Coldwater. It is our recommendation that UINR and other interested parties engage a landscape architect / land use planner to assist in the development of a new plan for a re-imagined Chapel Island.

From a technical perspective, we have examined three possible alternatives for Chapel Island. Namely,

1) Managed retreat – using future predictions of flooding and coastal erosion, we have identified the footprint of useable land on the southern island for the coming 100 years. To adapt to this reality, cabins and other land use would have to gradually move inland and northward to avoid flooding and erosion hazards. By 2100, this approach would result in the loss of approximately 50% of the public space presently in use. Costs for this are limited to the removal and

cleanup costs for cabins that lie within the identified flood and erosion hazard zones.

2) Structural accommodation (Protection). The lands that are presently used for summer cabins could be preserved over the next 100 years by raising the ground using imported fill, and by protecting the shoreline with armour stone revetment. The Island is not exposed to a particularly harsh wave climate, therefore, on a relative scale, the quantity of fill (soil) required to raise the land above the flood elevations is manageable, and the stone sizes and rock-fill quantities required to protect the shoreline are similarly manageable. One of the challenges, however, is that this is an island. Transporting materials to the island requires either a thick and reliable ice cover in winter or the use of barges in the summer. Reliable, safe ice cover sufficient for driving gravel trucks on is, perhaps, not as sure a thing as it was in years past; while the use of barges for hauling materials greatly increases construction costs.

   This strategy requires raising the overall land elevation by roughly 1 m and then stabilizing the shoreline with cobble and boulders. The fill volumes required for this are roughly 30,000 m^3, or the equivalent of 3,000 trucks. Planning level cost estimates for this work are $1.3 Million (2016 dollars, exclusive of HST).

   Aside from the costs and the overall scale of this undertaking, another drawback to this approach is the change that it would make to the waterfront. Instead of being able to easily beach a boat, or to wade from the grass out into the lake, you would now have to clamber over 20-30cm diameter granite rocks in order to get to the water. There might also be a considerable loss of nearshore habitat.

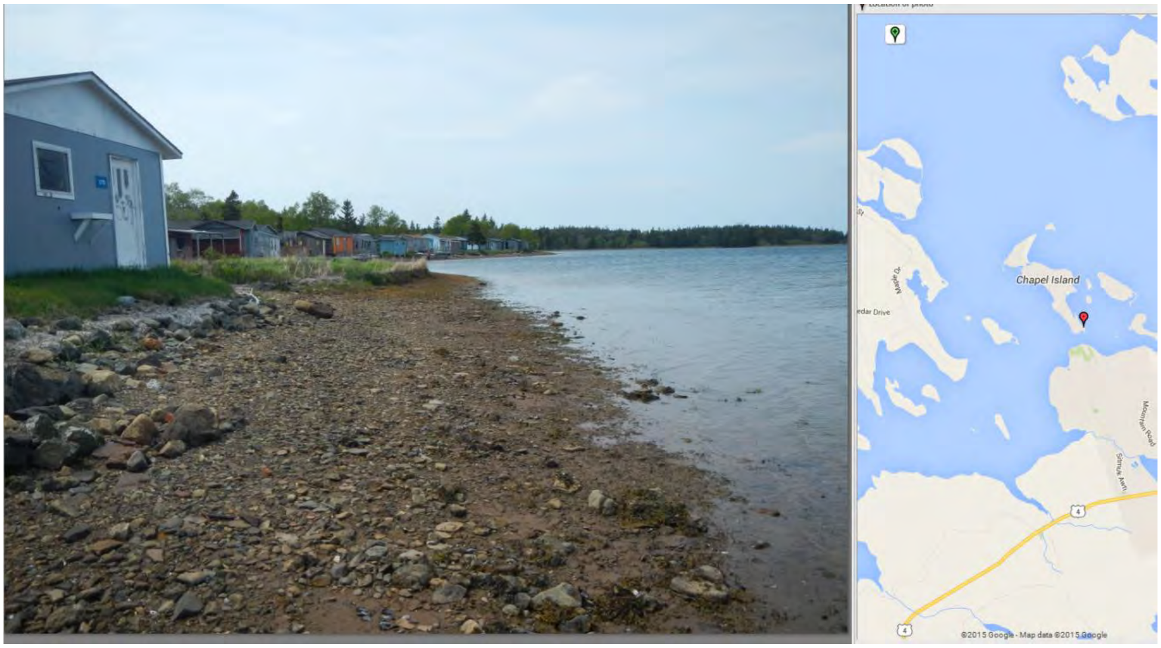


Figure 14 Summer Cabins on Chapel Island

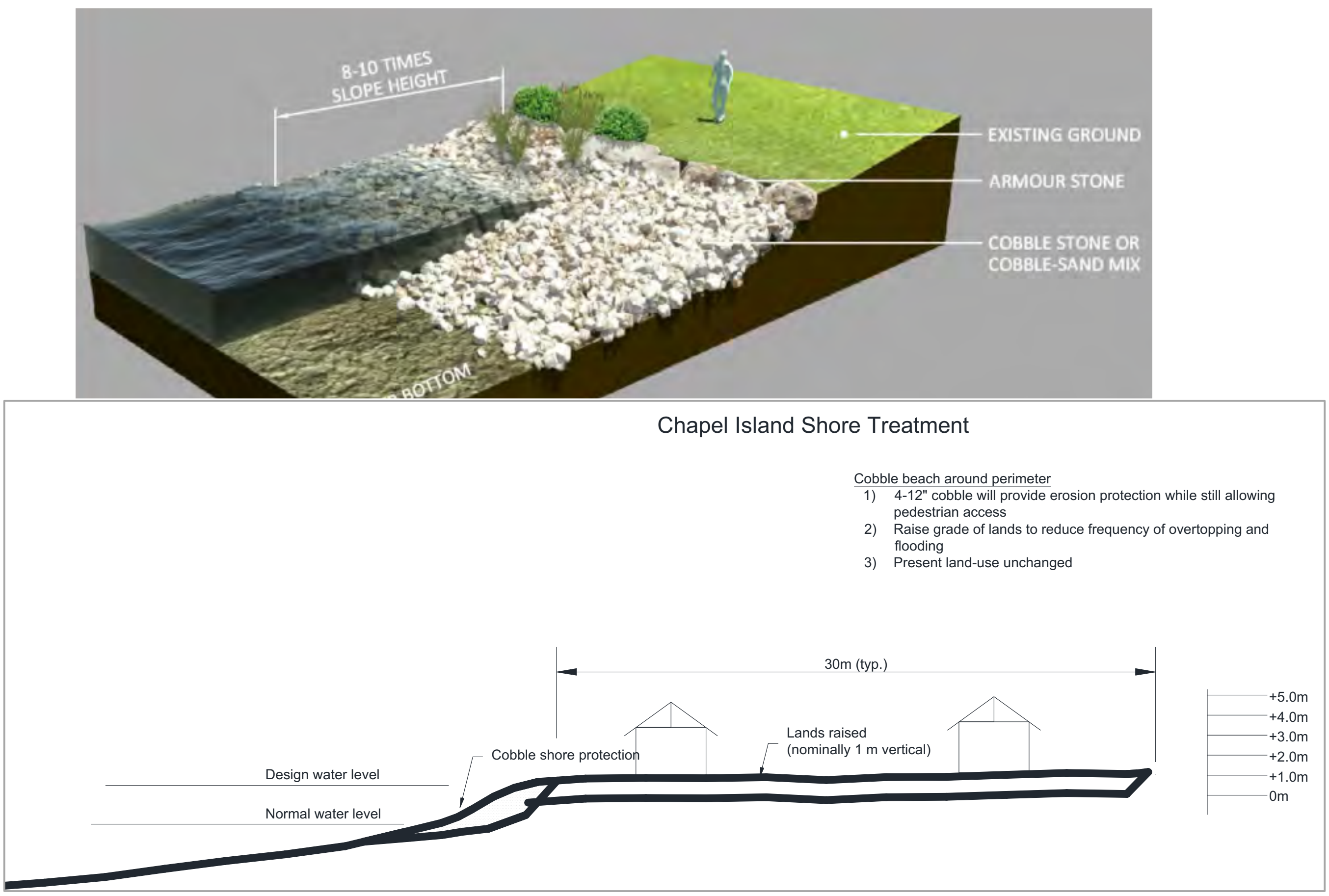


Figure 15 Raise and protect option - Chapel Island

3) Shoreline Restoration and a new land-use plan: In this approach, the cabins are moved back from the water's edge and the focus is on re-establishing a diverse shoreline with boulder clusters, pocket gravel beaches and a diversity of shoreline vegetation. The shoreline becomes a space for natural processes and public access. Cabins are moved to higher land where they are safe from erosion and flooding. Costs for this work would likely range between $300,000 to over $1,000,000. These costs would be highly dependent on the design of the facilities and shoreline treatment works and cannot be further developed without the afore-mentioned landscape architecture design study.

Figure 16 Possible Island restoration layout

3.5.1.3.2 Melikewe'j

The Melikewe'j site consists of extensive natural shorelines including bluffs, sand beaches, and barachois barrier spits. For the most part, these natural shorelines are expected to continue to evolve as they have in the past – although likely at an accelerated rate due to increased storminess, reduced ice cover and rising lake levels. Problem areas for erosion and flooding include the Big Harbour Island Road and a 2.5 km stretch of shoreline centred at the ancestral burial grounds (Cemetary Road and the Malagawatch Presqu'Isle).

Figure 17 Problem area – Big Harbour Island access road at Melikewe'j

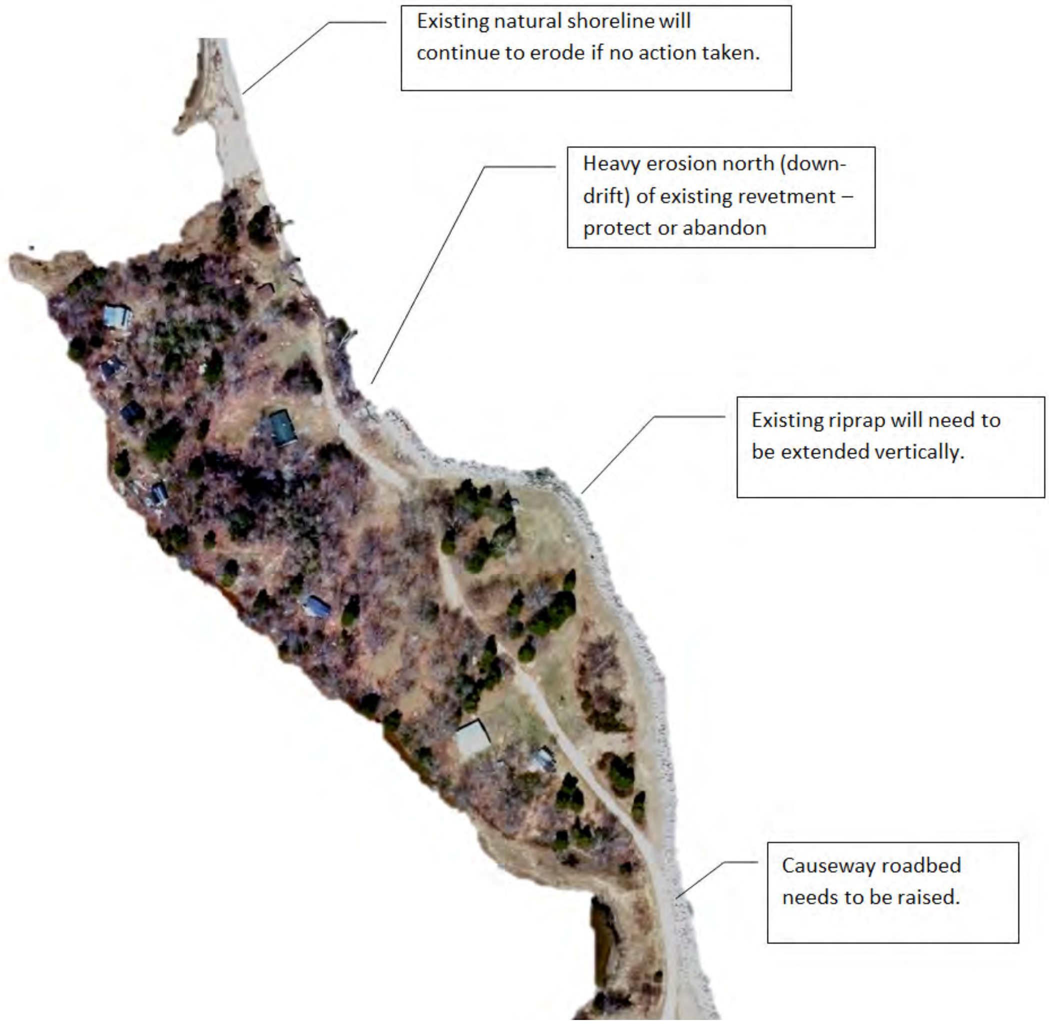


Figure 18 Problem areas at Melikewe'j

Figure 19 Existing revetment at cemetery and Shrine to St. Anne – Melikewe'j

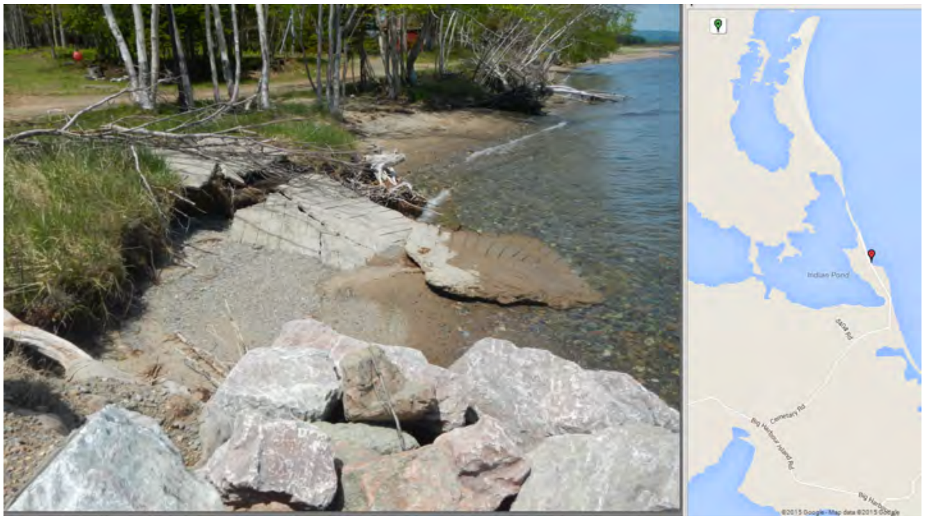


Figure 20 Heavy erosion just north of revetment – Melikewe'j.

Figure 21 Ongoing Erosion along spit to north of Presqu'Isle - Melikewe'j.

Alternatives: Several things are quite certain for Melikewe'j given the existing conditions of low-lying lands and historical erosion.

If road access to existing development on Big Harbour Island is to be maintained, then it is going to be necessary to raise the elevation of the roadbed in low-lying areas and to also place rip rap along the exposed edges of the roadway. There are no practical re-location/re-routing options available.

There is a 60 m long stretch of Cemetary Road just before the cemetery that is low-lying and flood-prone. This needs to be raised to maintain safe public access. There are no practical re-location/re-routing options available.

The existing shore protection in front of the cemetery and shrine is generally in good condition and adequately sized. Some maintenance is going to be required to increase the crest elevation to accommodate rising sea levels and increasing storm severity. Technically, the revetment is presently about 20cm lower than recommended by the analysis presented in this report. This is evidenced by some of the erosion that is occurring to the bluff above the top of the revetment. For planning purposes, we have assumed that revetment repairs can be deferred until 2040 and will again be needed in 2100.

As noted in GeoLittoral's analysis of shoreline change, the shoreline immediately to the north of the revetment is eroding rapidly. Measures need to be taken now to prevent loss of the end portion of Cemetary Road and the resulting damages to the properties behind the road. For this stretch of shoreline (extending roughly 100 m, to the end of Cemetary Road), there are three options:

- Do nothing and allow the erosion to continue (this will entail loss of the road and the two cottages located here).
- Extend the existing revetment design for a further 100 m. – This shifts the erosional region northward, away from any infrastructure, but results in a loss of beachfront.
- Extend shore protection along this reach using natural features such as nearshore reefs and artificial headlands to allow the formation of pocket beaches. This would provide a gradual transition from the hardened shoreline in front of the cemetery to a more natural shoreline along the spit. Beach access would be maintained allowing boat launching, recreational use and associated environmental/habitat benefits. This approach would likely be 30% more expensive than simply extending the revetment.

Planning level cost estimates (2016 dollars, exclusive of HST) are as follows:

Site: Melikewe'j

Element	Issue	Timeframe	Requirement	Treatment	Unit cost	Extent	Cost
Big Harbour Road	Flood prone	2016-2020	Raise 0.3 m (to Elev 1.4 m)	Raise roadbed and place revetment along sides of embankment	\$25/m^2	4900	\$ 112,700
				Class A riprap on water-side of road	\$90/m2	700	\$ 56,000
		By 2100	Raise a further 0.6 m (to Elev 2.0 m)	Raise roadbed and place revetment along sides of embankment	\$45/m^2	12600	\$ 504,000
				Class A riprap on water-side of road	\$90/m^2	1800	\$ 144,000
Cemetary Road	Flood prone	2016-2020	Raise 0.4 m (to Elev 2.6 m)	Raise roadbed and place revetment along sides of embankment	\$30/m^2	420	\$ 11,340
				Class D riprap on water-side of road	\$160/m^2	60	\$ 8,400
		By 2100	Raise a further 0.8 m (to Elev 3.4m)	Raise roadbed and place revetment along sides of embankment	\$55/m^2	420	\$ 21,000
				Class D riprap on water-side of road	\$155/m^2	96	\$ 13,440
Existing Revetment	Overtopping damage	By 2040	Raise to 2.74	Raise crest of revetment	\$155/m^2	560	\$ 78,400
		By 2100	Raise to 3.4 m	Raise crest of revetment	\$155/m^2	560	\$ 78,400
Presqu'Isle - north of revetment	Eroding rapidly	2016-2020	Protect (unless to be abandoned)	Extend revetment, incl. habitat works and natural features	\$3,000/m	100	\$ 200,000
				Sub-total			\$ 1,227,680
				Engineering and permitting @ 15%			\$ 184,152
				Contingency @ 20%			\$ 245,536
				Total			\$ 1,657,368
				Works required within 0-5 years			\$ 524,394
				Works in 2040			\$ 105,840
				Works in 2100			\$ 1,027,134

3.5.1.3.3 We'koqma'q

The We'koqma'q shoreline is sheltered from wave action with open water fetches limited to 1 kilometre or less. Design wave heights along this shore are H_s=0.24 m. Consequently, storm surge and wind setup are the dominant processes and coastal flooding is the main concern (as compared to wave damage or coastal erosion). The most pressing adaptation strategy here is to implement land use policies that identify coastal flood hazard zones (based on the hazard delineation maps presented in Appendix B of this report). This will direct any new development out of harm's way.

There are eight existing homes close to the shore that fall within the flood hazard zones. These will eventually require protection works to minimize the risk of coastal flooding. Since the erosion hazard along this shore is minimal, the flood protection works can likely be achieved by the placement of riprap along the shore and, in some cases, raising the buildings. Present-day flood elevations at We’koqma’q for a waterfront protected by a revetment slope are 1.41m CGVD28 (1.1 meters above normal water levels). This increases to almost 2m by 2100. Shore protection at these sites would consist of a 1m thick layer of 200-450 mm rip rap with a 2m wide crest. The front slope of the rip rap should lie on a 2:1 (horizontal:vertical) slope or flatter. Depending on individual site conditions, this type of shore protection should cost between $800 to $1,200 per linear meter. For a typical 30 m wide property, the cost would therefore be between $24,000 and $36,000.

For example, the following figure shows typical existing shore protection along the We’koqma’q shoreline. This armourstone with gravel backfill has a crest elevation of 1.2 m. To meet the 2015 flood hazard standard presented in this report, this revetment would have to be built up a further 20 cm vertically. By 2100 the revetment would need to be 75 cm higher than it presently is.

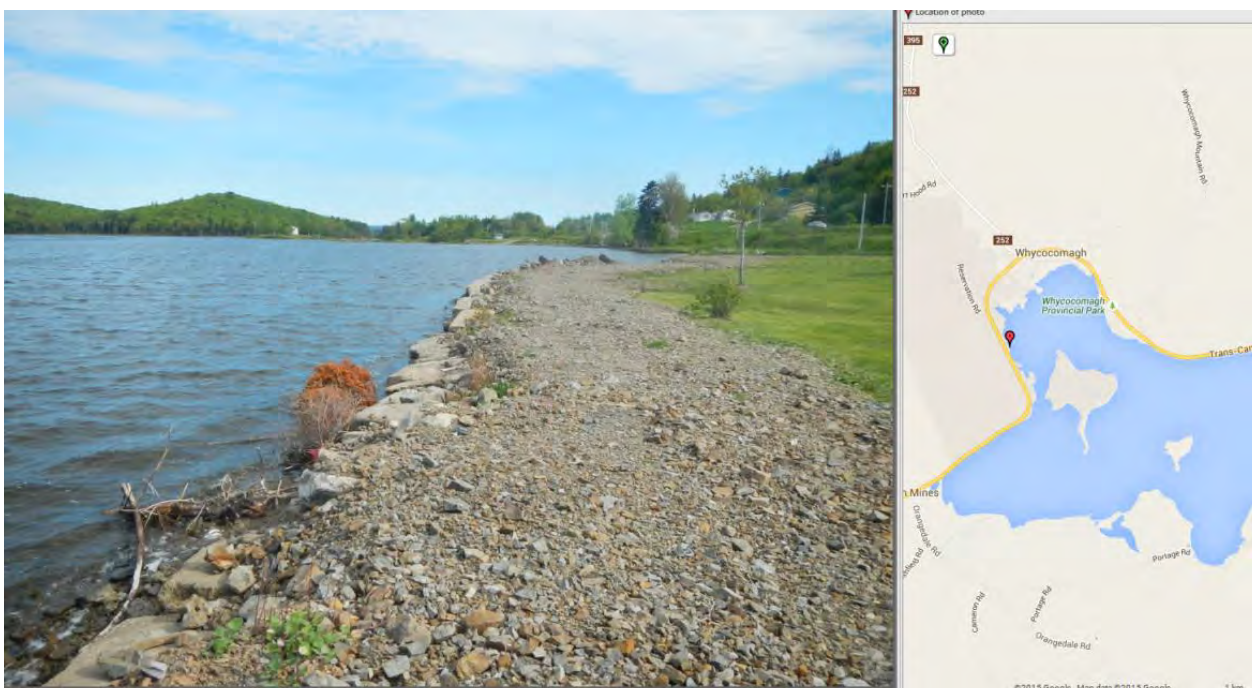


Figure 22 Existing shore protection at We'koqma'q.

3.5.1.3.4 Wagmatcook

Similar to We'koqma'q, the Wagmatcook shoreline is sheltered from wave action with open water fetches limited to 2 kilometres or less. Consequently, storm surge and wind setup are the dominant processes and coastal flooding is the main concern (as compared to wave damage or coastal erosion).

Coastal flood hazards along the Wagmatcook shoreline are dictated largely by flood levels, since wave action is limited along this shore. Present development along the shoreline (including the water treatment facility) is outside of the year 2100 coastal flood hazards and as such, no immediate actions are warranted. Future development and land use decisions should incorporate the flood hazard information provided within this report to ensure that new flood hazards are not created.

3.5.1.3.5 Eskasoni

The Eskasoni shoreline spans over 8 km and includes a diverse range of shore types including low-lying sandy barachois barriers and spits, low coastal plains and bluffs 5 meters or more in height. With a long fetch of open water to the southwest, this shoreline is exposed to waves up to H_s=1.6m (100-year return period wave height). The largest flood events are associated with strong north-easterly storms; therefore the highest waves do not typically occur at the same time as the highest flood waters.

As for other sites around the lake, the most pressing adaptation strategy here is to implement land use policies that identify coastal flood hazard zones (based on the hazard delineation maps presented in Appendix B of this report). This will direct any new development out of harm's way.

Existing waterfront development can be protected using a typical 2H:1V sloping armour stone revetment with crest elevations as identified elsewhere in this report (ranging from 1.89 m CGVD28 at present up to 2.76 m in 2100). Stone sizes used for shore protection here will be larger than at any other sites and may be as large as 1-3 tonnes. These requirements, however, vary from site to site and require a detailed site specific design.

Bluff erosion is a concern along some of the easterly shores at Eskasoni. At present, there are no residential buildings within 30 m of the bluff face. Bluff erosion is a natural process that supplies sediments to downdrift shores – this includes the many barrier spits just east of Eskasoni. If shore protection works were placed along these bluff faces, the sediment supply to these beaches would be reduced. Preserving this sediment supply is essential if they are going to be maintained as sea levels rise.

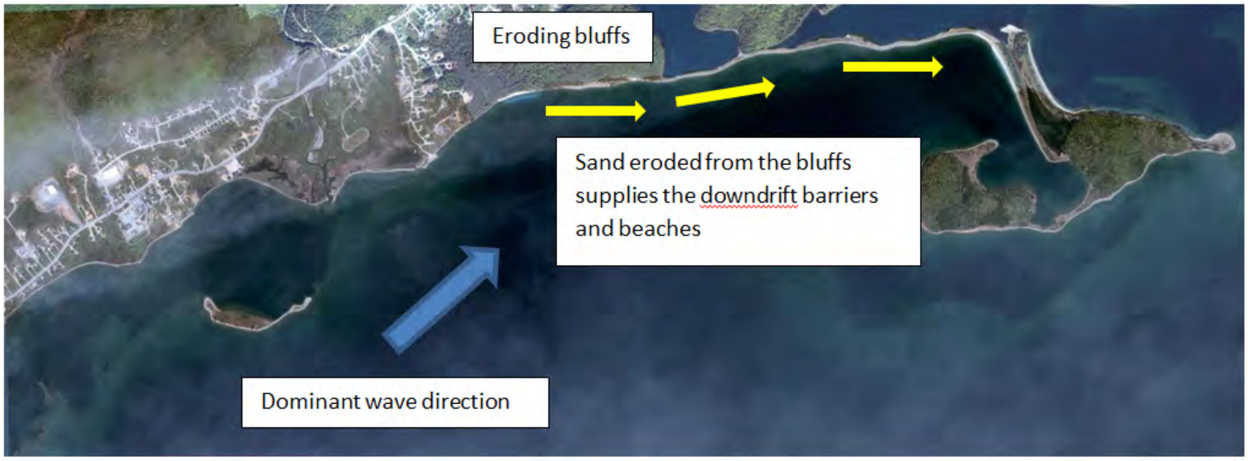


Figure 23 Bluff erosion and sediment supply – Eskasoni

3.5.1.3.6 Closing

The Bras d’Or Lakes form a unique and important natural feature with remarkable environmental characteristics, natural beauty and cultural resources. With the prospect of rising sea levels and an intensifying coastal climate, coastal flooding and erosion will generally increase along the lakes’ shores. This document provides valuable technical information on the expected flood levels and their frequency of occurrence both now and in the future.

Adaptation strategies and some specific construction works have been proposed for consideration by the Mi’kmaq communities of Bras d’Or Lakes. The greatest challenge facing the communities now is to decide where and when to build or reinforce shore protection measures and when to move back from the shore to allow nature the space it needs to expand the lakes’ boundaries with natural shore features such as bluffs, beaches, wetlands, etc..

3.5.2 Community Engagement

On June 9th a presentation on the modeling imagery of the coastline prepared for the Chapel Island Mission was presented to communities members who have cabins on the Island. A similar presentation was given on June 10th to residences of Malakowej’k on modeling imagery prepared for their community. On November 23rd, participants from both meetings were brought together in Membertou for a presentation on the risk-based assessment of coastal flooding hazards affecting the five communities prepared by Coldwater Consulting Ltd. Discussions were also held on the possible measures that could be taken to address these risks now and into the future.

On February 23rd, a meeting was held with the UINR Board of Directors and they were briefed on the results of the project as well as the feedback received from the community at the November 23rd session. The UINR board is comprised of the five Unama'ki Chiefs. At the request of the Potlotek Chief a presentation was also made on March 22nd to the Potlotek Elders.

Potlotek First Nation has engaged a consultant to identify overall short and long-term goals for Chapel Island. Included in this is an analysis of the environmental issues, archaeological issues and also opportunities for tourism and cultural development. UINR's report has been shared with the community and will support the issues identified for the island in terms of rising sea levels and climate change and the impact on the existing buildings located on the shoreline.

4. Acknowledgements

The availability of Bras d'Or Lakes water level data supplied by the Coastal Ecosystem Sciences Division, Maritimes Region, of Fisheries and Oceans Canada (Adam Drozdowski) has been critical in determining the extent of storm surge flooding events affecting five Mi'kmaq Communities in the context of climate change adaptation planning.

Our community Elders who generously gave their time and knowledge to help us better understand the impact of Climate Change in Unama'ki.

We also wish to acknowledge the contribution of two coastal geomorphologist: Dr. Serge JOLICOEUR (Université de Moncton) for his input in the interpretation of the erosion results and for his comments and suggestions on a previous draft of the report, and Bob TAYLOR (formerly of the GSC) for his insight in the recent evolution of the Malagawatch sand spit.

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6. TECHNICAL ANALYSIS

This section of the report provides a detailed technical analysis of:

1) Meteorological and oceanographic conditions affecting the Bras d’Or Lakes;
2) Expected effects of climate change and sea level rise;
3) The specific effects of wind and wave action on shoreline conditions;
4) The vulnerability of the waterfront to the coastal hazards of flooding and wave action; and
5) The effectiveness of various measures of shore protection and flood-proofing.

6.1 Previous Work

The first-phase report of this study of the impacts of climate change on the coastal First Nations communities of Bras d'Or Lakes (Daigle, O'Carroll, Young, & Paul, March 2015) explored the problem using a combination of air photo and GIS data. Based on relative sea-level rise projections for Baddeck from a Canadian government report (James, Henton, Leonard, Darlington, Forbes, & Craymer, 2014), inundation maps were generated for the communities of Eskasoni, Potlotek, Malikewe’j, We’koqma’q and Wagmatcook for the years 2030, 2050 and 2100, based on relative sea level rises of 0.14 m, 0.31 m and 0.86 m, respectively, and using a baseline HHWLT value for year 2010 of 0.4 m above CGVD28. Using a water level database from Fisheries and Oceans Canada (Drozdowski, Horne, & Bugden, 2014) storm surge flooding statistics were developed for a nearly annual average storm surge of 0.5 m for Big Bras d’Or (0.4 m for Little Bras d’Or) and a maximum storm surge of an undetermined return-period of 0.8 m for Big Bras d’Or (0.8 m for Little Bras d’Or). Flooding scenarios were then developed for the years 2010, 2030, 2050 and 2100. The scenarios include the sum of three values:

- baseline tide level taken as the Higher High Water at Larger Tides level;
- sea-level component, and;
- average and maximum storm-surge components.

These elevations were then presented as contour lines on the LiDAR digital elevation model for each community. The flooding maps revealed that Chapel Island and Malikewe’j will be the most impacted by rising sea levels. The south side of Chapel Island in particular will likely experience storm-surge flooding several times per year by year 2030. At Malikewe’j, the Big Harbour Island Road will experience overtopping from annual average storm surges by year 2030 and overtopping from HHWLT tides by year 2100. The present work aims to improve the estimate of the storm-surge components of this work, and to use the results of this analysis to evaluate future vulnerability under the combined effects of storms and climate change.

6.2 Data Sources

6.2.1 Bathymetry Data

Bathymetry data for the study was obtained from a number of sources. Detailed, high-resolution bathymetry was obtained from UINR in the form of Canadian Hydrographic Service (CHS) field sheet data for CHS Chart 4279. This 10 m data formed the basis for most of the modeling. In area where this data was missing, depth contours from CHS Charts 4277, 4278 and 4279 were digitized and added to the data set.

Large-scale bathymetry was obtained from the General Bathymetry Chart of the Oceans (GEBCO) available online at www.gebco.net. This data was only used for deep ocean bathymetry in the continental-scale hydrodynamic model.

Elevations were surveyed at a number of points near the shore at a number of the communities during the Coldwater site visit of June 2015. These were used to establish beach slopes for the run-up calculations.

6.2.2 Climate Data

Meteorological data were obtained from the Canadian government's Canadian Weather Energy and Engineering Datasets (CWEEDS), which is available online for each province at http://climate.weather.gc.ca/prods_servs/engineering_e.html. In the present case, the dataset for Sydney, NS was acquired. The data is hourly and spans the period 1953 to 2005. This was the primary source of data for air pressure, wind speed and wind direction.

Detailed, long-term ice cover data is not available for any locations within Bras d'Or Lakes. To circumvent this problem, ice cover data from the MSC60 marine hindcast data sets available from the Department of Fisheries and Oceans (DFO) were used in its place. The use of this data is discussed in more detail in *Ice Cover* (p. 46).

6.2.3 Local Data

A number of project data sets, including measured water levels from instrument deployments, LiDAR elevations, etc. were obtained from the UINR and were used extensively for model calibration and input.

Elevations were surveyed using a RTK-GPS system at points near the shore at a number of the communities during the Coldwater site visit of June 2015. The Trimble system (Geo-7x handheld with a Zephyr Model 2 Rover Antenna) provided up to 1 cm accuracy. These were used to establish beach slopes for the run-up calculations and to benchmark various infrastructure features.

6.3 Datum

The work in this report is presented in the horizontal using UTM20N NAD83. Vertical measurements are usually presented in CGVD28, but reference may be made to other reference water levels. Table 1 gives the values of local Mean Sea Level (MSL) and Chart Datum (CD) in CGVD28.

Table 1 Water level in Bras d'Or Lakes relative to datum

Level	CGVD28 (m)
MSL	0.3
CD	-0.4

6.4 Met-Ocean Assessment

There is insufficient field data of water levels in Bras d'Or Lakes to enable the generation of reliable long-term estimates of extreme water levels at the five coastal First Nations communities of Bras d'Or Lakes. One remedy in this type of situation is to generate data using a calibrated numerical model, from which estimates of extreme values can be made and this was the route adopted by Coldwater in the present case. The problem was approached by dividing water level forcing into the following constituent parts:

- *storm surge*, η_s – the super-elevation of the entire Bras d'Or Lakes system water level from the wind and pressure effects of large-scale storms and the underlying tidal fluctuations;
- *wind setup*, η_w – the local super-elevation of the water level in on part of the lake because of local winds, and;
- *wave run-up,* η_r – the maximum level at a particular site caused by wave action at the shore.

6.4.1 Storm Surge

The term *storm surge* is used in the present work to describe the super-elevation of the entire system's water level associated with the exchange between the ocean and the Lakes through Bras d'Or forced by large-scale storms and the tidal forces. The section is divided into two parts: in the first part, detailed hydrodynamic modelling is used to examine these processes; the second part describes the development of a site-specific parametric model that can be used for long-term simulations.

Detailed Modelling

To understand how storm surges were generated in Bras d'Or Lakes, Coldwater developed a hydrodynamic computer model (see Figure 24 and Figure 25). This continental-scale model uses finite element techniques to model water levels and flow speed patterns under a range of tidal and storm conditions. This model has 58,743 nodes and 108,856 elements. Using the model, we studied the relationship between storm surges in the Atlantic and winds over Cape Breton Island.

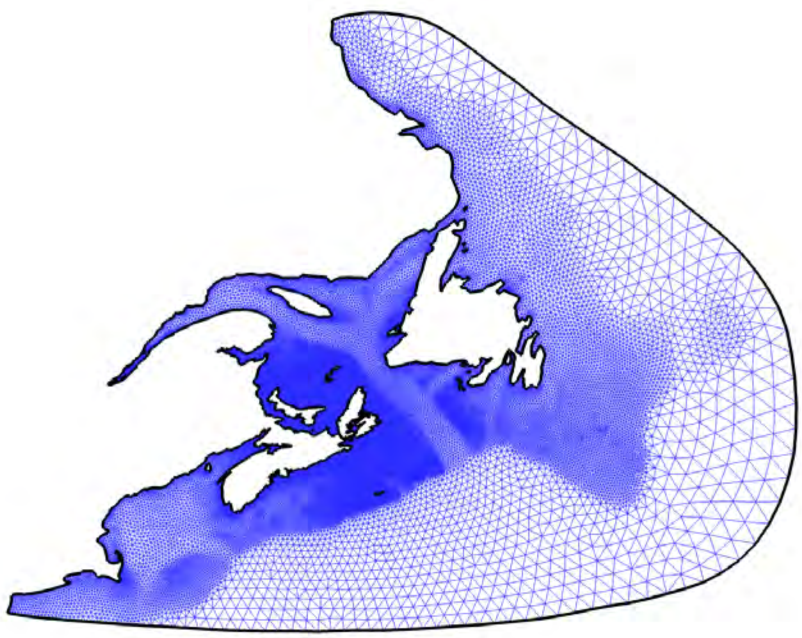

Figure 24 Continental-scale hydrodynamic model mesh

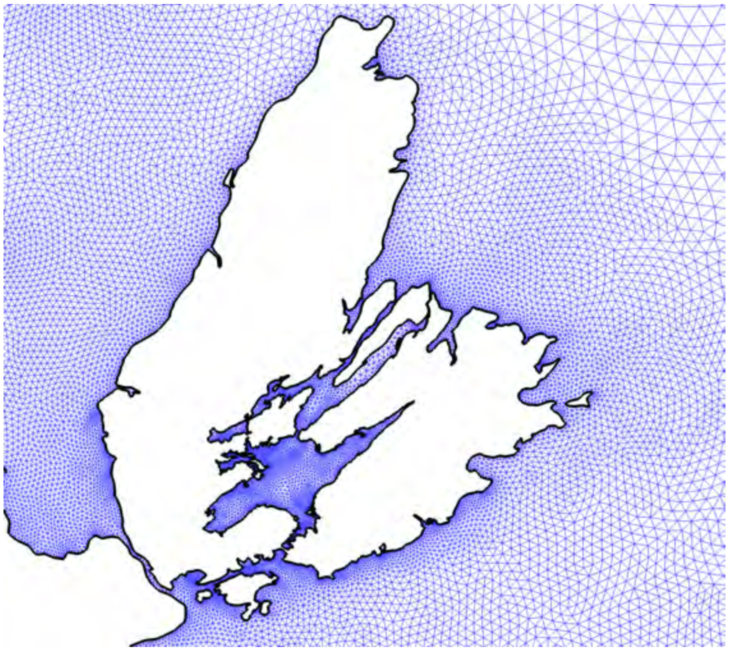

Figure 25 Continental-scale hydrodynamic model mesh. Detail around Cape Breton Island.

Under normal conditions, the rise and fall of the sea at the mouth causes water to flow back and forth down the long Bras d'Or entrance channel. Because of the predominantly semi-diurnal nature of the tide here (i.e., two high tides and two low tides per day), relatively little water enters the Lakes, resulting in a tidal range of only about 10 cm on average. During storms, however, strong winds and low pressure can elevate the sea at the entrance to Bras d'Or Lakes such that it becomes much higher than the water level in the Lakes. The surface gradient between the two bodies drives a flow into the Lakes just like a tidal flow, but because of the longer duration of these events a much larger amount of water enters the Lakes. This is illustrated in Figure 26 which shows the impact of a Nor-Easter over a four-day period. The storm arrives in the middle of day 1 and lasts for 24 hours. The figure shows the water level of the sea at the mouth and within the Lakes for the period with and without the storm. The storm surge or difference between the levels in the Lakes with and without the storm is also shown. The storm elevates the water level in the sea at the mouth in two ways: first, surface shear from the strong Northeast winds push water towards coast; second, the drop in air pressure during the storm causes water to flow in from the open ocean. After the storm passes, the water in the bay at the mouth can freely return to the open ocean and the level quickly returns to normal; however, the water in the Lakes can only escape to the sea through Bras d'Or and this narrow restriction slows the release of water and drop in level. As well, the drop in level is only periodic, since even with the elevated water level, the sea is often higher because of the tide; during these periods the Lakes level will continue to rise.

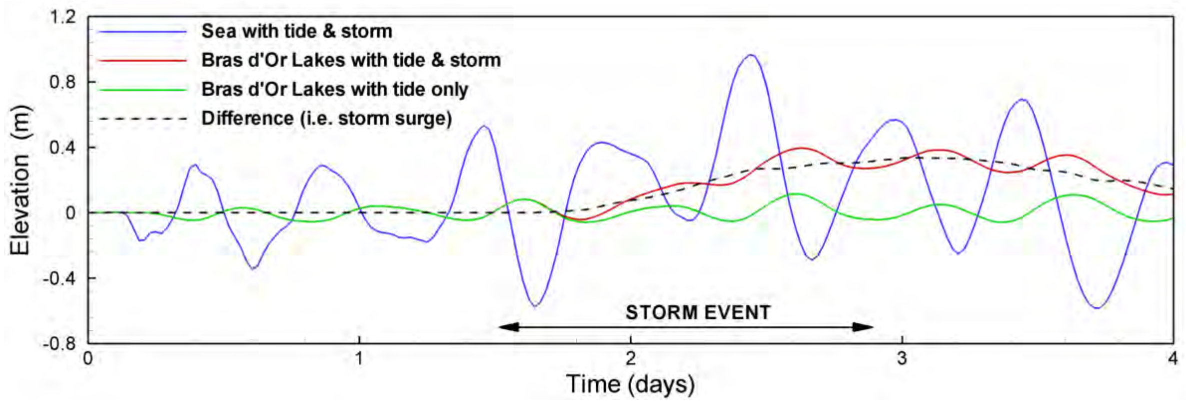

Figure 26 Modelled water levels in Bras d'Or Lakes with tides and tides plus storm.

While the continental-scale hydrodynamic model used above could be applied to study individual events, the thousands of simulations required to develop a predictive tool would be too time-consuming. Therefore, Coldwater undertook the development of a simpler computational model to predict surge levels based on measured winds and pressure.

Parametric Modelling

The hydrodynamic model simulation presented in the previous section illustrates how storms are the dominant physical process controlling storm surge. Also noted were the two mechanisms by which the storms caused the effect: wind shear and pressure drop. These two processes will form the basis of the new Bras d'Or Lakes parametric surge model[1].

The two processes can be described by two separate terms. First, the impact of the wind's shear on the surface of the sea can be described by a function of the form:

$$\frac{U|U|}{2g} \quad (1)$$

where U is the wind velocity (m/s), $|U|$ is the wind magnitude or speed (m/s), g gravitational acceleration (m^2/s). Second, the impact of the pressure drop can be described by:

$$\frac{\Delta P}{\rho} \quad (2)$$

where ΔP is the pressure drop (kPa), ρ is the density of the water (kg/m^3). Combining these two terms results in a simple equation for water level due to storm surge:

[1] Because of the nature of the parametric model, tidal effects are implicitly included in the model.

$$\eta_s = \alpha \frac{U|U|}{2g} + \beta \frac{P_0 - P}{\rho} \qquad (3)$$

where α and β are coefficients used to scale the relative importance of the two terms and the pressure drop, ΔP, has been expressed as the difference between the measured pressure, P, and a reference pressure, P_0, which can be taken as 101.325 kPa, the accepted standard air pressure at sea level. The values of the coefficients α and β can be determined from the measured wind and air pressure records at Sydney Airport and measured storm surges at Baddeck.

The Bras d'Or Lakes system is very large and does not respond instantaneously to meteorological fluctuations. Therefore, Equation 3 was tested to examine its sensitivity to pressure and wind speed variability. The tests showed the best results when both the pressure and wind speed were calculated as the average of the hourly measured values, U_i and P_i, over the preceding 24 hours:

$$U = \frac{1}{24} \sum_{i=-23}^{0} U_i$$

$$P = \frac{1}{24} \sum_{i=-23}^{0} P_i \qquad (4)$$

Since accuracy of the model is only really necessary for larger surge events we can restrict our calibration efforts to only examine those events where the storm surge exceeded 20 cm. Using this approach, combined with the use of wind speeds and pressures taken as the average of the preceding 24 hours to calibrate the coefficients α and β, results in the following equation:

$$\eta_{s_{Baddeck}} = 3.2646\times10^{-2} \frac{U|U|}{2g} + 9.0733\times10^{2} \frac{P_0 - P}{\rho} \qquad (5)$$

Storm surge predictions using Equation 5 with Sydney Airport hourly meteorological data from May 2009 to August 2014 is shown in Figure 27. As might be expected, there is a fair amount of spread in the results with when levels are in the -10 cm to +10 cm range where the tidal signal obscures the meteorological effects; however, the model is very accurate for larger surge events. This is illustrated in Figure 28, which shows the prediction for the December 2010 storm.

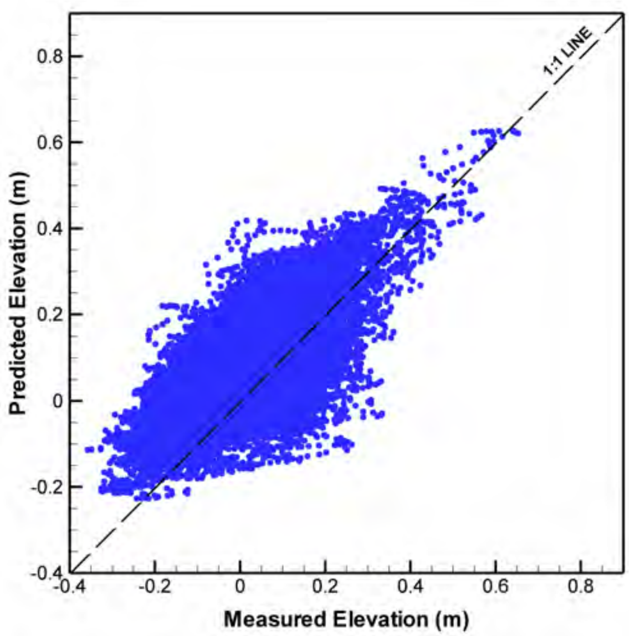

Figure 27 Comparison of measured and predicted hourly water level at Baddeck (07/2009 - 05/2014)

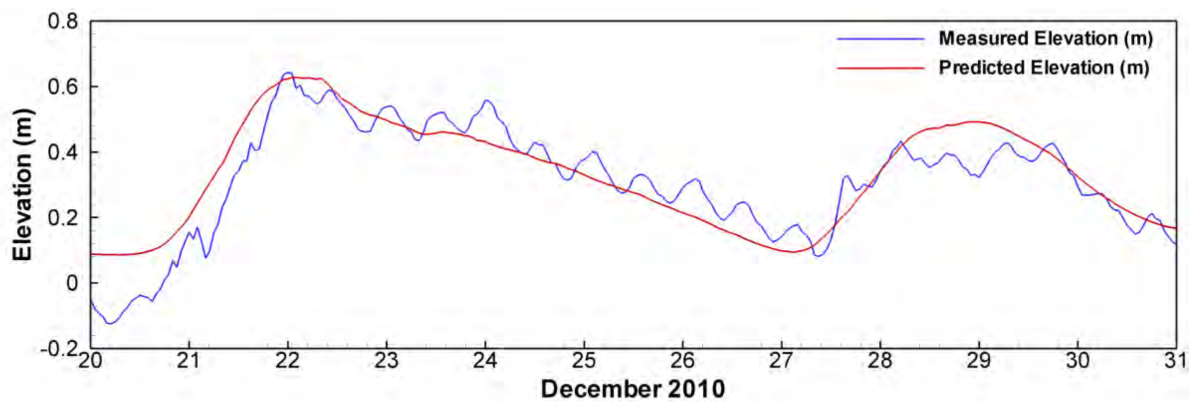

Figure 28 Comparison of measured and predicted hourly water level at Baddeck (December 2010 storm)

Local Calibration

In the previous section a predictive model for storm surge in Bras d'Or Lakes based on water level measurements at Baddeck was presented. Baddeck was chosen because of its central location and water level elevations here will tend to agree with average levels in the Lakes; however, storm surge will vary at the extreme ends of the Lakes. Local differences in elevation are illustrated in the December 2010 event shown in Figure 29.

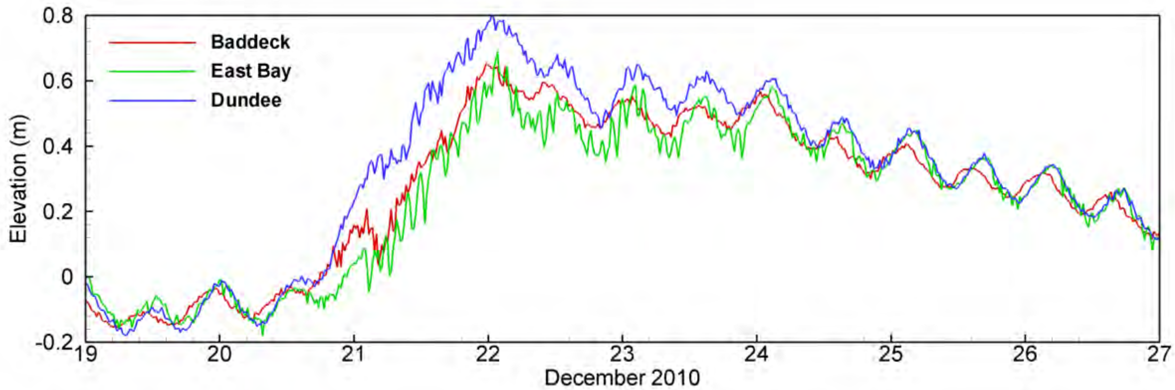

Figure 29 Water level at three locations during December 2010 event

In order to account for these differences, measured water levels at Dundee, St. Peter's, East Bay and Whycocomagh were compared to those measured at the same time at Baddeck. Definite patterns were evident that lead to the adoption of the following local storm surge equation:

$$\eta_S = \begin{cases} (1 + \kappa\eta_{S_{Baddeck}})\eta_{S_{Baddeck}} & \eta_{S_{Baddeck}} > 0 \\ \eta_{S_{Baddeck}} & \eta_{S_{Baddeck}} \leq 0 \end{cases} \quad (6)$$

where η_S is the local storm surge, $\eta_{S_{Baddeck}}$ is the storm surge at Baddeck computed from Eq. 5 and κ is the local calibration coefficient given by the values in Table 2.

Table 2 Local calibration coefficients for storm surge

Site	Potlotek	Malagawatch	Whycocomagh	Wagmatcook	Eskasoni
κ	0.6	0.3	-0.3	0	0.3

Equation 6 is used to model the storm surge at the First Nations communities. Under extreme events, the equation will yield higher storms surges at Potlotek and lower storm surges at Whycocomagh compared to that at Baddeck.

6.4.2 Wind Setup

Winds will drive circulation flows within the Lakes that will lower and elevate the levels in a similar fashion as the open ocean. This will result is higher or lower elevation at the ends of the various arms of the Lakes depending upon local wind direction and speed. This process is called *wind setup*, η_w. To add wind setup to the predictions, Coldwater generated a local Lake-scale hydrodynamic model. This finite element model has 12,379 nodes and 22,224 elements and covers the entire Lakes (see Figure 31). Unlike the continental-scale hydrodynamic model, this model has no connection to the open ocean and is operated with winds, but not tides. Preliminary simulations using this model illustrated that the Lakes respond quite rapidly to local wind forcing. This observation makes it possible to add wind setup to the storm surge predictions using individual simulations. Again, because we are most interested in extreme cases, the problem was simplified by studying only strong wind cases.

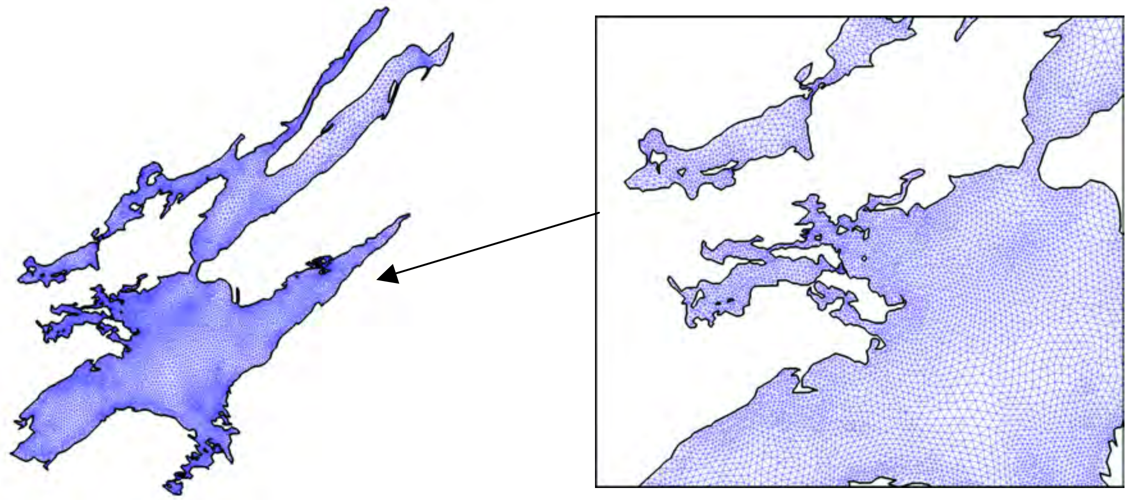

Figure 30 Local-scale model mesh and detail of model around Malikewe'j

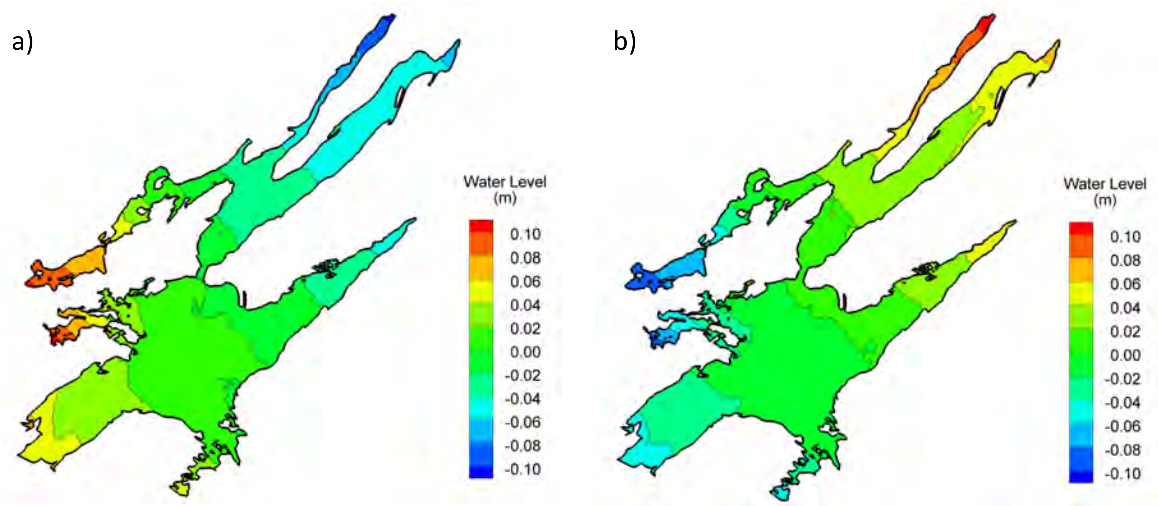

Figure 31 Computed setup: a) 50 km/h from 50°; b) setup for 50 km/h from 220°

Simulations were run using this Lake-scale model for a wide range of wind conditions, ranging from 30 km/h to 90 km/hr at 10° increments; in total, 252 simulations were conducted. Two typical results, 50 km/h winds from 50° and 220°, respectively, are shown in Figure 31. The predicted water level relative to that at Baddeck for each case at each of the five coastal First Nations communities was determined. This resulted in 5 sets of 252 wind setup values based on wind conditions. These can be used to adjust the Lake-wide surge estimates to the 5 coastal First Nations communities' locations.

6.4.3 Wave Run-up

Flooding, inundation and damage to the shore or structures at the shore, such as revetment, is mainly characterized by wave run-up and overtopping. *Wave run-up* refers to the vertical height to which a wave breaking at the shore can reach, whereas *wave overtopping* is the flow rate of water passing over a structure. These depend on the mean water surface elevation (surge + setup), incident wave conditions, and the geometry of the beach or structure.

The EurOtop prediction method (Van Gent, Pozueta, & Van den Boogaard, 2004) was developed specifically designed to predict wave run-up and overtopping on coastal structures. This prediction method was developed through a multi-national European Union research program and is the most comprehensive direct solution technique available for wave run-up/overtopping approach. Two of Coldwater's staff, Drs. Davies and MacDonald, were involved in the testing program that developed this technique and are hence quite familiar with its application.

Run-up at a location is predicted using:

$$R = \min \left\{ \begin{matrix} 1.65 H_{m0} \gamma_f \xi \\ H_{m0} \gamma_f \left(4 - \frac{1.5}{\sqrt{\xi}} \right) \end{matrix} \right\} \qquad 7$$

where R Is the run-up height (m), H_{m0} is the wave height at the toe of the structure (m), γ_f is a roughness coefficient, and ξ is the surf similarity parameter, a dimensionless parameter based beach slope and wave steepness:

$$\xi = \frac{m}{\sqrt{H_{m0}/L_o}} \qquad 8$$

where m is the beach or structure slope and L_o is the deepwater wavelength (m).

6.4.4 Ice Cover

Extreme water levels at the shore are produced by wind and wave action during the periods when the Lakes are ice free. The effect of ice cover is included in the present work by skipping those periods. This simple approach thus assumes that the Lakes are either entirely ice free or ice covered. Since ice generally becomes shore fast relatively early in the freeze-up process, this approach is reasonable.

Spatial maps of ice cover are available for average conditions; however, as will be seen below, the present approach requires continuous time series of meteorological and ice cover conditions. An examination of the average ice cover maps showed that conditions in the ocean near the mouth of Bras d'Or could serve as a proxy. These are available as part of the MSC60 marine hindcast data sets available from the Department of Fisheries and Oceans (DFO). Figure 32 shows a comparison of ice cover data; the top two plots show the spatial extent of ice coverage of Bras d'Or Lakes from (Petrie & Bugden, 2002) and the lower plot shows the percentage of the time that Node 10317 of the DFO MSC60 data set is ice covered during the period 1954 to 2005. While the two data sets are not directly comparable because of the different manner in which ice cover data is presented, they do show generally similar patterns, suggesting that the use of the DFO data would be a reasonable approximation of conditions on the Lakes.

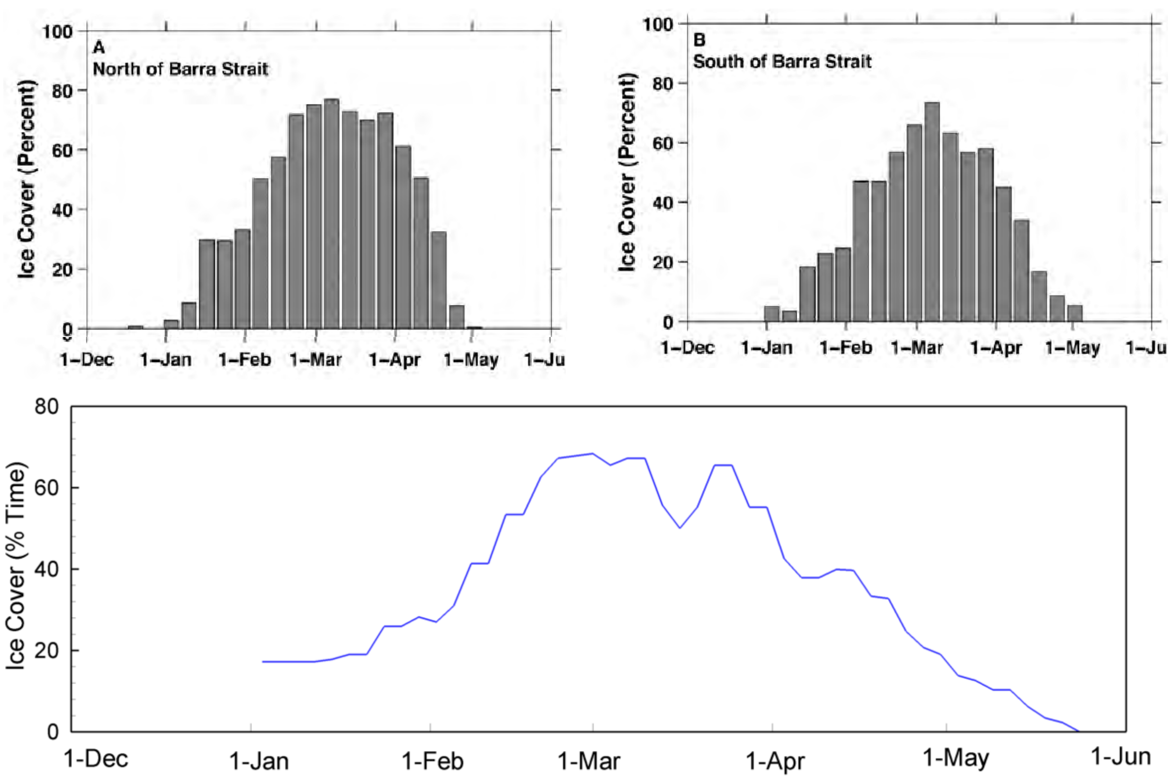

Figure 32 Ice coverage: top plots show spatial cover (Petrie & Bugden, 2002); bottom plot shows temporal cover (DFO)

6.4.5 Model Structure

Coldwater has developed a computational model that incorporates the processes described in the preceding sections to predict the extreme water level on a beach or structure at the five First Nations coastal communities of Bras d'Or Lakes. The instantaneous water level, ζ, are determined as the sum of the storm surge + wind setup, i.e. $\zeta = \text{MSL} + \eta_s + \eta_w$, except during periods of ice cover when $\zeta = \text{MSL}$ is assumed. Wave run-up is also calculated and stored for separate analysis. The model requires as input a time series of wind speed, wind direction, air pressure, and ice cover. In addition, information about the shore such as beach slope, or slope and depth of the shore protection structure is required. Simulations can be performed using the historical data or new data sets can be synthesized to generate hypothetical test conditions. This latter approach is discussed in the next sections.

6.4.6 Climate Change

The coastal First Nations communities around Bras d'Or Lakes will be exposed to a changing climate in the future. These changes will be manifested in a number of ways including sea-level rise, reduced ice cover, and increased intensity, duration and frequency of storms. These will factors will likely exacerbate the on-going coastal erosion and flooding. This section discusses the means by which these factors are taken into account in the climate change scenarios in this study.

Sea Level Rise

Sea level, and consequently the level of the Bras d'Or Lakes, is expected to increase significantly in the future further endangering the infrastructure and lands of the local First Nations coastal communities. A recent publication (James, Henton, Leonard, Darlington, Forbes, & Craymer, 2014) presents detailed predictions for sea level rise for specific locations around Canada and neighbouring US, including Baddeck. These projections are based on the Representative Concentration Pathway (RCP) scenarios of the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC AR5). They include contributions from the thermal expansion of the ocean, glacial melting and discharge, anthropogenic influences and local crustal movements (e.g., crustal subsidence and post-glacial isostatic rebound). A number of scenarios were studied and presented in the report; these are summarized in Table 3. The findings indicate that Baddeck will experience the highest relative sea-level rise of the 59 sites studied.

Table 3 Projected global sea-level rise (median, 5% and 95%) relative to 1986-2005 sea level

Scenario	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Global mean sea level rise (m) by 2081–2100	0.40 [0.26 to 0.55]	0.47 [0.32 to 0.63]	0.48 [0.33 to 0.63]	0.63 [0.45 to 0.82]
Sea-level Projections (m) at Baddeck, NS 2081-2100	0.557 [0.29 to 0.82]	0.644 [0.38 to 0.91]	0.673 [0.38 to 0.97]	0.813 [0.50 to 1.12]

The RCP scenarios were developed for the climate modelling community in order to integrate work being performed by research organizations around the world. The four scenarios can be summarized as follows (van Vuuren, et al., 2011):

- The RCP2.6 scenario is reduction scenario in which greenhouse gas concentrations peak around mid-century, then fall to low levels by 2100. Its development was based on approximately 20 published scenarios.
- The RCP4.5 scenario is a stabilization scenario in which greenhouse gas concentrations is stabilized shortly after 2100, without overshooting the long-range targets. It takes a intermediate approach to both emissions and mitigation efforts. Its development was based on 118 published scenarios and describes the majority of the scenarios published world-wide.
- The RCP6 scenario is a stabilization scenario in which greenhouse gas concentrations is stabilized shortly after 2100, without overshooting the long-range targets. It is very similar to RCP4.5, but assumes different in mitigation efforts. Its development was based on approximately 10 published scenarios.
- The RCP 8.5 scenario is based on increasing greenhouse gas emissions over time and is a high emission scenario. Its development was based on approximately 40 published scenarios.

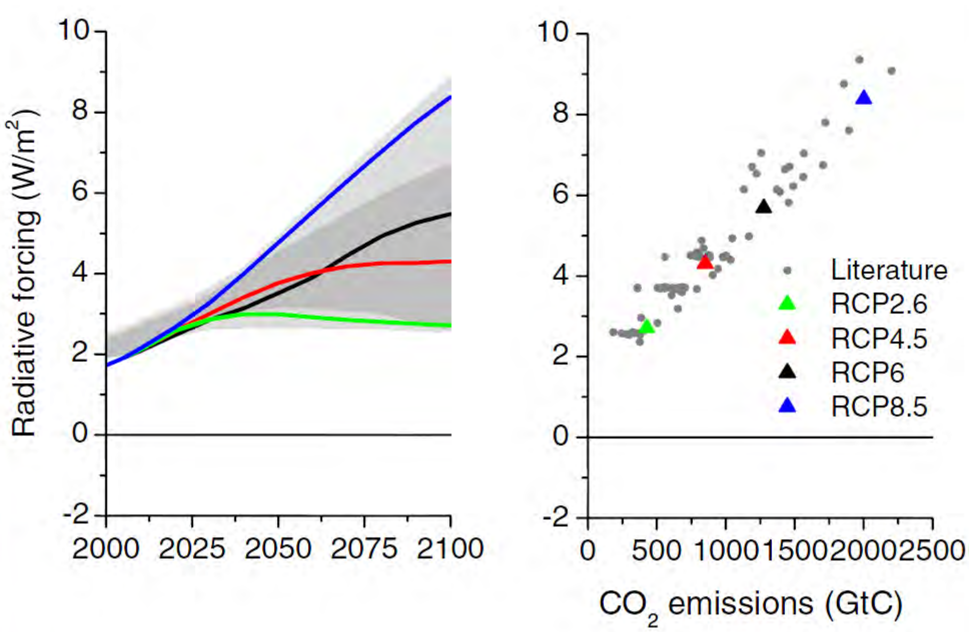

Figure 33 Radiative forcing (left) and CO2 emmisions (right) for the four RCP plans (van Vuuren, et al., 2011)

While RCP4.5 may arguably describe the most probable sea level rise scenario according to present research, recent emissions track closely to RCP8.5 (Zhai, et al., 2014) and incorporation of the upper end of the range in RCP8.5 may be more relevant to management and planning in coastal areas

(James, Henton, Leonard, Darlington, Forbes, & Craymer, 2014). Furthermore, at Baddeck the median value of the RCP8.5 scenario sea level rise (0.813 m) falls within the 5%-95% range for RCP4.5 (0.38 m to 0.91 m). Therefore, RCP8.5 scenario was adopted for use in the present work to establish sea levels into the future. Table 4 gives the projected mean sea levels for Baddeck for 2040 and 2100 based on the median values of the RCP8.5 scenario and the average sea levels between 1986 and 2005 (see Table 3). The value for 2040 was estimated by using a fitting method that the matches published values from James et al. (2014).

Table 4 Projected mean sea levels at Baddeck assuming sea level rise scenario RCP8.5

Year	MSL (m, CGVD28)	MSL - MSL_{2016}
2016	0.300	-
2040	0.479	0.179
2100	1.124	0.824

Shortened Ice Season

As discussed in the Climate Change Report (Daigle, O'Carroll, Young, & Paul, March 2015), there are measureable trends in sea ice that suggest accelerating decreases in cover. This impact of this process is investigated by considering the ultimate or most extreme situation, namely year-round open water.

Increased Storminess

As discussed in the Climate Change Report (Daigle, O'Carroll, Young, & Paul, March 2015), little hard data or model evidence exists that could be used to quantify estimates of increased intensity, duration and frequency of storms. The clearest link between the climate change and increased storminess concerns the projected increase in open water, which will lead to additional wave and surge impacts at times when the shore would have formerly been protected by ice. In order to examine possible increased storminess, a scenario will be developed by assuming a 5% increase in wind speed and a corresponding decrease in relative air pressure:

$$\widehat{U} = 1.05U \quad (9)$$

$$\widehat{P} = 1.05(P_0 - P) \quad (10)$$

Climate Scenarios

Based on the above information, we have developed three climate scenarios for input into the modelling:

1. Sea level rise in accordance with the RCP8.5 predictions (see Table 4).

2. Sea level rise as per 1., plus open water
3. Sea level rise as per 1., plus open water and increased storminess

The three scenarios will be compared to the *status quo* assumes the climate stays as it is today and is used only as a comparison

6.5 Vulnerability Assessment

Model simulations were performed for three cases at each of the five communities studied:

- elevation of storm surge at the community;
- elevation of maximum run-up at the shore, and;
- elevation of maximum run-up at a coastal structure.

The maximum run-up at the shore is computed assuming a 1:10 (V:H) beach slope, a slope consistent with the beaches measured during the June 2015 field campaign. The maximum run-up on a coastal structure was computed assuming a 1:2 (V:H) revetment with a single layer of armour stone.

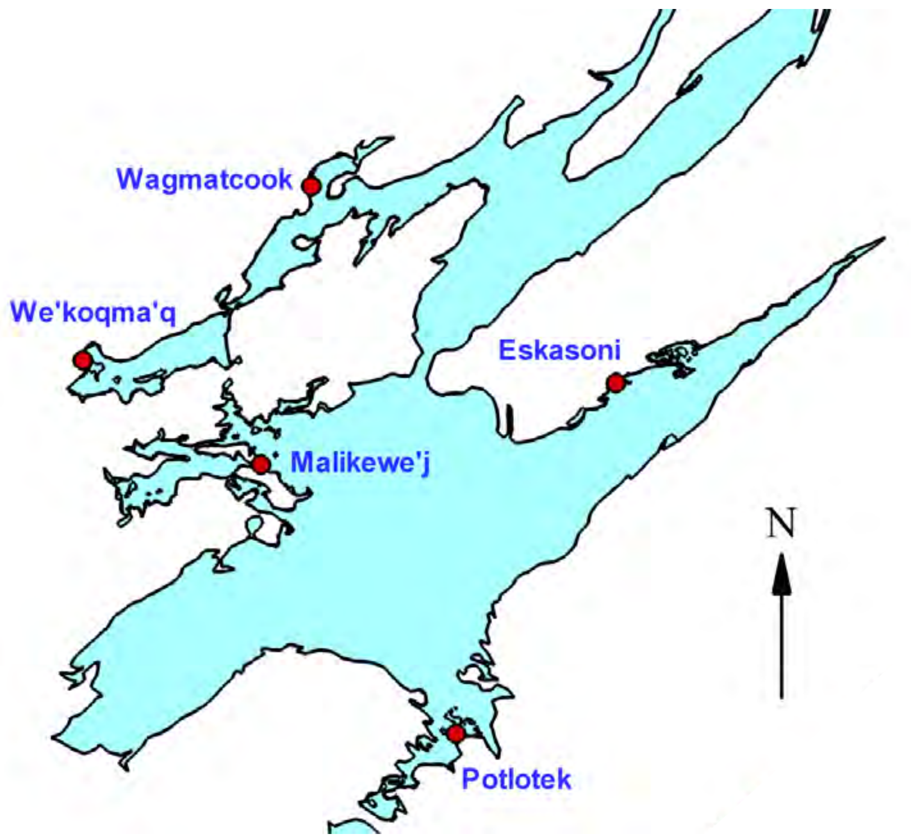

Figure 34 Locations of the First Nations communities studied

All elevation values were computed from the hourly predictions of the model; therefore, the elevations represent the instantaneous storm surge, instantaneous wind setup and instantaneous wave run-up. The simulations were conducted based on 53 years of data (1953-2005) using a 1 hour time step. This resulted in almost 465,000 individual water level estimates for each hypothetical structure at each community. For design and planning purposes, each set of results were then subjected to an extreme value analysis procedure using a Weibull distribution to determine the 100-year return period water levels for each case. An illustration of the technique is presented in Figure 35. The elevation estimates from the Weibull distribution are presented in the following tables.

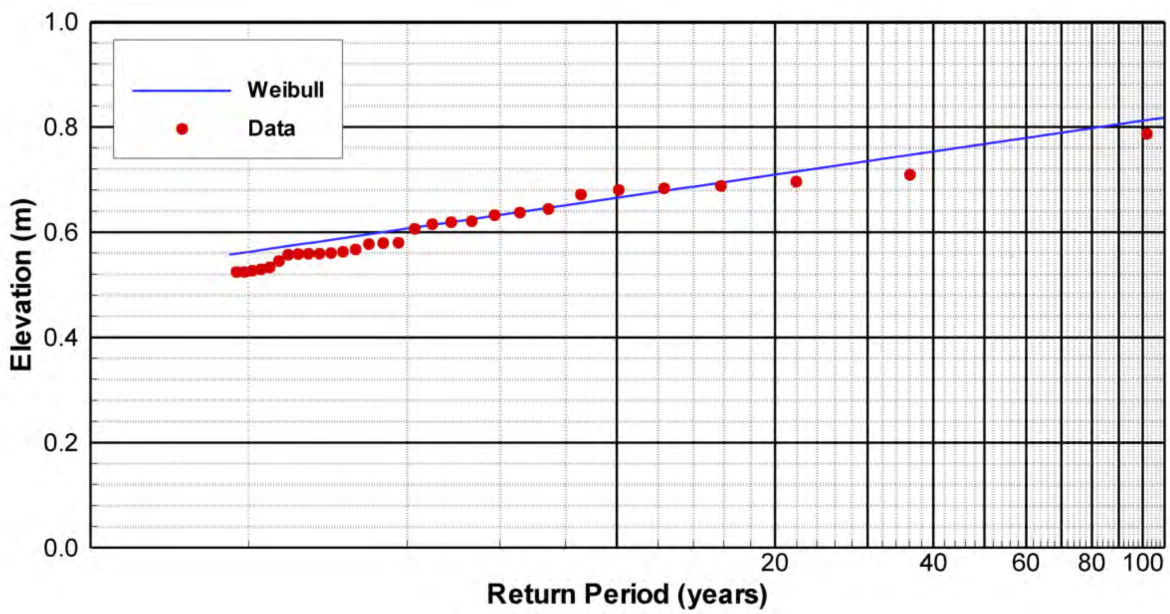

Figure 35 Example of the extreme value analysis curve fit

The predicted 100-year return period levels for each community are presented in the next section. This is followed by a section which presents these levels as inundation lines at selected locations.

6.5.1 Levels

The predicted 100-year return period surge and flood estimates for each community under a range of scenarios are presented below. The surge level values represent the elevation of the predicted still water level.

$$\text{surge level} = \zeta = \text{MSL} + \eta_s + \eta_w \quad (11)$$

The flood levels include the run-up values and give the vertical elevation of the combined surge, setup and wave action.

$$\text{flood level} = \zeta + R = \text{MSL} + \eta_s + \eta_w + R \quad (12)$$

The results are presented relative to both present-day MSL (i.e., MSL=0 in Eqs. 11 and 12), which is a meaningful measure for local residents, and CGVD28 (i.e., MSL=0.3 in Eqs. 11 and 12), which is useful in determining inundation flood lines.

Present-day Conditions

The predicted 100-year return period surge and flood level estimates for each community under present-day conditions are presented in Table 5. The surge level results vary between a low of 0.63 m above MSL at Wagmatcook to a high of 0.89 m above MSL at Potlotek. The flood levels show a different pattern because of the differences in wave action at the various communities; the highest beach flood elevation is 1.55 m above MSL at Malikewe'j whereas the lowest is 0.88 m above MSL at We'koqma'q.

Table 5 Predicted 100-year return period events under present-day conditions

Community	Relative to 2015 MSL (m)			Relative to CGVD28 (m)		
	Surge Level	Flood Level		Surge Level	Flood Level	
		Beach	Revetment		Beach	Revetment
Potlotek	0.89	1.30	2.18	1.19	1.60	2.48
Malikewe'j	0.81	1.55	2.25	1.11	1.85	2.55
We'koqma'q	0.68	0.88	1.11	0.98	1.18	1.41
Wagmatcook	0.63	0.90	1.33	0.93	1.20	1.63
Eskasoni	0.78	1.46	1.89	1.08	1.76	2.19

The present probability of encountering a particular level in a given year is presented in Table 6.

Table 6 Probability of encountering surge events of various magnitudes at the five communities in 2015

Community	Surge Elevation (m, CGVD28)								
	0.80	0.85	0.90	0.95	1.00	1.05	1.10	1.15	1.20
Potlotek	> 99%	> 99%	> 99%	> 99%	62%	21%	7%	3%	1%
Malikewe'j	> 99%	61%	28%	13%	6%	3%	1%	1%	< 1%
We'koqma'q	24%	10%	4%	2%	1%	< 1%	< 1%	< 0.1%	< 0.1%
Wagmatcook	41%	10%	3%	1%	< 1%	< 0.1%	< 0.1%	< 0.1%	< 0.1%
Eskasoni	> 99%	85%	32%	12%	5%	2%	1%	0%	< 0.1%

Future Climate Change Scenarios

The predicted surge levels and probability of encountering various surges in a given year are presented for 2040 and for 2100 are presented in Table 7 through Table 10. These results have been computed assuming sea-level rise, full year open water and increased storminess. As expected, the 2040 and 2100 levels are higher than the 2015 levels presented in the previous section, primarily because of the expected 0.179 m and 0.824 m increases in sea level, respectively. The overall patterns remain the same the each site; Potlotek, Malikewe'j and Eskasoni will see the highest levels. With sea level rise, a damaging 1.2 m CGVD28 surge that today at Potlotek has only about a 1% chance of occurring will have a 62% chance of occurring. By 2100, these will occur annually.

Table 7 Predicted 100-year return period events assuming RCP8.5 and year-round open water and increased storminess for 2040

Community	Relative to 2015 MSL (m)			Relative to CGVD28 (m)		
	Surge Level	Flood Level		Surge Level	Flood Level	
		Beach	Revetment		Beach	Revetment
Potlotek	1.25	1.50	2.39	1.55	1.80	2.69
Malikewe'j	1.06	1.81	2.44	1.36	2.11	2.74
We'koqma'q	0.92	1.09	1.30	1.22	1.39	1.60
Wagmatcook	0.92	1.17	1.55	1.22	1.47	1.85
Eskasoni	1.06	1.78	2.11	1.36	2.08	2.41

Table 8 Probability of encountering surge events assuming RCP8.5 and year-round open water and increased storminess for 2040

Community	Surge Elevation (m, CGVD28)								
	1.00	1.05	1.10	1.15	1.20	1.25	1.30	1.35	1.40
Potlotek	> 99%	> 99%	> 99%	> 99%	62%	34%	19%	10%	6%
Malikewe'j	> 99%	> 99%	72%	32%	14%	6%	3%	1%	1%
We'koqma'q	25%	12%	6%	3%	1%	1%	< 1%	< 1%	< 0.1%
Wagmatcook	66%	25%	10%	4%	1%	1%	< 1%	< 0.1%	< 0.1%
Eskasoni	> 99%	> 99%	66%	29%	13%	6%	2%	1%	< 1%

Table 9 Predicted 100-year return period events assuming RCP8.5 and year-round open water and increased storminess for 2100

Community	Relative to 2015 MSL (m)			Relative to CGVD28 (m)		
	Surge Level	Flood Level		Surge Level	Flood Level	
		Beach	Revetment		Beach	Revetment
Potlotek	1.89	2.15	3.04	2.19	2.45	3.34
Malikewe'j	1.71	2.46	3.09	2.01	2.76	3.39
We'koqma'q	1.57	1.74	1.95	1.87	2.04	2.25
Wagmatcook	1.56	1.82	2.20	1.86	2.12	2.50
Eskasoni	1.70	2.43	2.76	2.00	2.73	3.06

Table 10 Probability of encountering surge events assuming RCP8.5 and year-round open water and increased storminess for 2100

Community	Surge Elevation (m, CGVD28)								
	1.55	1.60	1.65	1.70	1.75	1.80	1.85	1.90	1.95
Potlotek	> 99%	> 99%	> 99%	> 99%	> 99%	> 99%	58%	32%	18%
Malikewe'j	> 99%	> 99%	> 99%	> 99%	67%	30%	13%	6%	3%
We'koqma'q	99%	48%	23%	11%	5%	3%	1%	1%	< 1%
Wagmatcook	> 99%	> 99%	60%	23%	9%	3%	1%	< 1%	< 1%
Eskasoni	> 99%	> 99%	> 99%	> 99%	61%	27%	12%	5%	2%

The predicted 100-year return period surge and flood level estimates for 2040 and 2100 for each community and each future climate change scenarios (see *Climate Scenarios*, p. 50) are presented in Table 11 through Table 24, which are shown in *Appendix A – Predicted Levels* (p. 59).

6.5.2 Inundation

The predicted 100-year return period surge and flood estimates in the previous section were presented in terms of elevation. In this section, these elevations are used together with LiDAR elevation data to develop inundation lines in plan. Several sites are investigated at each community. These lines show how far inland the flooding would reach. Flood hazard lines assuming run-up on a 1:10 beach, which represents the extreme waterline and the line seaward of which flood protection would be required are shown on each plot for:

- Conditions in 2040 assuming RCP8.5 sea-level rise (25 years out)
- Conditions in 2100 assuming RCP8.5 sea-level rise (85 years out)

The inundation plots for the five communities are presented in *Appendix B – Predicted Inundation Lines* (p. 67).

Potlotek

Two sites are examined at Potlotek: the southern end of Chapel Island, and; the area around the dock on the mainland. The southern end of Chapel Island is very low lying and subject to flooding. Even without surge action, much of the area around the church will be inundated daily by 2100 and flooding much of the presently habitable land to the east. When surge and run-up is included to produce the flood hazard line, the situation is far worse (see Figure 36); most of the structures around the church lie within the 2040 flood hazard line. The situation worsens with sea-level rise, but the church itself should be safe until 2100. The mainland area near the dock is low-lying as well and some of this area will flood on a daily basis by 2100. Storm action floods much of this area today and this loss of land use will progress in the future (see Figure 37).

Malikewe'j

The coastal barrier used for road access at Malikewe'j will be at risk from flooding in 2040, as will large parts of this spit (see Figure 38). By 2100, road access during surge events will be impossible. The houses near the southern end of the island should be safe until 2100, at least. The access road at the western end of the community is very low lying and is subject to flooding today. The road could be submerged on a daily basis by 2100. As is illustrated in Figure 39, surge events endanger the road today and will only worsen over time unless the road is raised.

We'koqma'q

The southern-most of the two sites will see some land loss and by 2100 the daily water line will reach the buildings. Surge events will endanger the lower buildings by 2040 (see Figure 40). This will increase so that by 2100 the other buildings will be subject to flooding during surge events. To the north, a similar story will unfold. Here the main road will be subject to flooding during surge events by 2100 (Figure 41). Buildings in this area will begin to be in danger by 2100 as well.

Wagmatcook

The situation at Wagmatcook is somewhat better than the preceding sites; here, surges and sea level rise will lead to land loss, but should not endanger any buildings or community infrastructure, including the sewage treatment facility (see Figure 42 and Figure 43).

Eskasoni

Eskasoni is very large, so the community has been broken up into five parts for this analysis. There will be a change in the daily waterline over the next 75 years, although this should only impact the community at the western end and at other low lying areas. Flood hazard lines today (Figure 44 through Figure 48) suggest that most buildings and community infrastructure are safe and should remain so to 2040. By 2100, however, this will have changed and some protection works or relocation will be required for a number of buildings.

Appendix A – Predicted Levels

Today's Conditions

Table 11 Predicted 100-year return period events under present-day conditions

Community	Relative to 2015 MSL (m)			Relative to CGVD28 (m)		
	Surge Level	Flood Level		Surge Level	Flood Level	
		Beach	Revetment		Beach	Revetment
Potlotek	0.89	1.30	2.18	1.19	1.60	2.48
Malikewe'j	0.81	1.55	2.25	1.11	1.85	2.55
We'koqma'q	0.68	0.88	1.11	0.98	1.18	1.41
Wagmatcook	0.63	0.90	1.33	0.93	1.20	1.63
Eskasoni	0.78	1.46	1.89	1.08	1.76	2.19

Table 12 Probability of encountering surge events under present-day conditions

Community	Surge Elevation (m, CGVD28)								
	0.80	0.85	0.90	0.95	1.00	1.05	1.10	1.15	1.20
Potlotek	> 99%	> 99%	> 99%	> 99%	62%	21%	7%	3%	1%
Malikewe'j	> 99%	61%	28%	13%	6%	3%	1%	1%	< 1%
We'koqma'q	24%	10%	4%	2%	1%	< 1%	< 1%	< 0.1%	< 0.1%
Wagmatcook	41%	10%	3%	1%	< 1%	< 0.1%	< 0.1%	< 0.1%	< 0.1%
Eskasoni	> 99%	85%	32%	12%	5%	2%	1%	< 1%	< 0.1%

Future Conditions - Sea-level Rise

Table 13 Predicted 100-year return period events assuming RCP8.5 sea-level rise for 2040

Community	Relative to 2015 MSL (m)			Relative to CGVD28 (m)		
	Surge Level	Flood Level		Surge Level	Flood Level	
		Beach	Revetment		Beach	Revetment
Potlotek	1.07	1.48	2.36	1.37	1.78	2.66
Malikewe'j	0.99	1.72	2.43	1.29	2.02	2.73
We'koqma'q	0.86	1.06	1.29	1.16	1.36	1.59
Wagmatcook	0.81	1.08	1.50	1.11	1.38	1.80
Eskasoni	0.96	1.64	2.07	1.26	1.94	2.37

Table 14 Probability of encountering surge events assuming RCP8.5 sea-level rise for 2040

Community	Surge Elevation (m, CGVD28)								
	1.00	1.05	1.10	1.15	1.20	1.25	1.30	1.35	1.40
Potlotek	> 99%	> 99%	> 99%	> 99%	39%	14%	5%	2%	1%
Malikewe'j	96%	44%	20%	9%	4%	2%	1%	< 1%	< 1%
We'koqma'q	16%	7%	3%	1%	< 1%	< 1%	< 0.1%	< 0.1%	< 0.1%
Wagmatcook	23%	6%	1%	< 1%	< 0.1%	< 0.1%	< 0.1%	< 0.1%	< 0.1%
Eskasoni	> 99%	57%	21%	8%	3%	1%	< 1%	< 1%	< 0.1%

Table 15 Predicted 100-year return period events assuming RCP8.5 sea-level rise for 2100

Community	Relative to 2015 MSL (m)			Relative to CGVD28 (m)		
	Surge Level	Flood Level		Surge Level	Flood Level	
		Beach	Revetment		Beach	Revetment
Potlotek	1.72	2.13	3.00	2.02	2.43	3.30
Malikewe'j	1.64	2.37	3.07	1.94	2.67	3.37
We'koqma'q	1.50	1.70	1.93	1.80	2.00	2.23
Wagmatcook	1.46	1.72	2.15	1.76	2.02	2.45
Eskasoni	1.60	2.28	2.71	1.90	2.58	3.01

Table 16 Probability of encountering surge events assuming RCP8.5 sea-level rise for 2100

Community	Surge Elevation (m, CGVD28)								
	1.55	1.60	1.65	1.70	1.75	1.80	1.85	1.90	1.95
Potlotek	> 99%	> 99%	> 99%	> 99%	> 99%	> 99%	35%	12%	4%
Malikewe'j	> 99%	> 99%	89%	40%	18%	8%	4%	2%	1%
We'koqma'q	91%	37%	15%	6%	2%	1%	< 1%	< 1%	< 0.1%
Wagmatcook	> 99%	79%	20%	5%	1%	< 1%	< 0.1%	< 0.1%	< 0.1%
Eskasoni	> 99%	> 99%	> 99%	51%	19%	7%	3%	1%	< 1%

Future Conditions - Sea-level Rise and Open Water

Table 17 Predicted 100-year return period events assuming RCP8.5 and year-round open water for 2040

Community	Relative to 2015 MSL (m)			Relative to CGVD28 (m)		
	Surge Level	Flood Level		Surge Level	Flood Level	
		Beach	Revetment		Beach	Revetment
Potlotek	1.17	1.48	2.36	1.47	1.78	2.66
Malikewe'j	1.01	1.76	2.37	1.31	2.06	2.67
We'koqma'q	0.88	1.06	1.29	1.18	1.36	1.59
Wagmatcook	0.87	1.12	1.51	1.17	1.42	1.81
Eskasoni	0.98	1.78	2.07	1.28	2.08	2.37

Table 18 Probability of encountering surge events assuming RCP8.5 and year-round open water for 2040

Community	Surge Elevation (m, CGVD28)								
	1.00	1.05	1.10	1.15	1.20	1.25	1.30	1.35	1.40
Potlotek	> 99%	> 99%	> 99%	53%	29%	15%	8%	4%	2%
Malikewe'j	> 99%	68%	31%	14%	6%	3%	1%	1%	< 1%
We'koqma'q	19%	8%	4%	2%	1%	< 1%	< 1%	< 0.1%	< 0.1%
Wagmatcook	34%	12%	4%	2%	1%	< 1%	< 0.1%	< 0.1%	< 0.1%
Eskasoni	> 99%	79%	31%	12%	5%	2%	1%	< 1%	< 1%

Table 19 Predicted 100-year return period events assuming RCP8.5 and year-round open water for 2100

Community	Relative to 2015 MSL (m)			Relative to CGVD28 (m)		
	Surge Level	Flood Level		Surge Level	Flood Level	
		Beach	Revetment		Beach	Revetment
Potlotek	1.81	2.13	3.00	2.11	2.43	3.30
Malikewe'j	1.66	2.41	3.01	1.96	2.71	3.31
We'koqma'q	1.52	1.70	1.93	1.82	2.00	2.23
Wagmatcook	1.51	1.76	2.16	1.81	2.06	2.46
Eskasoni	1.63	2.43	2.71	1.93	2.73	3.01

Table 20 Probability of encountering surge events assuming RCP8.5 and year-round open water for 2100

Community	Surge Elevation (m, CGVD28)								
	1.55	1.60	1.65	1.70	1.75	1.80	1.85	1.90	1.95
Potlotek	> 99%	> 99%	> 99%	> 99%	94%	50%	27%	14%	8%
Malikewe'j	> 99%	> 99%	> 99%	63%	28%	13%	6%	3%	1%
We'koqma'q	87%	38%	17%	8%	3%	1%	1%	< 1%	< 1%
Wagmatcook	> 99%	88%	31%	11%	4%	1%	< 1%	< 1%	< 0.1%
Eskasoni	> 99%	> 99%	> 99%	72%	28%	11%	4%	2%	1%

Future Conditions - Sea-level Rise, Open Water and Increased Storminess

Table 21 Predicted 100-year return period events assuming RCP8.5 and year-round open water and increased storminess for 2040

Community	Relative to 2015 MSL (m)			Relative to CGVD28 (m)		
	Surge Level	Flood Level		Surge Level	Flood Level	
		Beach	Revetment		Beach	Revetment
Potlotek	1.25	1.50	2.39	1.55	1.80	2.69
Malikewe'j	1.06	1.81	2.44	1.36	2.11	2.74
We'koqma'q	0.92	1.09	1.30	1.22	1.39	1.60
Wagmatcook	0.92	1.17	1.55	1.22	1.47	1.85
Eskasoni	1.06	1.78	2.11	1.36	2.08	2.41

Table 22 Probability of encountering surge events assuming RCP8.5 and year-round open water and increased storminess for 2040

Community	Surge Elevation (m, CGVD28)								
	1.00	1.05	1.10	1.15	1.20	1.25	1.30	1.35	1.40
Potlotek	> 99%	> 99%	> 99%	> 99%	62%	34%	19%	10%	6%
Malikewe'j	> 99%	> 99%	72%	32%	14%	6%	3%	1%	1%
We'koqma'q	25%	12%	6%	3%	1%	1%	< 1%	< 1%	< 0.1%
Wagmatcook	66%	25%	10%	4%	1%	1%	< 1%	< 0.1%	< 0.1%
Eskasoni	> 99%	> 99%	66%	29%	13%	6%	2%	1%	< 1%

Table 23 Predicted 100-year return period events assuming RCP8.5 and year-round open water and increased storminess for 2100

Community	Relative to 2015 MSL (m)			Relative to CGVD28 (m)		
	Surge Level	Flood Level		Surge Level	Flood Level	
		Beach	Revetment		Beach	Revetment
Potlotek	1.89	2.15	3.04	2.19	2.45	3.34
Malikewe'j	1.71	2.46	3.09	2.01	2.76	3.39
We'koqma'q	1.57	1.74	1.95	1.87	2.04	2.25
Wagmatcook	1.56	1.82	2.20	1.86	2.12	2.50
Eskasoni	1.70	2.43	2.76	2.00	2.73	3.06

Table 24 Probability of encountering surge events assuming RCP8.5 and year-round open water and increased storminess for 2100

Community	Surge Elevation (m, CGVD28)								
	1.55	1.60	1.65	1.70	1.75	1.80	1.85	1.90	1.95
Potlotek	> 99%	> 99%	> 99%	> 99%	> 99%	> 99%	58%	32%	18%
Malikewe'j	> 99%	> 99%	> 99%	> 99%	67%	30%	13%	6%	3%
We'koqma'q	99%	48%	23%	11%	5%	3%	1%	1%	< 1%
Wagmatcook	> 99%	> 99%	60%	23%	9%	3%	1%	< 1%	< 1%
Eskasoni	> 99%	> 99%	> 99%	> 99%	61%	27%	12%	5%	2%

Appendix B – Predicted Inundation Lines

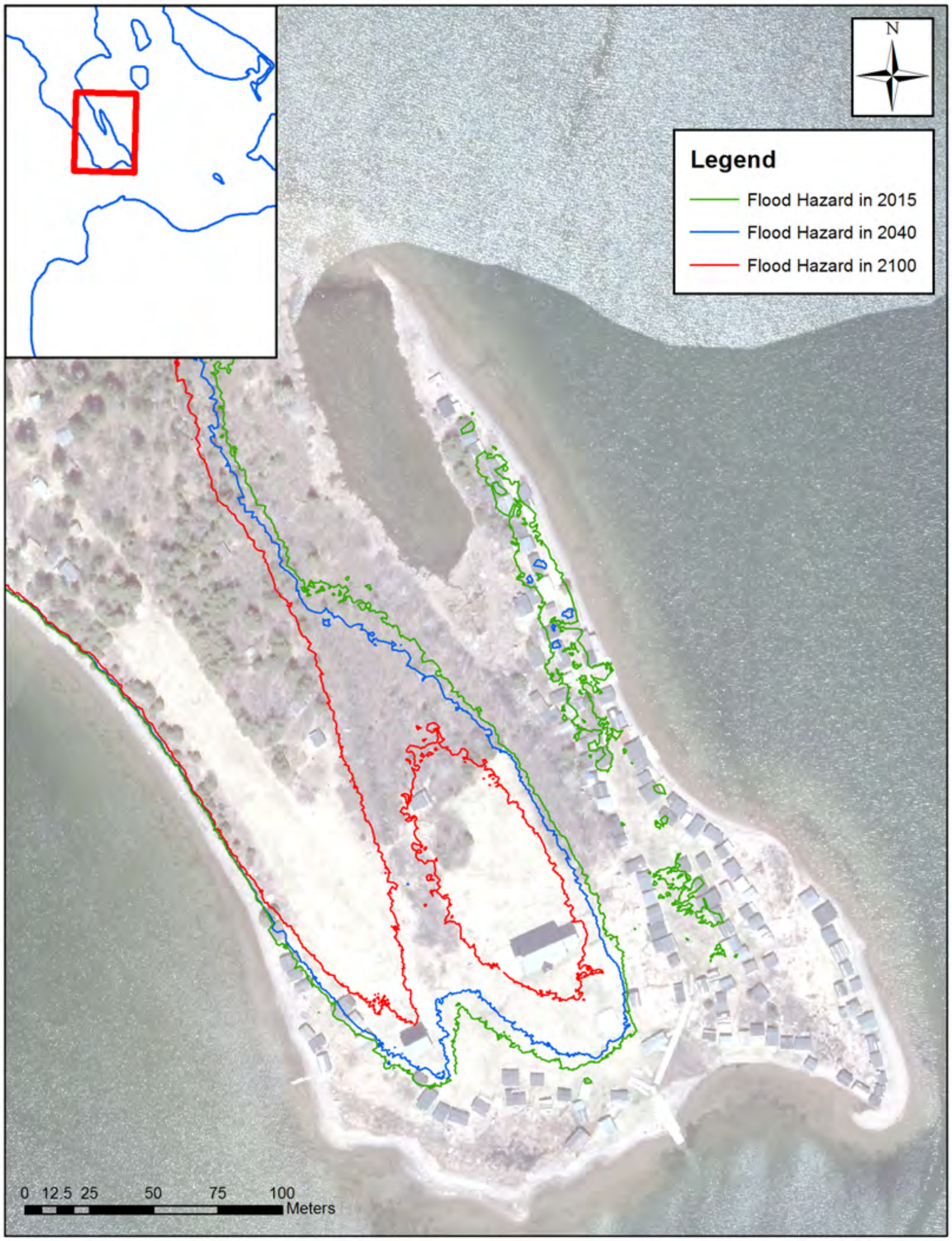

Figure 36 Potlotek flood hazard (1/2)

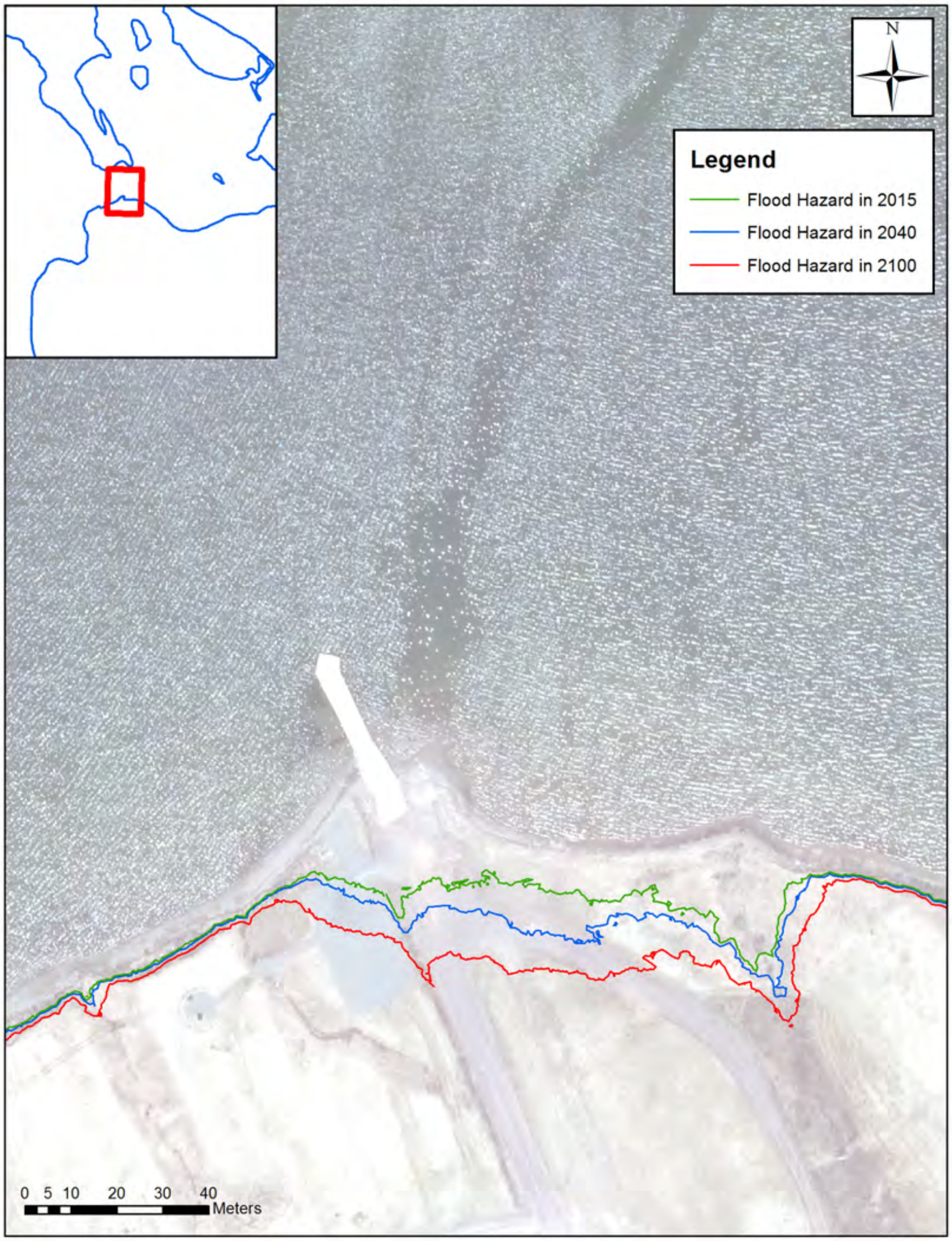

Figure 37 Potlotek flood hazard (2/2)

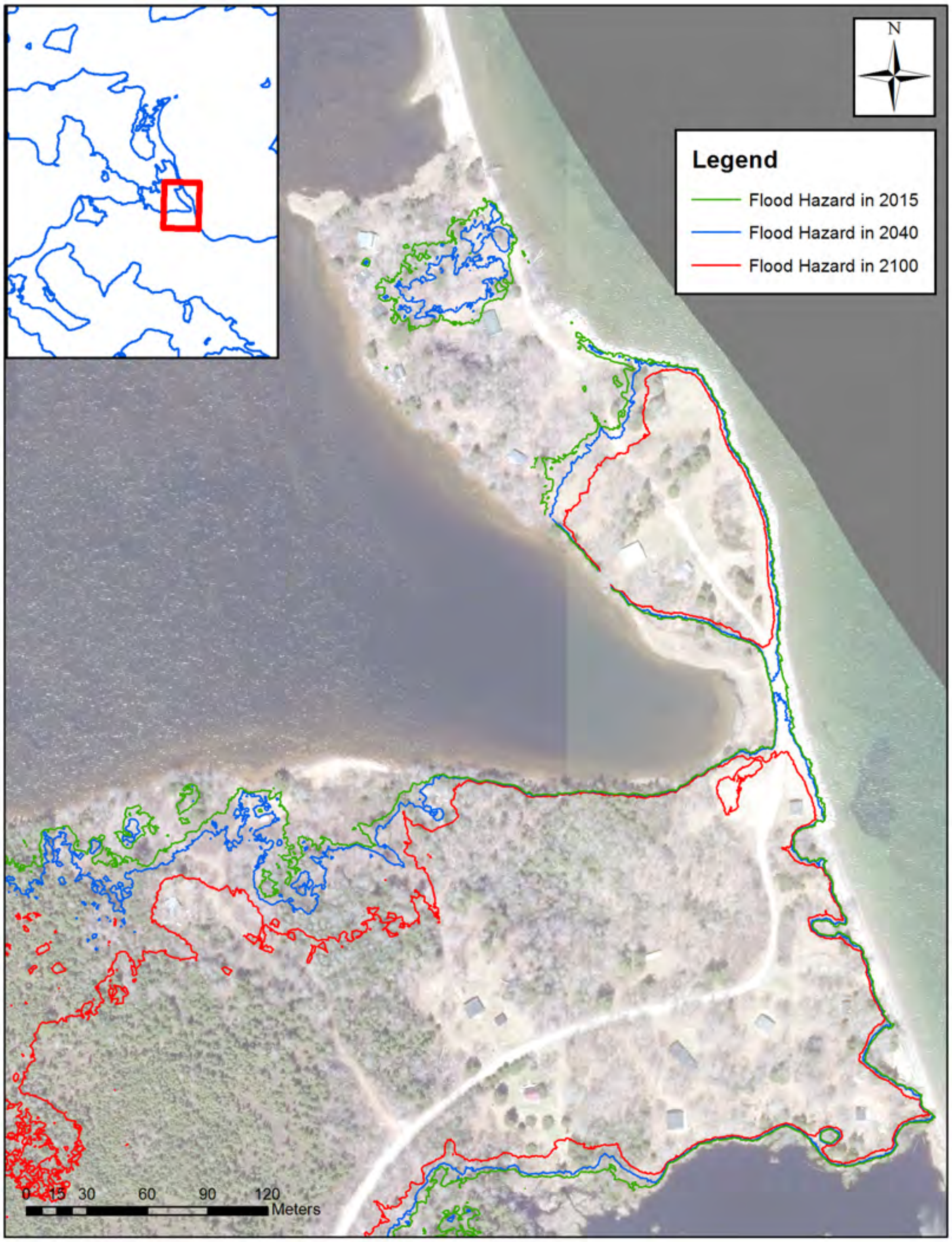

Figure 38 Malikewe'j flood hazard (1/2)

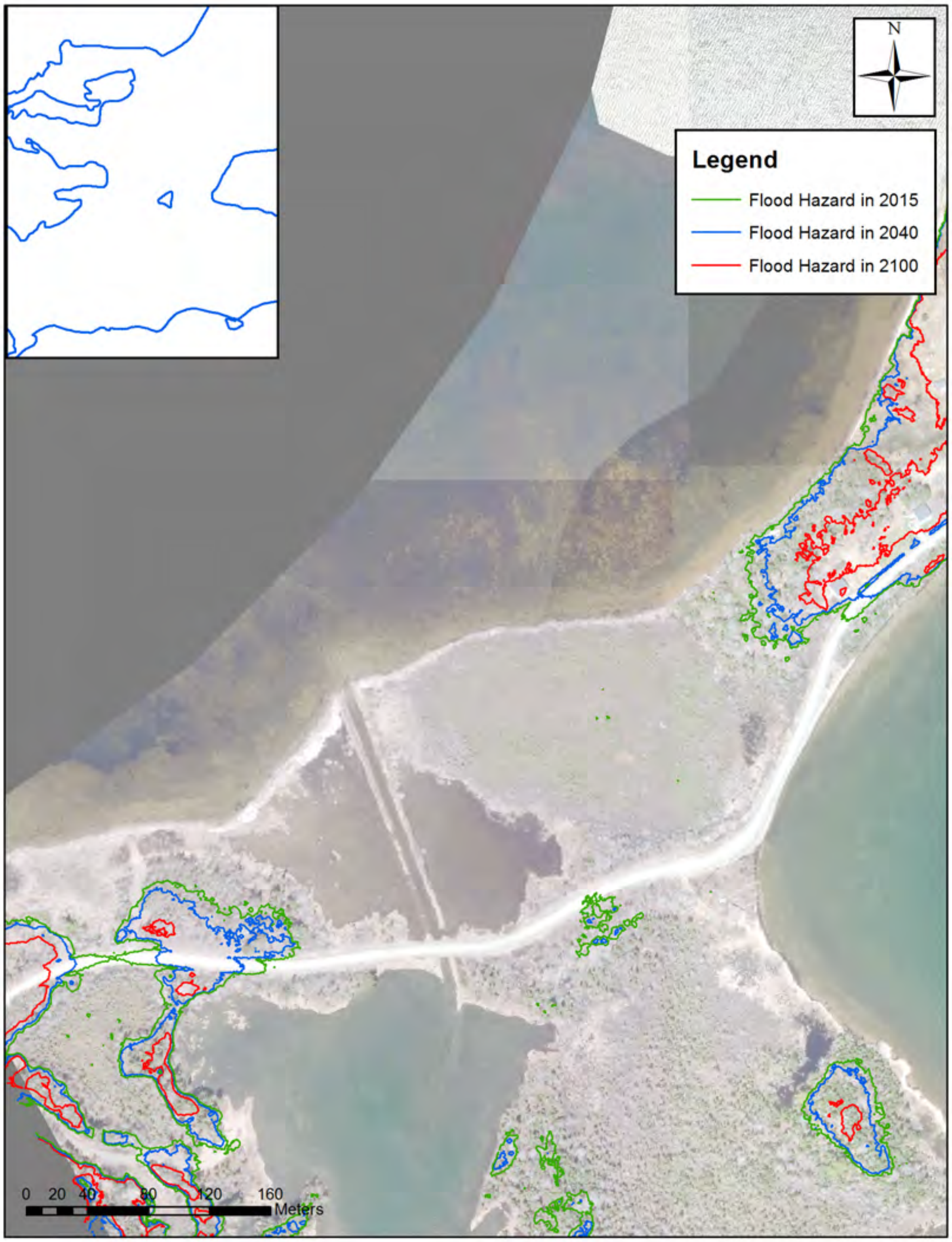

Figure 39 Malikewe'j flood hazard (2/2)

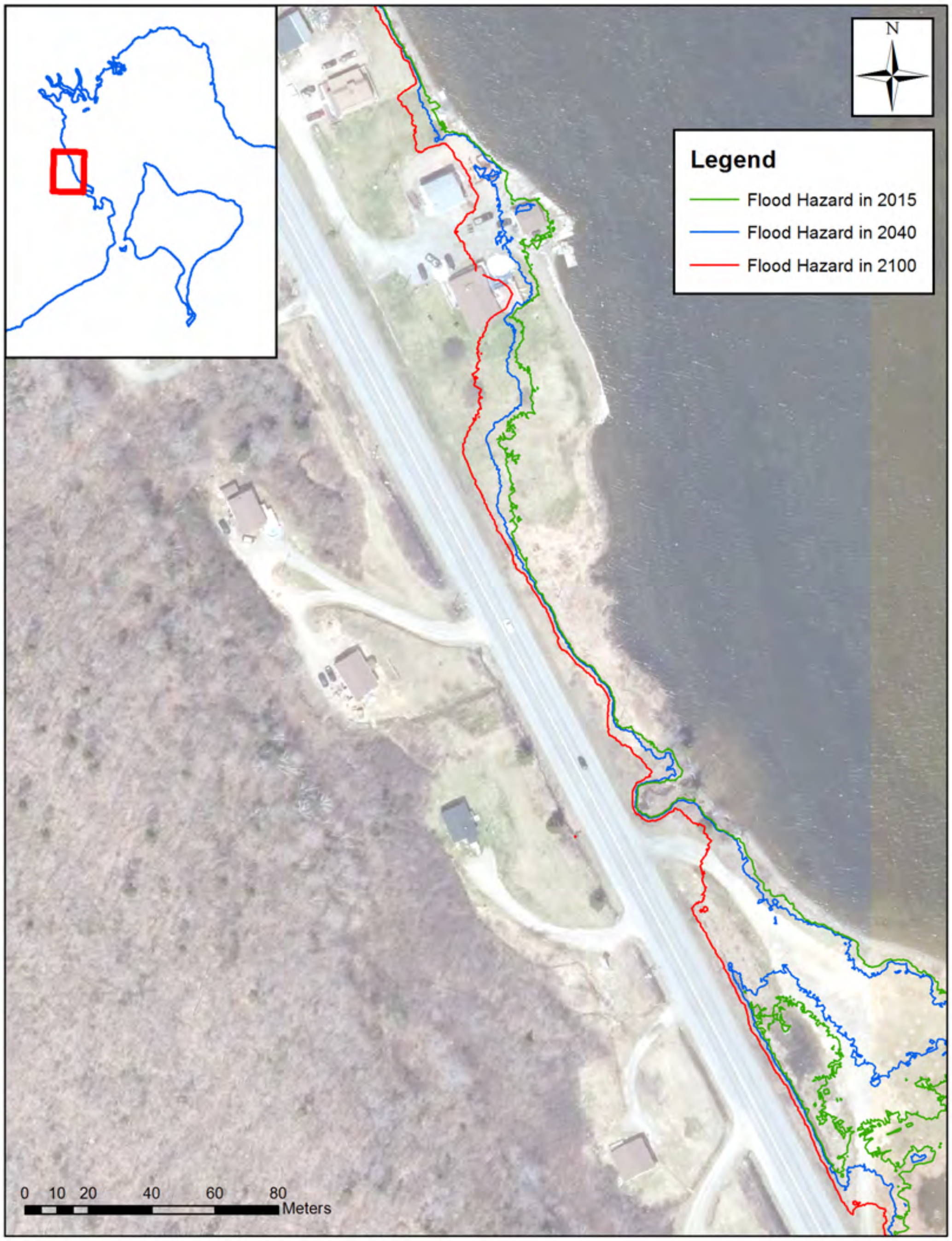

Figure 40 We'koqma'q flood hazard (1/2)

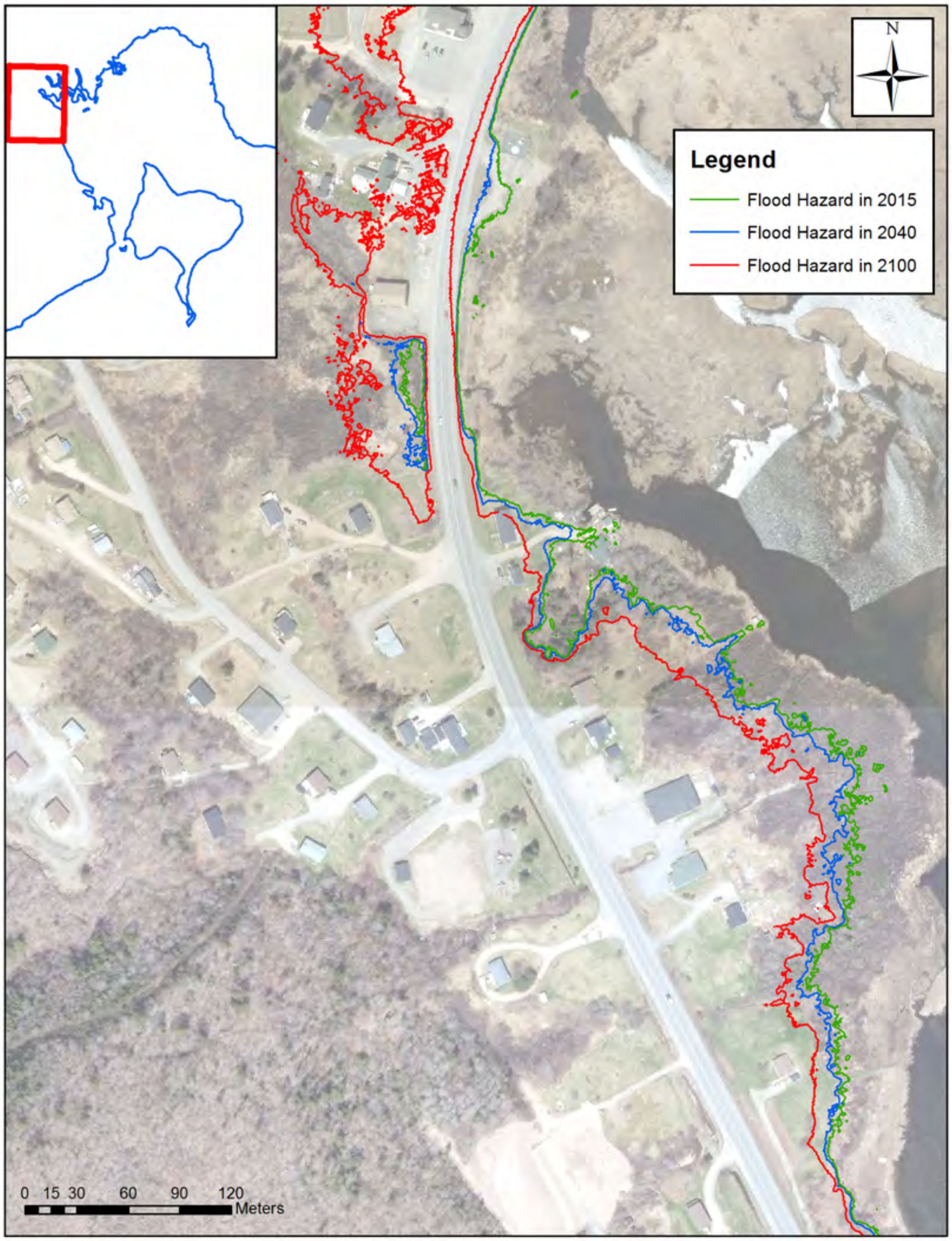

Figure 41 We'koqma'q flood hazard (2/2)

Figure 42 Wagmatcook flood hazard (1/2)

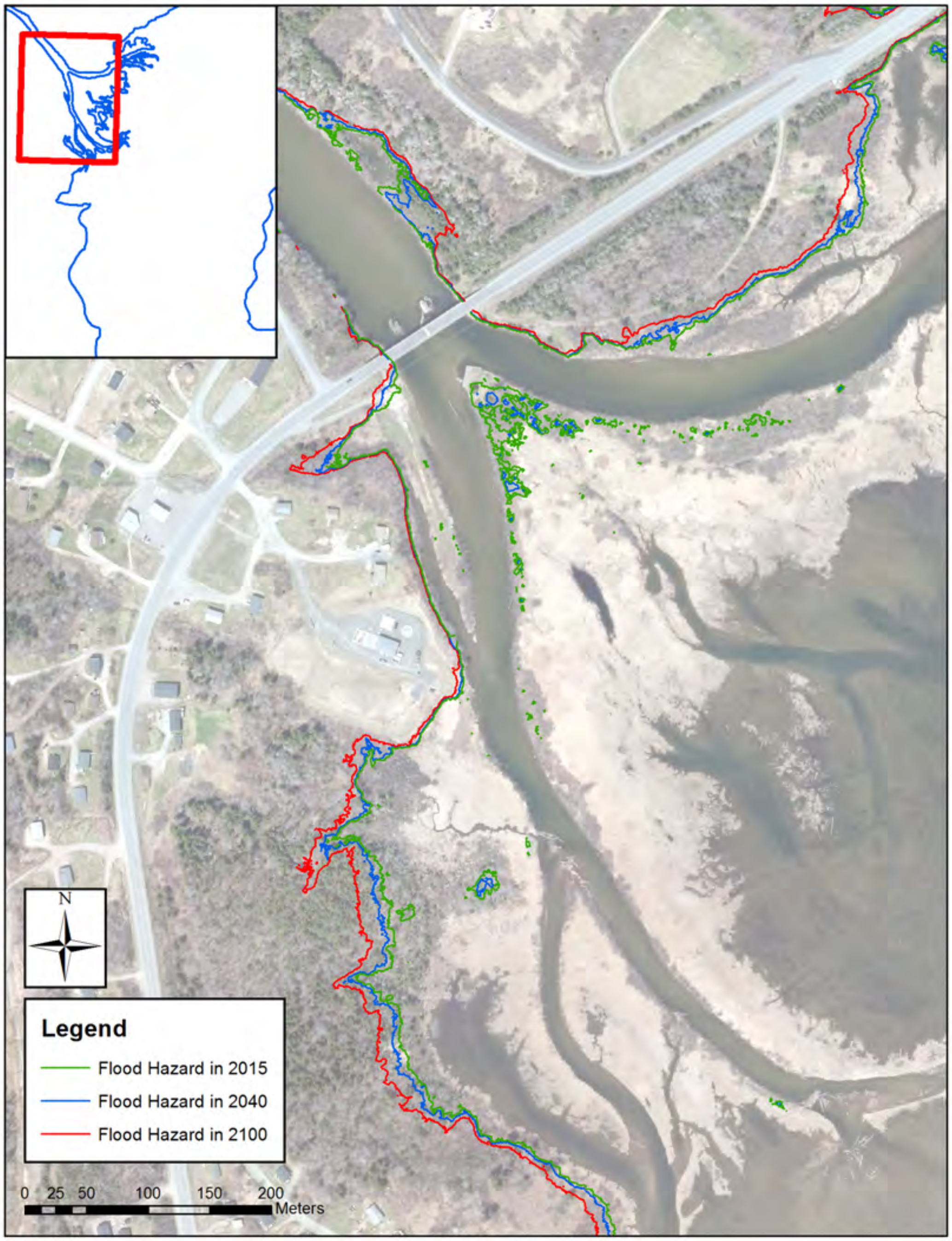

Figure 43 Wagmatcook flood hazard (2/2)

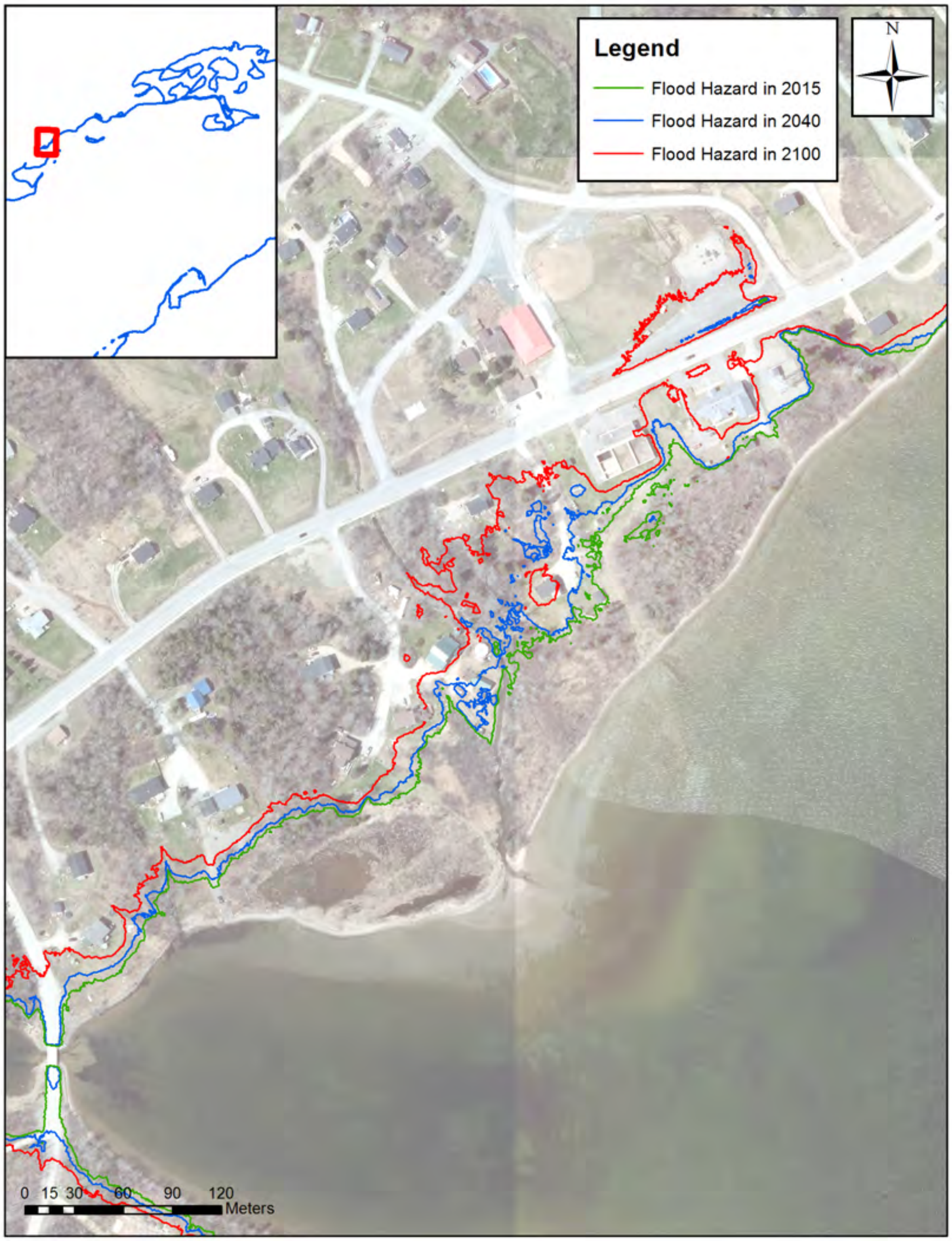

Figure 44 Eskasoni flood hazard (1/5)

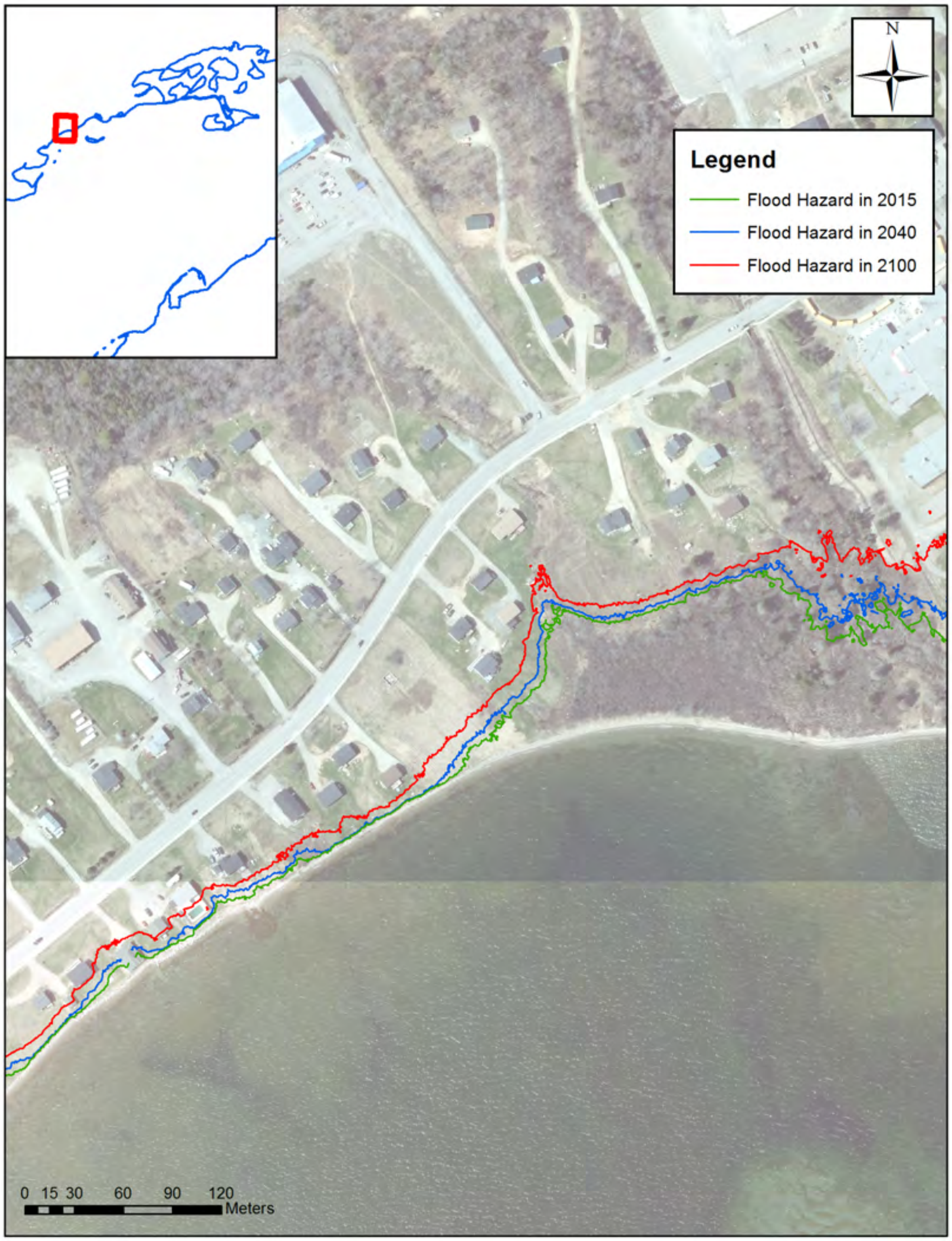

Figure 45 Eskasoni flood hazard (2/5)

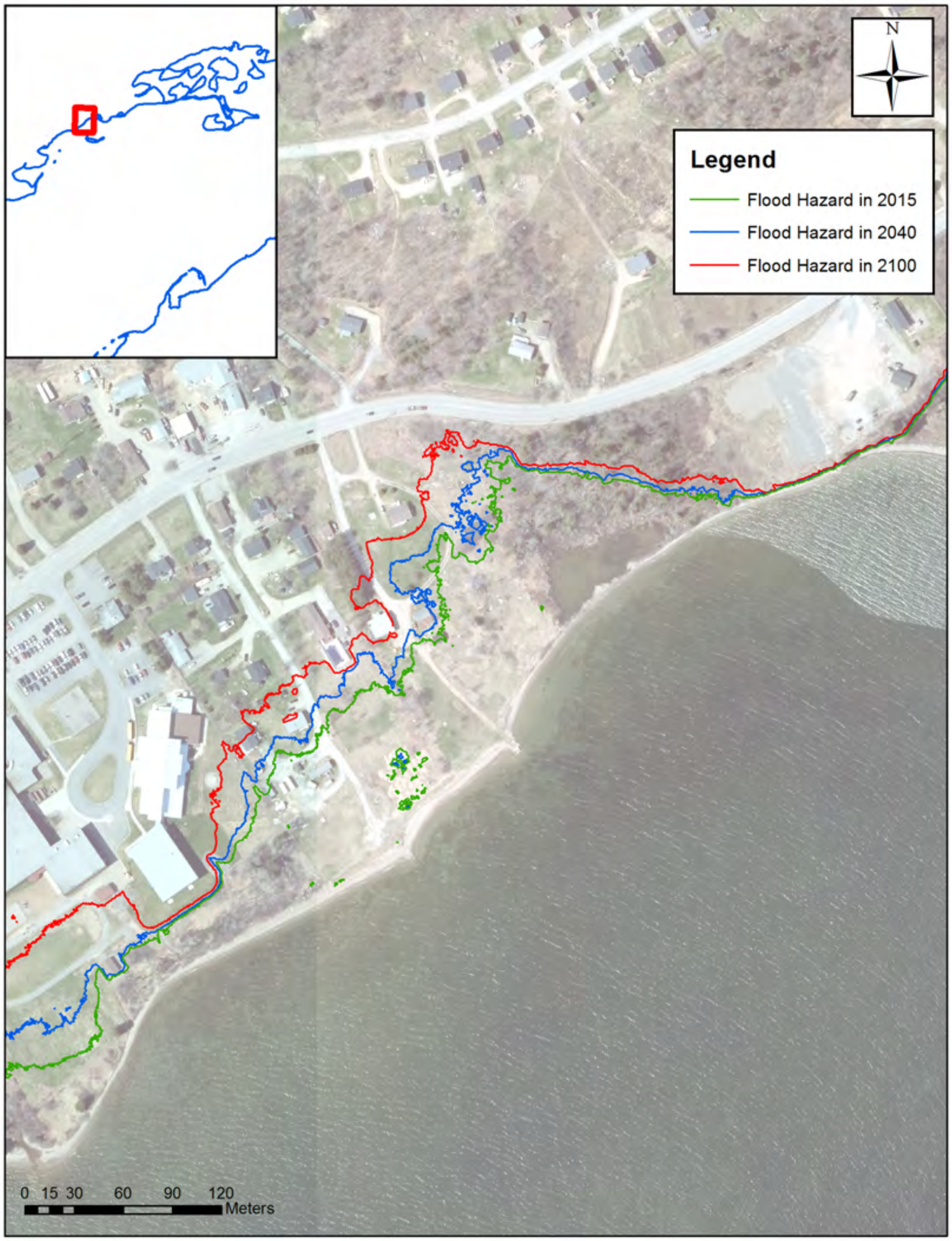

Figure 46 Eskasoni flood hazard (3/5)

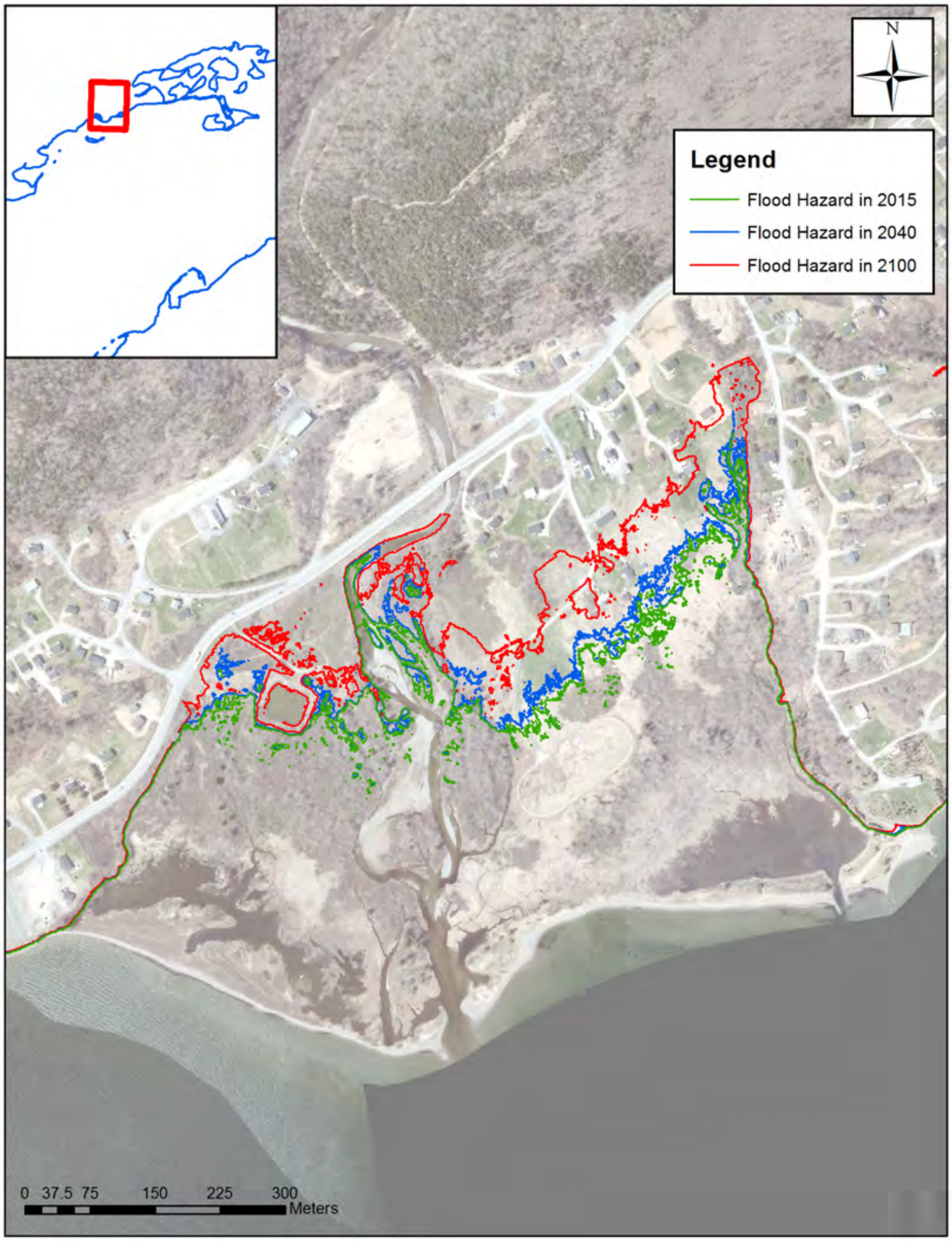

Figure 47 Eskasoni flood hazard (4/5)

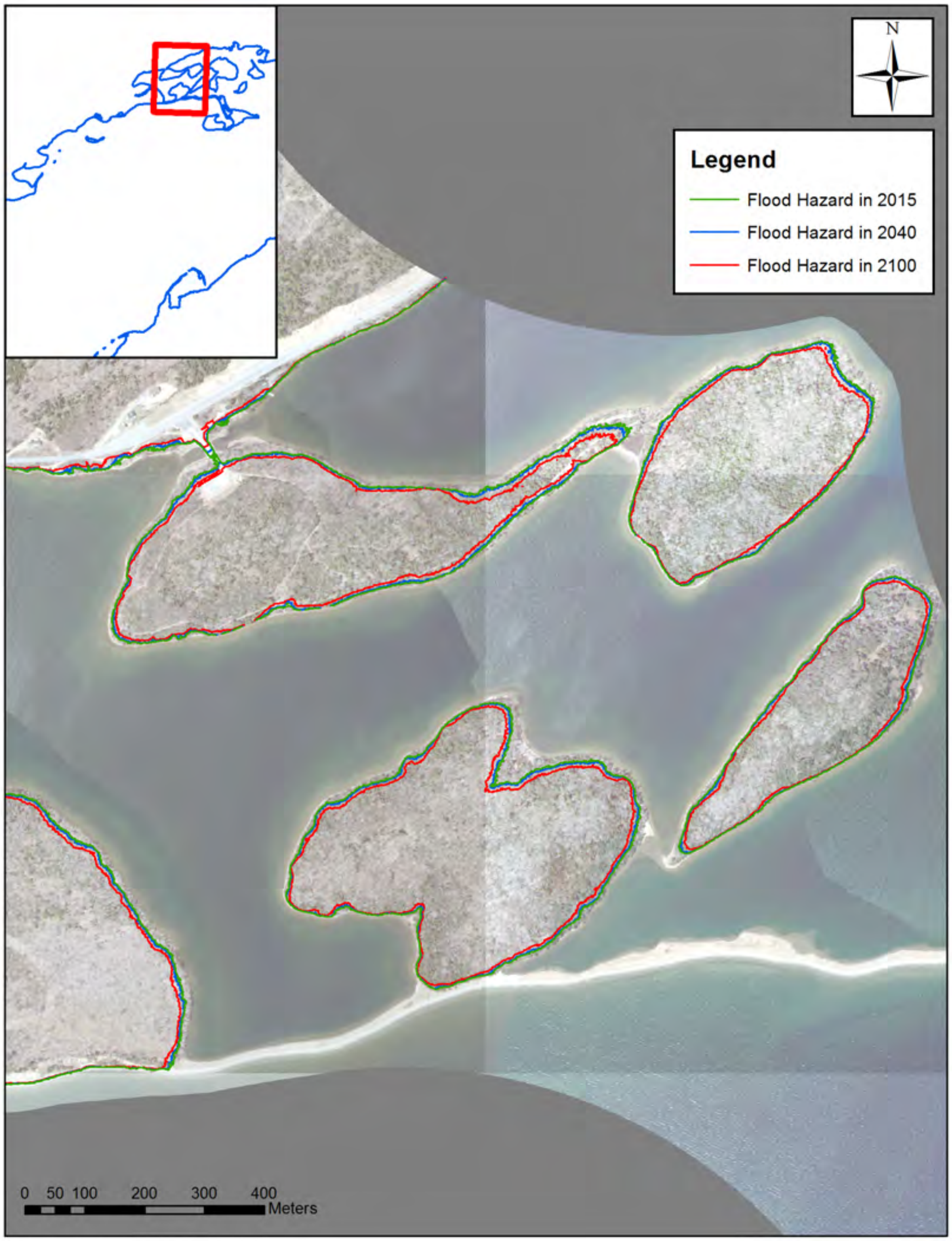

Figure 48 Eskasoni flood hazard (5/5)

Appendix C – TEK Workshop Proceedings

Impacts of Climate Change and Sea-Level Rise on the Mi'kmaq Communities of the Bras D'Or Lakes

Traditional Ecological Knowledge (TEK) Workshop

October 15, 2014

In attendance: Charlie Dennis, Albert Marshall, Murdena Marshall, Dianna Denny, Ernest Johnson, Dennis Isadore, Howard Jeddore, Joe Googoo, Judy Googoo, Noel Joe Gould, Cameron Paul, Norman Basque, Daniel Paul, Terry Denny, Susie Marshall

UINR held a Traditional Ecological Knowledge (TEK) workshop with elder's from the 5 Mi'kmaq communities in Cape Breton/Unama'ki. The Unama'ki Institute of Natural Resources (UINR) represents the five Mi'kmaq communities of Unama'ki and was formed to address First Nation's concerns regarding natural resources and their sustainability. The purpose of the workshop was to gather TEK on observed changes in the severity and frequency of storms or changes in the natural patterns in the environment. The TEK gathered on storm surges will be used to compliment the work being conducted on storm surge modeling. It should be noted that the views in this workshop are those of the participants and do not represent those of the entire Mi'kmaq nation.

The workshop began with an opening prayer by Albert Marshall. An overview on current climate change concerns was given by Pie'l Lalo San Paul and Nadine Lefort. Charlie Dennis explained to the elder's the purpose of the meeting and how the information will be used to compliment the work UINR was doing on climate change impacts on the Unama'ki Mi'kmaq communities. The elders were given a number of questions (attached) to aid in the discussion on climate change. Topics included frequency, timing and strength of storms as well as observational changes in seasons and natural patterns.

Storms

Storms are more frequent but are shorter in duration. Storms use to last up to 48 hours but now we get the same impact in a shorter period of time. At one time people used to be housed up at home for 3-4 days, now we are out after a day. There were several storms where it would last up to a whole week. The impact of storms is more severe now than it was ever before. High water levels are causing lots of flooding in several areas. In 2004 water levels in Potlotek (Chapel Island) reached near the church, most of the cabins on the east side of the island were flooded under water. These levels stayed up to around 2 weeks.

In 1929 there was a severe storm; they called it the famous "August Gale" (Kuwik). It almost destroyed the cabins at Chapel Island. There was also mention of a storm in the early 1970's during the month of October which caused a lot of damage all over Cape Breton Island.

Erosion is also a big problem that people encounter. If there is no ice present during the winter months then there is no barrier to protect the unstable shorelines. For the last 7 years we have had no ice in

Bras d'Or lakes except for last year when we had a cold spell. Around 20 years ago you would see 2-3 feet of ice everywhere. Most Elders believed that storms are getting worse. There was recollection of flooding after many days of rain. Now rain storms are over within 24 hours.

Changes in Seasons

It was observed that seasons are starting at different times. People used to gather bunchberries during piamu'nkue'kimk, now they're out in mid-august where they used to be out in October. Some of the Elder's commented that the budding of the trees is also a month later than usual. This year it was about a month behind growing season, because of the long winter we had. We will see how long this winter will be.

Salmon are late because the water is too warm. There has been a high count in striped bass. Flooding was believed to be increasing due to clear cutting. They used to be able to plant potatoes around May 20th of each year, now they are planting them in mid-June because of the frosty nights. One elder spoke of a friend's father who used a slingshot shaped piece of alder to look for water. She believed that there is more water than there used to be before.

In early April tupsi (alder) use to be available to eat when going hunting, but there isn't that much available anymore. Quanchl (hazelnuts) used to thrive, but now they are difficult to find anywhere. December used to be called "Aqtapu" (halfway through winter), now it occurs mid-February. According to one elder the meaning is three moons, now it's off by two months.

When beavers and muskrats are making their homes, it was a sign that winter was coming. If they were to make their homes in the middle of the pond, we were expecting a hard winter. Beavers didn't build their homes in mountains if they were expecting a lot of snow.

Last year was the first real winter in a long time (2014), seems like the weather is correcting itself. This past winter was about the same winter as winters from about 15-20 years ago. In 2010 the water was 2-3ft higher than normal for about 3 weeks. The temperature also was up about 3 degrees more than normal. In the winter the water was colder, but there was no ice.

Around 50 years ago there was a piece of land that was used to fish called "Netquik", but now it's gone. They used to siku'ka'tisink (pick grass) there.

When it's -10 or -15, go to a river the rocks underneath are frozen.

Lakes and ponds have been frozen over, but not so frozen that trucks can drive on the ice as in the past. Temps are not cold enough for thick ice.

In the last 3 years the water level has been rising. Trapping along the water is harder, not many kataq (eel) in Wagmatcook (Nyzana), but there is more Jikaw (stripe bass).

In Waycobah bay, if there is no ice then the water temperature drops at a dangerous rate. When the ice covers the bay then the water temperature stays normal for healthy fish growing. You need more fresh water to cover the lake or bay to get ice, if there is more salt water then you will have less ice coverage.

Elders also commented that there are number of different species in the lakes that are not supposed to be in there. Elders commented that the lakes must be getting warmer, because of the lack of the Atlantic cod. In certain places the eel has disappeared, but some areas still have them.

The water may be too warm, which in turn caused a lot of the oyster to die.

Natural Patterns

When there were big snowflakes coming that's when rabbits were out, they called it "Aplikumjowiksaq." When there's a storm coming, birds come into the shore.

One elder shared that they used to observer Seagulls flying to the west, and they would ask their Grandfather what was happening to the Seagulls, and he commented that they are flying to greet the storm and sure enough later in the day wind and rain would come.

Oyster fisherman used to say that if you see birds mainly the cormorant drying their wings while perched on an old pole or a wharf, that's a sure sign you will not be able to gather oysters for days. If you see those sun rays through the clouds forget about oyster fishing for a few days.

He would also observe the leaves on trees and when you hear the leaves dancing you have wind and unsettling weather coming.

After a thunderstorm there wouldn't be any eel around as they would go into deeper water, so it would be recommended not to go eeling for a few days.

When there was rain coming there would not be that many blue jays around. One Elder commented that when they observed blue jays making shrilling noise it was a sure sign of rain. Another person mentioned that she was observing squirrels chattering and running all over the place, this was also a sign of unsettling weather. If there is a storm coming no animal will be calm.

When high winds were coming kwimu (loons) would move to smaller areas.

When fireflies come out in the beginning of spring that is when you start collecting muskwi (white birch).

Some Elders commented that rabbits tend to be more active just before a storm, because they want to feed as much as possible before snow comes. One Elder claimed that there are porcupines in Cape Breton because a dog came home filled with porcupine quills around its nose.

An old tale about "Puoin" that he exiled porcupines and skunks from Cape Breton because they had tortured a man with quills and spray. So the puoin (friend of a priest) exiled the animals from Unama'ki.

Eagles are fishing on nice days. There was a bird smaller than an eagle called "pipukwes", used to see them fishing all the time don't see them much anymore.

Peju (cod) used to come to the surface and eat little red bugs stuck to moss. If animals aren't out after the storm then you know it's not over. If atutuwej (squirrels) are stingy with their food you know there is a storm coming. When you look across the water, spruce trees will appear black when it's going to rain. Fish won't bite during southeast winds. Alder turns red when freezing rain is coming. Ring around the moon (awialusink) means it will rain or snow a day and a half.

When clouds look like sheep, high winds are coming. Mackerel scale sky meant that high winds are coming.

Animal's homes are bigger when bad weather is expected.

One time ago the best time to trap foxes is a couple days before a storm that is when the fox is careless, because they just want to fill up with food before hard times.

One elder commented that the Otter is more active during storms and they spend a lot of time in small ponds just playing around, that is when they are easy to trap.

Over the last few years it was noticed that some of the Canada Geese are not flying up North to nest, they are having their young on the shores and marshes in Bras d'Or lakes. This was believed to be because there is more open water than before. One time they would stay for a while and then they would move either to the South or North. There were so many at one time that when they flew by in the fall they would block the sun. It would stay dark for a minute or two.

Fall starts later than usual. Winter has been about a month behind, but last year it was on time.

Plamu (salmon) are about 10 days late in We'koqma'q. Hazelnuts normally get ripe in early September, but this year they were a month early. Bunchberries are 2 weeks to 1 month early.

Cranberries are usually ready in November, now they are ready in early October.

Atomkomink (strawberries) and kwiman (blueberries) used to be indicators as they were ready at a certain time, now the pattern is all different depending on the weather. Kapaqte'jkl (gooseberries) are not where they used to grow.

When its windy at the beach, eels are plentiful in Qataqnko'qwitijik. Eels are headed for the mud.

There is an abundance of plants on the ground level where there were hardly any plants before, now a variety of plants are overabundant. This was observed this year and last year.

Purple angelica used to be a rare find now they grow pretty heavy. Jikijijk (Periwinkle) are abundant. Elephant leaves are abundant. Pakosi (water lily) used to be at the beach but not anymore.

Bras d'Or lakes used to be a big spawning ground for aquatic life, not so much now. It may be a combination of habitat, over fishing, environment, etc.

Air currents and wind direction seemed to have changed, because it doesn't go north anymore it goes around us now in circular currents.

Not a lot of softshell clams, maybe because green crab has decimated the population. There used to be a lot of mussels (kata'skl) at the island not anymore.

Because of warming trends habitat in the Bras d'Or lake is changing. There is a lot of siltation building up where one time there was a rocky bottom. There used to be so many lobster people just didn't know what to do with them. People were dumping market lobsters by the tons on their fields, using it for fertilizer. Now today there is only a few lobster licenses left in Bras d'Or Lakes and fishermen are having a hard time making a living off lobster.

If you see muskrat's building push ups or huts in ponds or swamps it's a sure sign it's going to be a good winter. If you don't see these huts it means the muskrats are building along banks or mounds off the shore line. This is the same for the Beaver.

Along the shores of Nyanza bay people used to harvest hay 50 years ago, along the marsh next to their community now that's all under water.

For years an Elder had been setting traps along the shores and ponds of Middle River but now his favorite spots are all under water because the water levels are too high.

The bear population has increased the last few years especially around the area in Whycocomagh Hills and the Highlands. Eels are starting to come back and more eels are seen when they are torching for them at night. This year eels are feeding and before they would be in the mud by now. Water temperature is still around 15 degrees. Oysters are slowly coming back, they are seeing more on the wild beds. More oyster seed is being observed on eel grass and other materials such as stones, rocks, and shells of all kinds.

The number of striped bass in the Bras d'Or Lake has increased and also in the freshwater tributaries. The sizes of the bass are from juveniles to those in record numbers. They were not sure if this has to do with warm water temperatures.

Impacts of Climate Change and Sea-Level Rise on the Mi’kmaq Communities of the Bras D’Or Lakes

TEK Workshop Questions
Eskasoni, Oct 15, 2014

Storms

1. Do we have more storms now than we used to?

2. When we have storms, do they last longer (for more than a day or two)? Or did storms in the past last longer?

3. When we have storms, what kinds of impacts are you seeing (high water levels, flooding, erosion)? Is it better or worse than it used to be?

Season

4. Have you noticed any changes in season? For example, have you notice changes with spring budding of trees? Or is winter starting at a different time?

5. Have you noticed changes with water temperatures or ice conditions on the Bras d’Or? Does it freeze in different places?

Natural Patterns

6. What animals gave cues about storms? Is it different for different types of storms? (or in different season?) Have you noticed any changes in these cues lately?

7. Have you noticed other patterns changing in our environment Do you see a difference in animal behaviours? Are spawning or mating behaviours changing? Are plants growing in different areas?

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