Quinte Conservation Shoreline Management Plan

Prepared for:

Quinte Conservation

June 21, 2022

Prepared by:

Zuzek inc.
ONE WORLD

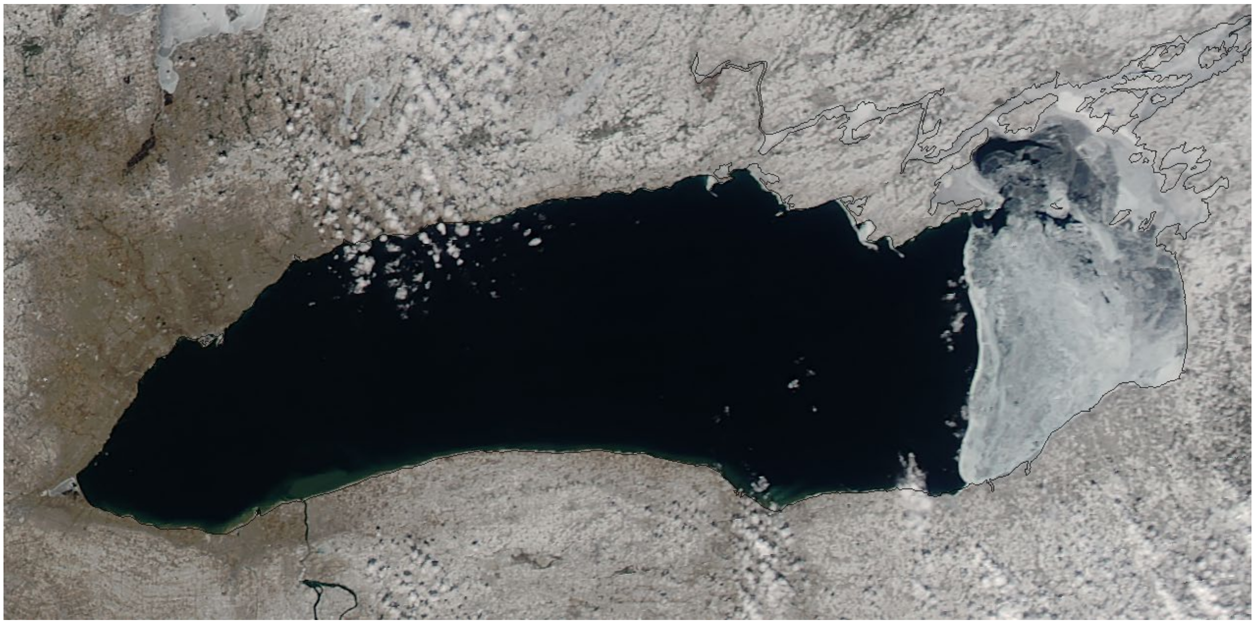
In association with:

SJL ENGINEERING

DHI

Terraprobe
an Englobe Company

Winter Ice Cover in the Bay of Quinte and Kingston Basin



PROFESSIONAL GEOSCIENTIST
PETER J. ZUZEK
PRACTISING MEMBER
1121
ONTARIO

P. Zuzek, P.Geo.
June 27, 2022

LICENSED PROFESSIONAL ENGINEER
S. J. LOGAN
100189144
Jun 21, 2022
PROVINCE OF ONTARIO

Disclaimer:

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EXECUTIVE SUMMARY

The Quinte Conservation (QC) shoreline is located on the northeast shore of Lake Ontario and includes a significant portion of the Bay of Quinte. Refer to the map below for the QC boundary and neighbouring Conservation Authorities. Zuzek Inc. in partnership with SJL Engineering Inc., DHI Water & Environment Inc., and Terraprobe Inc. were retained to prepare a Shoreline Management Plan (SMP) for QC.

The Planning Act (1990) and Conservation Authorities Act (1990) provide the legislative framework for QC to develop programs to regulate development on hazardous lands and by extension develop this SMP. In recognition of the broad geography and varying shoreline conditions throughout the study area, the QC shoreline was sub-divided into 16 reaches with updated shoreline hazard mapping and shoreline management recommendations developed for each (see map below).

Field work for the study commenced in the summer of 2021, which followed two recent years of record setting water levels on Lake Ontario in 2017 and 2019. These high water periods highlighted the vulnerability of the QC shoreline to flooding and erosion hazards. Updated statistical analysis of measured lake levels resulted in new higher 100-year flood levels for the Cobourg and Kingston water level gauges. Detailed storm surge modelling was completed to evaluate gradients in water levels between the gauges during severe storms and establish new spatially varying 100-year flood levels for the individual shoreline reaches. Wave uprush calculations were completed for 77 locations throughout the geography. This information was used to update the flooding hazard limit throughout the 16 shoreline reaches.

Historical aerial photographs were georeferenced and compared to recent orthophotography to calculate new long-term recession rates for the erodible bedrock shores and beaches in the study area, with measured recession rates ranging from 0.10 m/yr to 0.42 m/yr. A fixed stable slope angle was established for the bedrock shorelines (1.75H to 1.0V) based on published data and field observations. Collectively, this new information was used to map the erosion hazard limit throughout the study area for the first time.

Additional technical analysis and field work completed for the study, including the generation of a new nearshore wave climate, wave uprush calculations, and the review of over 4,000 oblique aerial photographs collected for the project were used to identify and map the dynamic beach hazard limit where appropriate. This hazard had not previously been mapped within the QC jurisdiction. Development and site alterations are not permitted within the dynamic beach hazard limit.

Due to the COVID-19 pandemic, public engagement was structured around online tools and platforms to gather valuable insights from landowners and stakeholders. Erosion and flooding impacts increased dramatically in 2017 and 2019, as did impacts to wetlands and beaches. Meeting participants were very interested in working further with the Conservation Authority to understand these impacts and to develop options to reduce impacts from natural hazards in the future.

Based on the results of the technical analysis, updated hazard mapping, and feedback from the public consultation, shoreline management recommendations were prepared for the 16 shoreline reaches. Approaches to reduce future risks, increase resilience to coastal hazards, and protect natural shorelines were developed. Five key principles and approaches to mitigate coastal risks were highlighted, including protecting natural shorelines, avoiding further development on hazardous lands, accommodating risks for existing development, retreating and re-aligning land uses, and protecting shorelines with nature-based solutions and traditional engineering structures.

With the completion of the SMP, new applications for development or site alteration along the QC shoreline will be evaluated using the updated hazard mapping and other recommendations in the plan. It is recommended that the SMP be adopted into local Official Plans, and that future land use planning consider not only the updated hazard mapping produced as a component of this study, but also the impacts of climate change as discussed in Section 4.5 and as directed by the Provincial Policy Statement (PPS, 2020). Further local studies have been recommended to address eroding road infrastructure, emergency access challenges for low-lying developments, and to improve beach management practices, for example. Wherever possible, natural shorelines should be preserved, and new development and site alterations should be directed away from hazardous lands.

GLOSSARY

Barrier Beach – narrow, low-lying strip of beach and dunes that separate a large body of water (e.g., Lake Ontario) from a smaller water body such as an inland embayment, river outlet, marsh, or lake.

Dynamic Beach – portion of the shoreline featuring sediment transported by wave action, extending offshore to the limit of wave action on the underwater bed and onshore to the limit of the dynamic profile adjustments, consisting of beach material and associated dune systems potentially subjected to reshaping during periods of high water levels and intense storms.

Embryo Dunes – part of a healthy dune system, embryo dunes are newly formed dunes located lakeward of the foredune and at the back of the dry beach. Wind blown sand is transported to the embryo dunes from the dry beach and stabilized by vegetation.

Foredunes – principal dune ridge that forms landward of the dry beach and embryo dunes. Typically, they are vegetated with native grasses and shrubs that can survive disturbances from wind and waves. Foredunes are generally stable under average lake levels conditions but can erode during storms at high lake levels.

Shoreline Hardening – the introduction of man-made features to a shoreline including protection or other development/alterations that prevent the shoreline from behaving naturally in response to coastal conditions (i.e. the opposite of a natural shoreline).

Shoreline Armouring – the presence or implementation of erosion protection structures constructed on the shoreline with the specific purpose of preventing or mitigating shoreline erosion, flooding, or both.

Stable Slope – the condition and angle at which an inclined slope can withstand its own weight and external forces without experiencing displacement, erosion, or failure.

Toe of Slope – the lowest elevation and furthest lakeward portion of an inclined slope. The toe of slope often defines the transition to a flatter beach or land surface.

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PROFESSIONAL GEOSCIENTISTS
PETER J. ZUZEK
PRACTISING MEMBER
1121
ONTARIO

P. Zuzek, P.Geo.
June 27, 2022

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1.0 INTRODUCTION

Quinte Conservation's (QC) jurisdictional boundary covers more than 6,000 square kilometres and includes the Lake Ontario shoreline around Prince Edward County and the Bay of Quinte shoreline within numerous Municipalities, as noted in Figure 1.1. The boundary of the neighbouring Conservation Authorities to the west and east (Lower Trent and Cataraqui, respectively) is also noted on the map. Zuzek Inc. in association with SJL Engineering Inc., the Danish Hydraulic Institute (DHI), and Terraprobe were retained by QC to develop this shoreline management plan (SMP). Several components of the study including wave modelling, storm surge modelling and wave uprush analyses were also completed for the Cataraqui Conservation Authority and documented in a separate report (SJL, 2022).

Figure 1.1 Study area location map

The remainder of Section 1.0 summarizes the principles and objectives of this SMP and recent flooding and erosion impacts related to the record high lake levels experienced throughout the QC region in 2017 and 2019.

1.1 Principles and Objectives of the Plan

The development of the Quinte Conservation SMP was guided by the principles and objectives outlined below and the legislative requirements outlined in Section 2.0.

Principles:

- Sustainable Coastal Development: strives for a sustainable balance between the environment, society, and the economy when making management decisions along the shoreline and planning for new development.

- Integrated Coastal Zone Management (ICZM): ICZM is a dynamic, multi-disciplinary, and iterative process of promoting the sustainable management of our coastal zones. ICZM seeks, over the long-term, to balance environmental, economic, social, cultural, and recreational objectives, all within the limits of a dynamic coastal ecosystem. ICZM and by extension this SMP, provides policy direction and a process for protecting coastal development and maintaining healthy coastal ecosystems. Management decisions within the coastal zone should be framed within littoral cells, sub-cells, or reaches that define the movement and deposition of sediment along the shoreline. If sediment transport is not a dominant process, management recommendations should be developed for shoreline reaches with similar physical, ecological, and land use characteristics.

Objectives of the Shoreline Management Plan:

- Preserve natural shorelines and geodiversity.
- Maintain sediment supply to local beaches and barrier beach ecosystems.
- Update coastal hazard mapping using the best available data and technical analyses to protect new development from coastal hazards.
- Investigate climate change impacts on coastal hazards and provide recommendations to consider in future planning studies.
- Develop reach specific coastal management recommendations to protect nature, avoid future development on hazardous lands, reduce risks for existing development, and protect buildings and infrastructure exposed to coastal risk through nature-based solutions, grey-green hybrid solutions, and traditional engineered structures.
- Protect and enhance existing public infrastructure and amenities along the coast.
- Increase the resilience of coastal communities and beaches.

1.2 Recent Flooding and Erosion Impacts

Lake Ontario established a new record high in 2017, which lasted only two years until an even higher high was established in June of 2019. The extreme lake level conditions in the summer of 2017 and 2019 were the result of record high water supplies to the Great Lakes system, and resulted in extensive flooding across the Canadian and United States Great Lakes shorelines. This included portions of the QC shoreline of Lake Ontario and the Bay of Quinte.

Examples of flooded properties in the Bay of Quinte are provided in Figure 1.2, where static lake levels inundated shoreline properties in numerous locations. Inundation of the lake shoreline also occurred in Prince Edward County, as did bank erosion along several roads (Figure 1.3).

Hennessy Street, Belleville

Yacht Club Road, Deseronto

Figure 1.2 Bay of Quinte flooding in 2019

Brewers Road, Prince Edward County

Bank Erosion at Road

Figure 1.3 Lake Ontario flooding and bank erosion

1.3 Report Structure

The report is organized into eight principal sections and covers the legislation and technical direction guiding the SMP, field investigations, coastal data acquisition, technical analysis, hazard mapping, public and partner engagement, shoreline management recommendations, and study conclusions and recommendations. The QC shoreline has been divided into 16 reaches (sections), with a summary of each shoreline reach provided, including local conditions, shoreline characteristics, natural versus hardened shoreline, infrastructure vulnerability to natural hazards, variables for hazard mapping, and shoreline management recommendations. Please contact Quinte Conservation for additional details not presented herein or copies of the shoreline hazard mapping.

1.4 Conversions Between Vertical Datums

Table 1.1 outlines the vertical datum conversions between the 1985 International Great Lakes Datum (IGLD'85) and the Canadian Geodetic Vertical Datums (1928 and 2013).

Table 1.1 Vertical datum conversations for the study area

Datum Conversion	Calculation
Convert IGLD’85 Elevation to CGVD2013	Subtract 0.4 m from IGLD’85 to get CGVD2013
Convert IGLD’85 Elevation to CGVD28	Subtract 0.05 m from IGLD’85 to get CGVD28
Convert CGVD2013 Elevation to IGLD’85	Add 0.4 m to CGVD2013
Convert CGVD28 Elevation to IGLD’85	Add 0.05 m to CGVD1928

2.0 LEGISLATION AND TECHNICAL DIRECTION

The relevant legislation and technical documents that guide shoreline management and hazard mapping are reviewed.

2.1 The Planning Act and Provincial Policy Statement

The *Planning Act* (1990) is an important piece of provincial legislation that outlines the municipal planning process in Ontario, promotes sustainable economic development, and protection of the natural environment. The Act integrates matters of provincial interest and outlines how official plans are prepared by Municipalities. It also outlines the process of regulating land uses through zoning bylaws and variances and outlines the process for subdividing land. Local citizens must be informed about the planning process in their community, are encouraged to provide feedback, and can appeal decisions to the Ontario Land Tribunal.

The *Planning Act* gives the Province of Ontario the authority to develop and issue a Provincial Policy Statement (PPS), with the latest update released in 2020. The PPS recognizes that Ontario's long-term prosperity requires resilient communities supported by strategic development plans, protection of natural resources, and sustainable economic growth. The PPS is a key part of Ontario's policy-led land use planning system and sets out the policy framework for municipalities to regulate the development and use of land. To ensure healthy and resilient communities, the policy statement recommends: 1) avoid development patterns that cause negative environmental impacts or safety concerns (such as developing on hazardous lands), 2) promote development in existing settlement areas to avoid unnecessary land conversions (e.g., avoid conversion of agricultural land to urban land), and 3) promote development that conserves native biodiversity.

To promote healthy and active communities, the PPS recommends maintaining existing and providing new public access to our shorelines. Existing Provincial Parks, Conservation Areas and other natural areas must be protected from negative impacts associated with new development. The linkages between the protection of Ontario's natural heritage system and long-term environmental health and social well-being are also highlighted, including the following recommendations:

- Natural features and areas (e.g., Provincially Significant Wetlands) shall be protected for the long term.

- The long-term ecological function and biodiversity of natural heritage systems should be maintained, restored, and improved where possible.

- Development and site alterations shall not be permitted on wetlands, fish habitat or habitat of endangered and threatened species.

The shoreline of Lake Ontario represents an area, as identified in the PPS, where the diversity and connectivity of natural features and their long-term ecological function should be maintained, restored, or improved in recognition of the linkages between natural heritage features and areas, surface water features and ground water features. To implement this PPS requirement, development and site alteration is not permitted in significant wetlands (coastal or otherwise) and may only be permitted in certain other features if it has been demonstrated that there will be no negative impacts on the features or their ecological functions.

The Conservation Authorities have a delegated responsibility with respect to Section 3.1 of the PPS to ensure that development is directed away from areas of natural or non-manmade hazards where there is unacceptable risk to public safety, property, or assets, such as buildings. Development shall be directed, in accordance with guidance developed by the Province (as amended from time to time), to areas outside of hazardous lands adjacent to the shorelines of the Great Lakes which are impacted by flooding hazards, erosion hazards or dynamic beach hazards. More explicitly, development and site alteration shall not be permitted within the dynamic beach hazard and areas that would be rendered inaccessible to people and vehicles during times of flooding hazards, erosion hazards, or dynamic beach hazards. Furthermore, planning authorities shall prepare for the impacts of a changing climate that may increase the risks associated with natural hazards. Finally, development and site alterations must not create new hazards, aggravate existing hazards, or result in adverse environmental impacts.

The PPS was revised effective May 2020 following recommendations of the Provincial Special Advisor on Flooding “to recognize that mitigating risk to public health or safety or of property damage from natural hazards, including the risks that may be associated with the impacts of a changing climate, will require the Province, municipalities and Conservation Authorities to work together”. It should also be noted that Section 3.1.3 was revised to include the following statement; “Planning authorities shall prepare for the impacts of a changing climate that may increase the risk associated with natural hazards”. In other words, if climate change projections suggest higher lake levels may be possible or that erosion rates may be higher in the future, this information should be integrated into planning decisions. At the time this SMP was published, the Ministry of Northern Development, Mines, Natural Resources, and Forestry (NDMNRF) was completing technical studies on the inclusion of climate change factors in regulatory hazard mapping. Presently, there is no published guidance on how to include the impacts of climate change when mapping flooding, erosion, and dynamic beach hazards in Ontario.

2.2 Conservation Authorities Act and Ontario Regulation 97/04

The responsibility and mandate Conservation Authorities (CAs) have to regulate activities on hazardous lands is outlined in Section 28(1) of the *Conservation Authorities Act* (1990). CAs have the authority to make regulations applicable to activities under its jurisdiction, such as prohibiting or regulating development if the control of flooding, erosion, dynamic beach, pollution, or the conservation of land may be affected.

Ontario Regulation 97/04 was developed under the *Conservation Authorities Act* in 2004 and requires CAs to develop their own generic regulations. The objectives of the regulations include:

- Minimize the potential for loss of life and property damage;
- Reduce the necessity for public and private expenditures for emergency operations, evacuation, and restoration of properties subject to flooding;
- Regulate flood plain and hazardous lands development that could limit channel capacity and increase flood flow, leading to emergency and protective measures;

- Make information available regarding flood prone or hazardous lands areas;
- Regulate the draining or filling of wetlands which may reduce natural water storage capacity;
- Regulate development on or adjacent to potentially hazardous slopes;
- Reduce soil erosion from valley slopes; and
- Minimize water pollution or degradation of water quality associated with filling, development, and alteration activities

For the coastlines of the Great Lakes, the limit of hazardous lands is defined as the furthest landward extent of the following:

- **Coastal Flooding:** the 100-year flood level plus an allowance determined by the CA for wave uprush and other water related hazards.
- **Erosion:** the future shoreline position accounting for shoreline recession over a 100-year planning horizon plus a stable slope allowance.
- **Dynamic Beach:** an allowance to accommodate dynamic beach movements over time.

The Regulated Area is determined as the greatest landward extent of the hazardous lands described above, plus an additional allowance determined by the Authority, not to exceed 15 m. The Authority may grant permission for development in the Regulated Area if, in its opinion, the control of flooding, erosion, dynamic beaches, pollution or the conservation of land will not be affected by the development.

2.2.1 Quinte Conservation Ontario Regulation 319/09

Quinte Conservation was granted its regulation number (319/09) in 2009 and it outlines Quinte Conservation's role with regulating:

- Development in river or stream valleys, wetlands, shorelines and hazardous lands and associated allowances.
- The straightening, changing, diverting or interfering in any way with the existing channel of a river, creek, stream, watercourse or for changing or interfering in any way with a wetland.
- Other areas where, in the opinion of the Minister, development should be prohibited or regulated or should require the permission of the Authority.

Section 2.0 of *Ontario Regulation 319/09* outlines the jurisdiction of QC and Section 4.0 summarizes the approach to hazard mapping along the shoreline, including the flood hazard, the erosion hazard, and the dynamic beach hazard. Guidelines for evaluating development applications near or on hazardous lands are also outlined in *Ontario Regulation 319/09*. Proponent of development or site alteration must follow the regulation and QC's Policy Manual (2019).

2.3 Guidance Documents

The technical methods followed in the SMP to assess coastal hazards and map the hazardous lands are based on the following documents.

2.3.1 Technical Guidance for Great Lakes – St. Lawrence River System (MNR, 2001a)

In 2001, the Ministry of Natural Resources and Forestry (MNRF) released the Technical Guide for the Great Lakes – St. Lawrence River System and Large Inland Lakes (MNR, 2001a). These guidelines provide the technical basis and procedures for establishing the hazard limits for flooding, erosion, and dynamic beaches in Ontario as well as scientific and engineering options for addressing the hazards.

This document is currently under review to consider the technical adequacy of the guidance and to evaluate options to integrate the impacts of climate change on natural hazards, as stipulated in Section 3.1.3 of the PPS (2020).

2.3.2 Understanding Natural Hazards (MNR, 2001b)

MNRF prepared Understanding Natural Hazards (MNR, 2001b) to assist the public and planning authorities with an explanation of the Natural Hazard Policies (3.1) of the Provincial Policy Statement under the *Planning Act*. This publication updates and replaces the older Natural Hazards Training Manual (from 1997).

2.3.3 Guidelines for Developing Schedules of Regulated Areas (MNR, 2005)

Additional technical information for establishing the boundaries of hazardous lands adjacent to the coastline of the Great Lakes are provided by Conservation Ontario and MNRF (2005) in a document entitled Guidelines for Developing Schedules of Regulated Areas. Additional technical information used to define hazardous lands and supplement the information in Ontario Regulation 97/04 is provided, including the following details relevant to this SMP:

- **Coastal Flooding:** in the absence of detailed technical information, the wave uprush limit is 15 m measured horizontally from the 100-year combined flood level.

- **Erosion:** the 100-year erosion allowance must be determined with a minimum of 35 years of shoreline recession data and the stable slope angle should be taken as 3:1 (H:V) in the absence of detailed, site-specific data.

- **Dynamic Beach:** in the absence of detailed technical information, the dynamic beach extent is the sum of the 100-year combined flood level, the 15 m wave uprush limit, and an additional 30 m allowance for the dynamic nature of beach movements.

3.0 FIELD INVESTIGATIONS AND DATA AQUISITION

The field work and data acquisition completed to develop the SMP are discussed in Section 3.0.

3.1 Oblique Aerial Photography

More than 4,000 photographs of the Quinte Conservation (QC) shoreline were captured during August and September of 2021. Although some photos were captured from a boat where no-fly zones were in effect (e.g., near Trenton Air Base), the majority of photographs were aerial oblique photographs captured using an unmanned aerial vehicle (UAV). All photos captured for the project were compiled into a georeferenced photographic database of the QC shoreline. The photo database was the primary source of information for the characterization of the project shoreline, as discussed in Section 3.2, including the development of a shoreline protection database. The photo database also provided the study team with the ability to view and assess portions of the shoreline that would otherwise have been inaccessible by land. Figure 3.1 provides a map showing the locations of all photographs captured for the project.

Figure 3.1 Locations of all georeferenced boat and aerial oblique photographs of the shoreline captured for the project

The UAV used to capture aerial oblique photographs featured a built-in camera with a 12.7 megapixel sensor, three-axis image stabilization and geotagging capabilities. Photographs were typically taken from an elevation of 40 – 60 m, a horizontal distance of 60 – 100 m offshore, and with shore parallel spacing of individual images such that overlap between photos was generally achieved. This allowed for complete shoreline coverage in most photographed areas with sufficient resolution to assess the shoreline characteristics including the presence and type of shoreline protection structures. Where appropriate, images were captured from a higher elevation to provide an increased range of view. This includes areas featuring large barrier beaches, coastal wetlands, or extended portions of shoreline with increased erosion or flooding risks. Sample photographs of the QC shoreline from the compiled photo database are provided in Figure 3.2 to Figure 3.5.

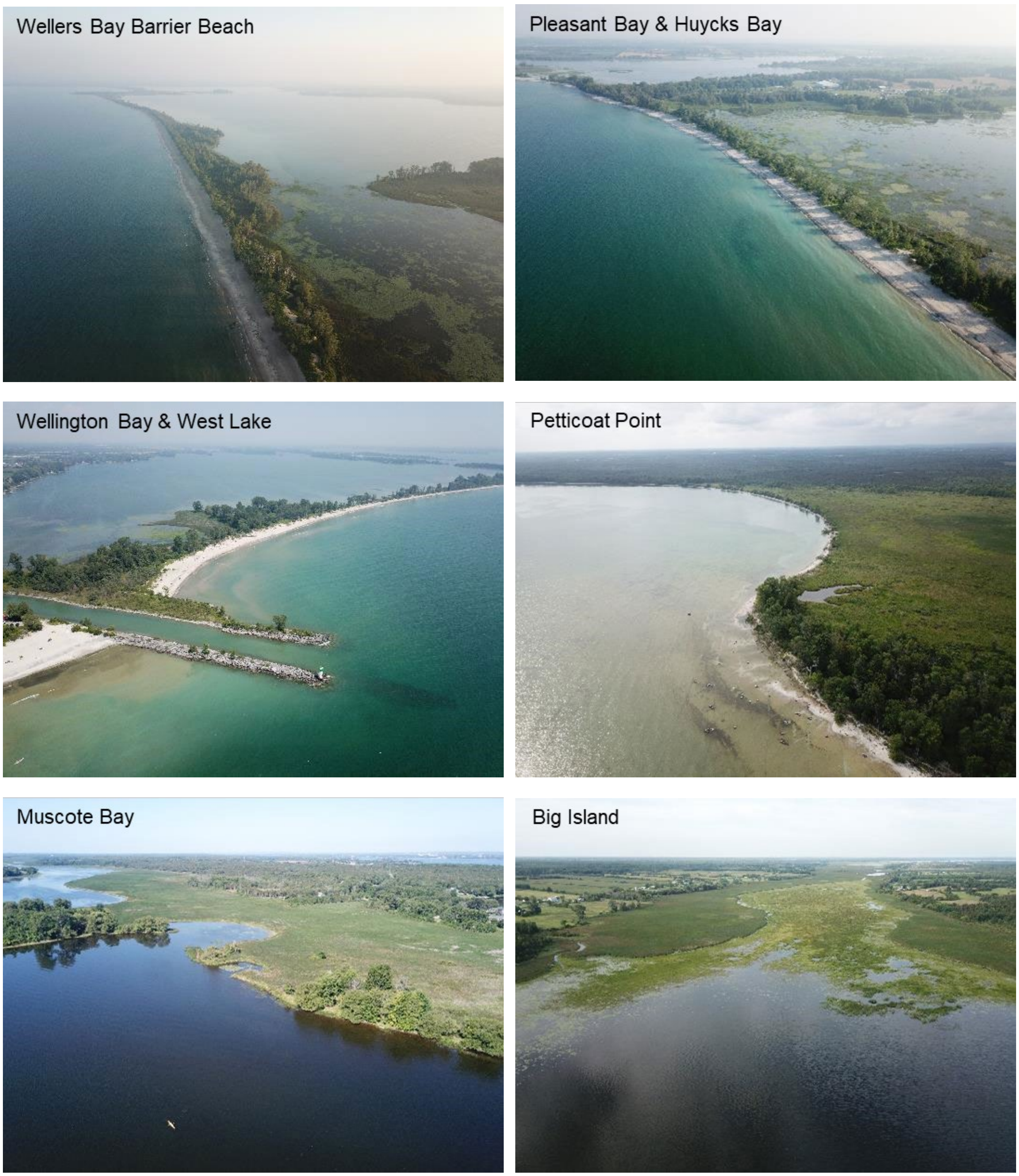


Figure 3.2 Examples of beach and wetland shorelines from the aerial oblique photo database (photographed Aug/Sep 2021)

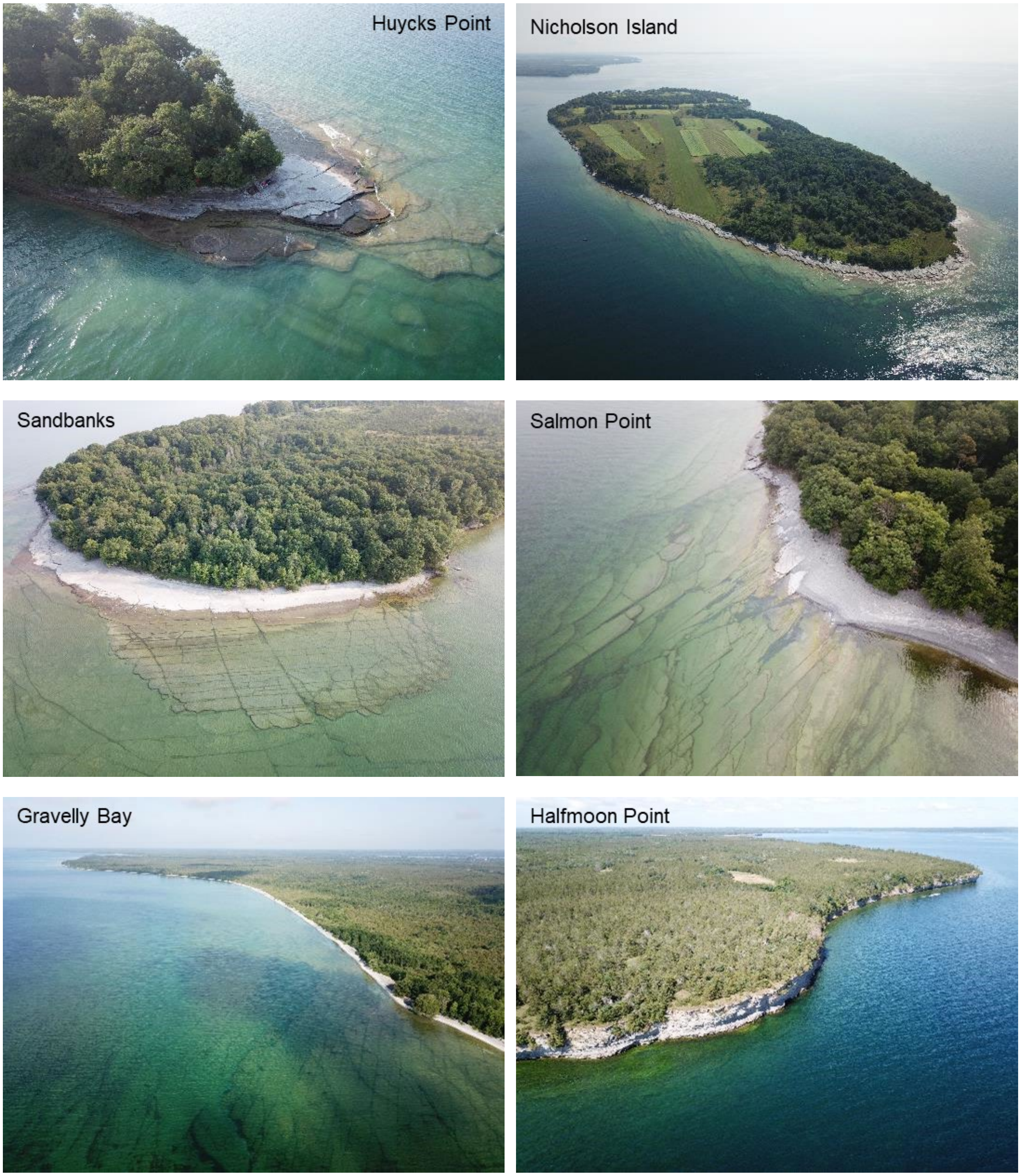


Figure 3.3 Examples of bedrock shorelines from the aerial oblique photo database (photographed Aug/Sep 2021)

Figure 3.4 Examples of steep bank and cliff shorelines from the aerial oblique photo database (photographed Aug/Sep 2021)

Figure 3.5 Examples of developed shorelines from the aerial oblique photo database (photographed Aug/Sep 2021)

3.2 Shoreline Characterization

The unique characteristics of the QC shoreline are described, including the bedrock geology, significant natural features, and assessment of natural versus hardened shoreline.

3.2.1 Role of Bedrock Geology

Prince Edward County is a large bedrock peninsula that consists of three limestone units, including the Verulam Formation, lower Lindsay Formation, and the upper Lindsay Formation (see Figure 3.6 and Figure 3.7). While harder and more erosion resistant than glacial till or glacial outwash deposits found to the west, the interbedded limestone and shale does erode through a variety of physical and chemical weathering processes, such as wave attack at the bank toe, freeze-thaw cycles, and desiccation (wetting and drying).

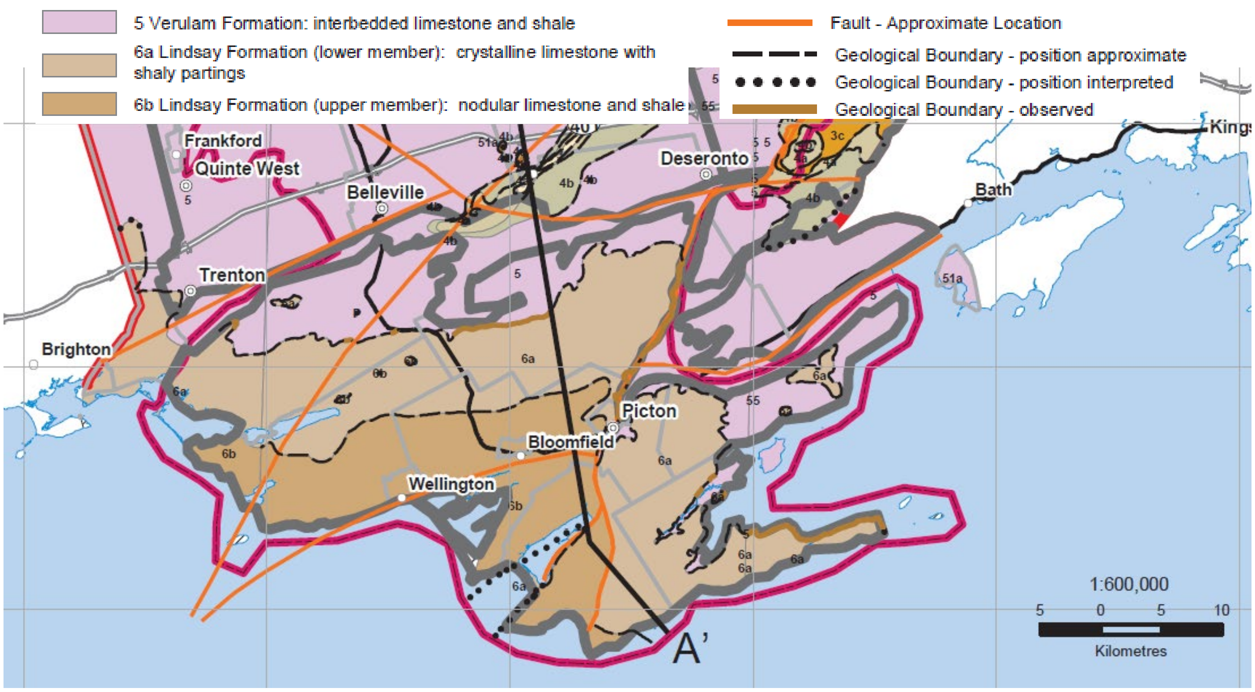


Figure 3.6 Bedrock geology of study area (source: Dillon)

Eroding limestone bank

Limestone shelf at base of seawall

Figure 3.7 Eroding limestone bank and shelf in study area

3.2.2 Significant Natural Features

The study area shoreline, including the lake and bay, is characterized by prominent bedrock headlands and sheltered embayments, as seen in the conceptual diagram in Figure 3.8 (left). The bedrock headland associated with Little Bluff Conservation Area and beach is also presented in Figure 3.8 (right). The embayments typically feature beaches, barrier beaches, and/or expansive coastal wetlands.

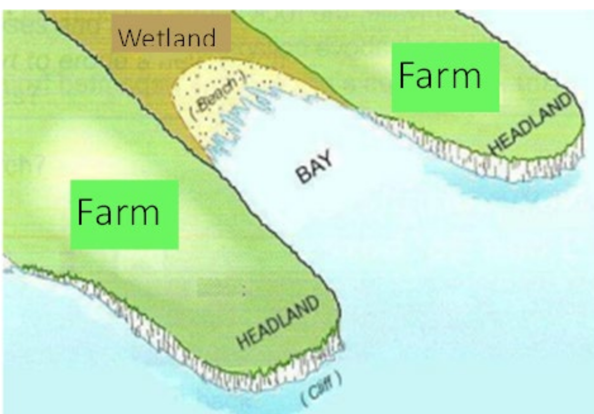


Figure 3.8 Conceptual diagram of a headland-embayment system (left) and headland at Little Bluff Conservation Area (right)

This unique combination of eroding bedrock headlands and nearshore lake bottom features, the physical processes responsible for eroding and transporting sand and gravel along the shoreline to beach environments, and the sheltered coastal wetlands is collectively known as geodiversity. The International Union for the Conservation of Nature recently provided best practice guidance for the conservation of natural areas and geodiversity, which emphasizes the protection of the physical environment including landforms and natural processes (Crofts, R. et al, 2020).

The study area also features a large number of provincially significant coastal wetlands and rare beach-dune ecosystems, such as those found at Sandbanks and North Beach Provincial Parks, and Wellers Bay National Wildlife Area. Refer to Figure 3.9. The southeast shoreline features Prince Edward Point National Wildlife Area, Timber Island Nature Preserve, and the False Duck Island Lighthouse on Swetman Island, which is a recognized Federal heritage building.

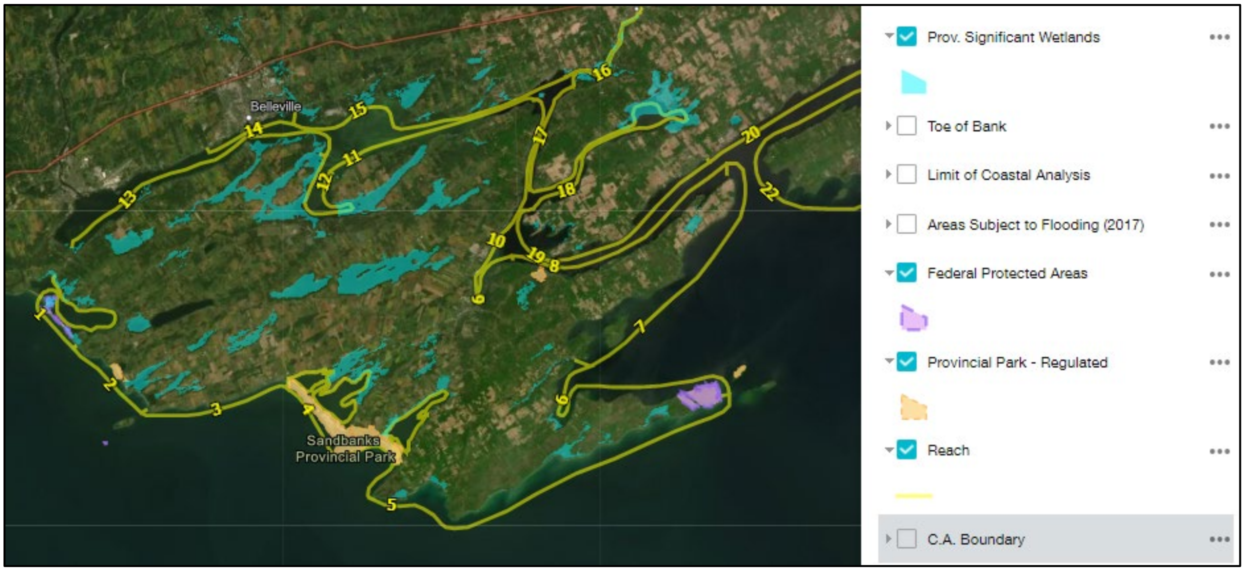


Figure 3.9 Provincially significant wetlands and federal/provincial regulated areas

The entire southeast shore of Prince Edward County and the northeast portion of the Bay of Quinte is recognized as an important bird area by Birds Canada. Refer to Figure 3.10. Just outside the limits of the SMP, the entirety of Presqu'ile Provincial Park to the west and Amherst Island to the east are also recognized as important bird areas.

Figure 3.10 Birds Canada Important Bird Areas

3.2.3 Shoreline Hardening

A comprehensive shoreline protection database was developed as a component of the study to document the state of the Quinte Conservation shoreline as of July 2021. The database was created primarily from the oblique aerial photographs discussed in Section 3.1. All major built-up areas and private property shore protection structures were included in the database. Of the more than 500 km of documented shoreline, approximately 82 km was deemed to be armoured, representing approximately 16% of the total project shoreline.

Each shoreline segment added to the database was delineated with start and end coordinates and assigned information including the following key parameters:

- **Shoreline type:** hardened or natural shoreline.
- **Significant natural feature:** the presence of a beach, barrier beach, bedrock headland, wetland, tributary, emergent shoal, etc.
- **Shoreline protection:** primary shoreline protection structure (i.e. stone bank protection, revetment, precast concrete seawall, sheet pile seawall, armour stone seawall, etc.).
- **Other significant shoreline infrastructure**: jetty, boat ramp, permanent dock, marina, etc.

The completed database was used to assess statistics pertaining to the project shoreline. Shoreline type and shoreline protection statistics were tabulated for each project reach and for the total project shoreline. Refer to Section 4.1 for the delineation of project reaches.

Across the entire Quinte region shoreline (more than 500 km), it was determined that approximately 16% of the shoreline featured some form of shoreline protection, with the remaining 84% being in a predominantly natural state. Of the areas that are protected, 48% were found to be simple stone bank protection (typically not engineered). The next most common shoreline protection types were cast-in-place concrete seawalls, armour stone seawalls, and engineered revetments, at 13%, 11% and 10% of the armoured shoreline, respectively. Sample statistics from the shore protection database are provided in Figure 3.11 and Figure 3.12. The entire shoreline protection database including tabulated statistics has been provided to the Conservation Authority in digital form. The provided shore protection database and all presented statistics are reflective of the state of the shoreline in July 2021. Statistical summaries of each project reach are provided as a component of the reach summaries featured in Appendix A.

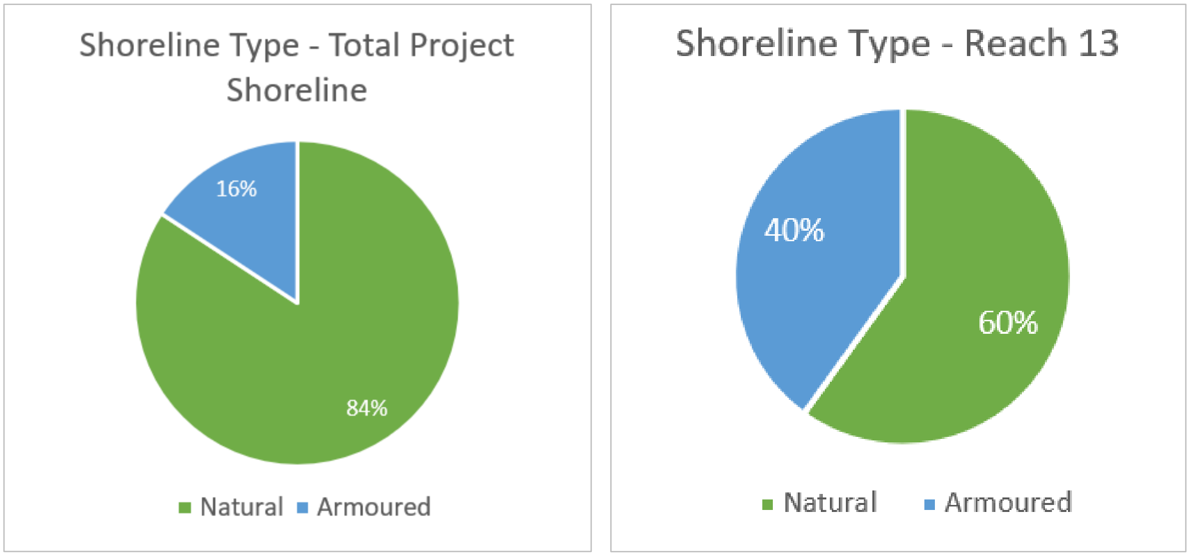


Figure 3.11 Shoreline type statistics for the total project shoreline (left) and Reach 13 (right)

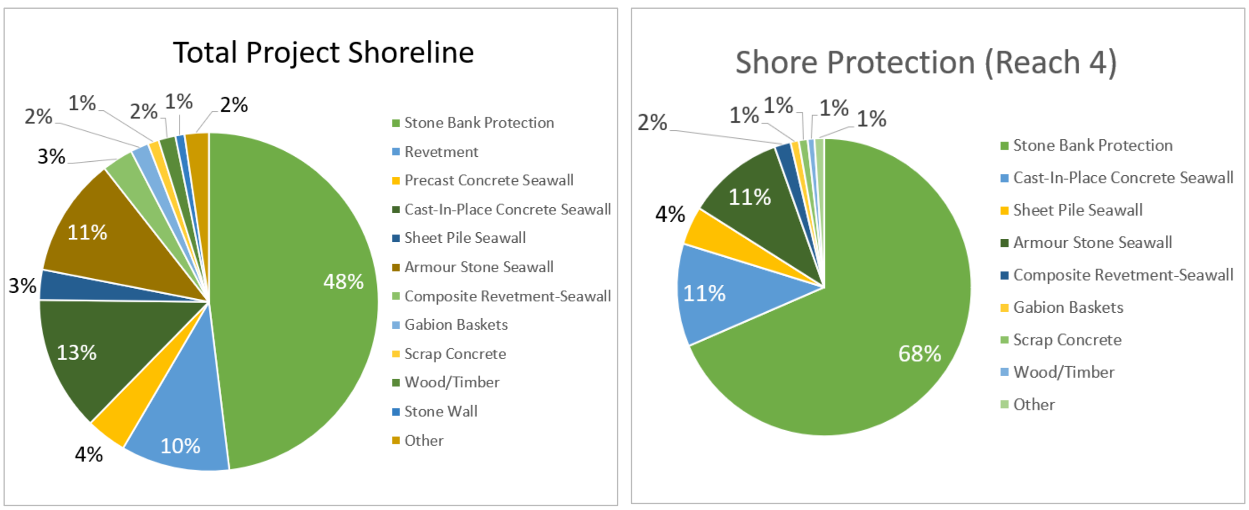


Figure 3.12 Shoreline protection statistics for the total project shoreline (left) and Reach 4 (right)

3.3 Bathymetric Data

Sources of bathymetric data leveraged for the study and new information collected by the study team is summarized.

3.3.1 Existing CHS Bathymetry

The Canadian Hydrographic Service (CHS) maintains a bathymetry dataset called 'NONNA' for non-navigational use in the Great Lakes. NONNA bathymetry is a compilation dataset and is based on the best available survey data collected by CHS. This dataset is provided in two resolutions: 10 m fixed grid (NONNA-10), and a 100 m fixed grid (NONNA-100). Coverage is limited to the exposed Lake Ontario shoreline. There is no coverage in the Bay of Quinte.

NONNA-10 bathymetry was downloaded as tiled raster datasets and then mosaiced to form a single raster (Figure 3.13). This raster was used to extract offshore bathymetry profile data as well as to generate bathymetric contours for mapping.

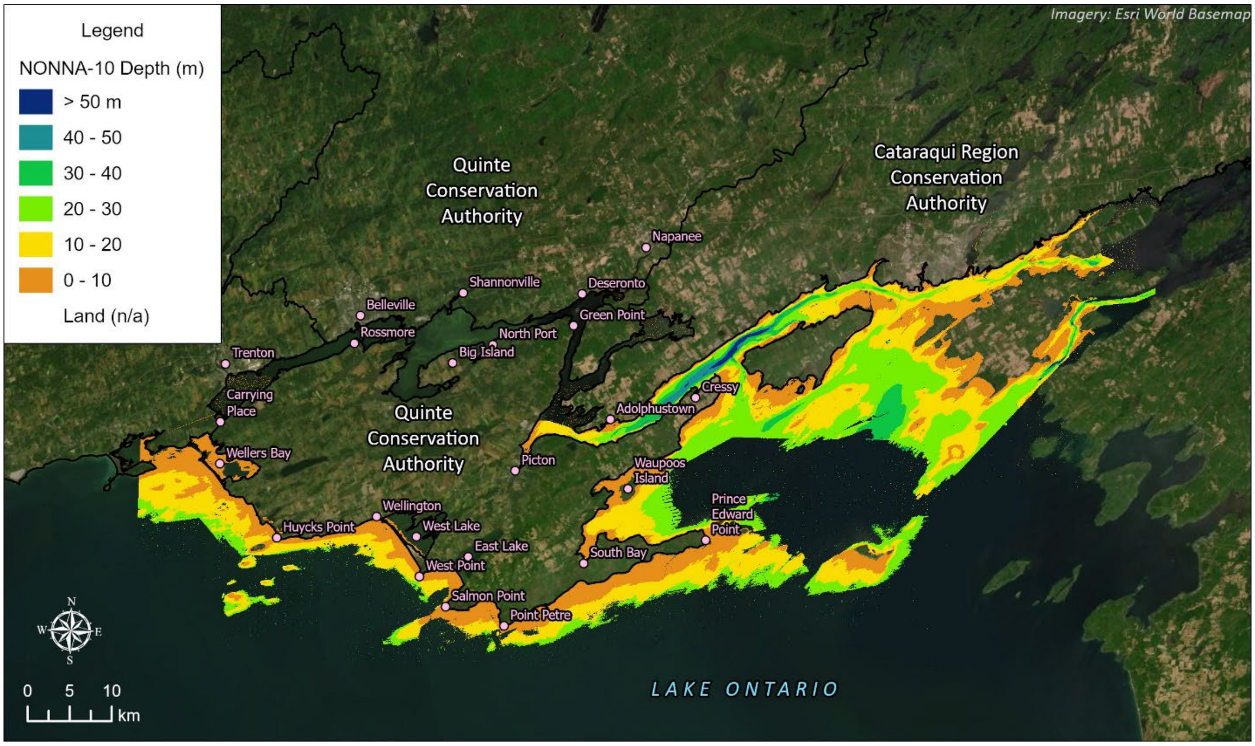


Figure 3.13 CHS NONNA-10 bathymetry

3.3.2 GLAHF Lake-wide Bathymetry

The Great Lakes Aquatic Habitat Framework (GLAHF) provides bathymetry surfaces for the Great Lakes, based on data obtained from NOAA National Centers for Environmental Information and CHS. These lake-wide bathymetry surfaces are in raster format and fit to a 30 m grid resolution. This dataset provided information on the depths within the Bay of Quinte and was used to fill in gaps not covered by other higher resolution NONNA datasets. The GLAHF bathymetry surface for Lake Ontario and the Bay of Quinte is shown in Figure 3.14.

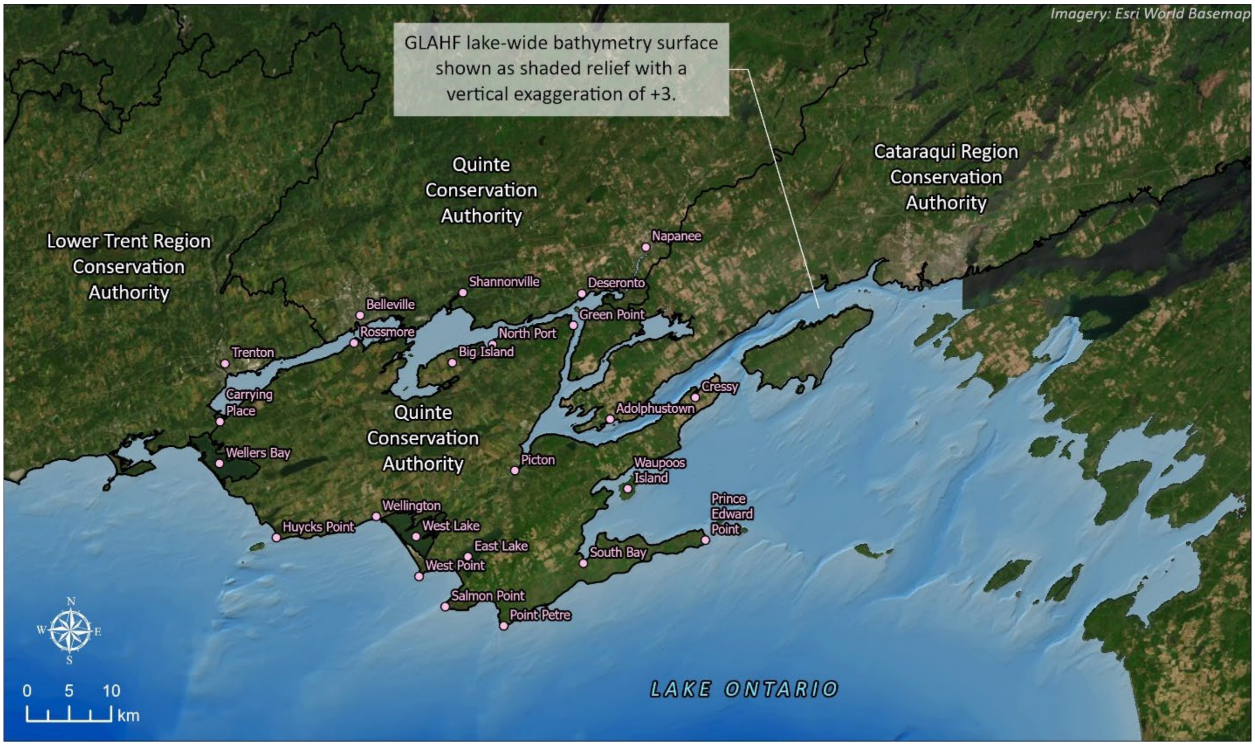


Figure 3.14 GLAHF-NOAA lake-wide bathymetry

3.3.3 Summer 2021 Nearshore Survey

Staff from Zuzek Inc. conducted a nearshore bathymetry survey from August 3-5, 2021. The raw data was collected with a SOLIX unit, a single-beam bathymetric and sonar system with built-in navigation and recording tools. The transducer was mounted at the back of the boat with a dedicated GPS antenna located directly above the unit. Refer to Figure 3.15. The unit auto-corrects for the depth of the transducer below the lake surface and the depths were recorded every second.

Figure 3.15 SOLIX data collection unit and transducer mount

A total of 35 recordings were collected within the project study area. See Figure 3.16 for an overview of the bathymetry data and colour-coded depths.

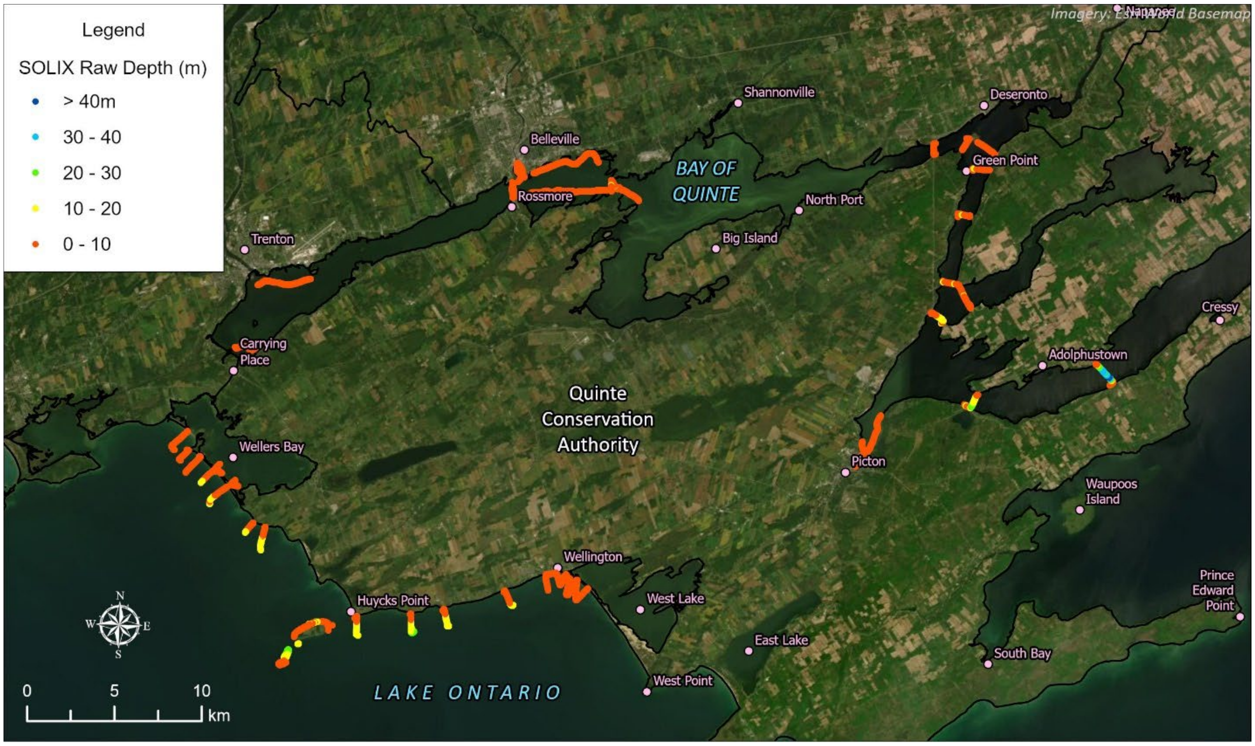


Figure 3.16 August 2021 SOLIX bathymetry survey

The depth readings were corrected using an average of hourly water levels from the Kingston water level gauge (#13988) and the Cobourg gauge (#13590), acquired from the Government of Canada (Fisheries and Oceans) water level website. The measured water levels were averaged for the duration of the survey and then averaged between gauges. To calculate the corrected lake bottom elevation in the IGLD'85 datum, the average water level was added to the SOLIX depth for the corresponding day. For example, the average hourly water level for the duration of the survey completed on August 3, 2021, was 74.83 m IGLD'85, taken from the Kingston gauge. The average water level for the same time period was 74.84 m IGLD'85 taken from the Cobourg gauge. Therefore, the average of these two gauges was 74.835 m. A SOLIX depth of -1.5 m would translate to a corrected elevation of 73.34 m (74.84 + (-1.5)).

The hourly water level data for Cobourg can be found here:
https://tides.gc.ca/en/stations/13590/2021-08-03?tz=EST

The hourly water level data for Kingston can be found here:
https://tides.gc.ca/en/stations/13988/2021-08-03?tz=EST

The SOLIX also collects 2D sonar imaging in cross-section and bottom image formats. The sonar imaging provides continuous data to help characterize the lake bottom substrate. Refer to the sample output in Figure 3.17. In the downward imaging (right), bedrock is clearly visible transitioning to a sand bottom near the shoreline. The cross-section (middle) records a bedrock substrate and transition to sand. The boat location is noted in the left panel.

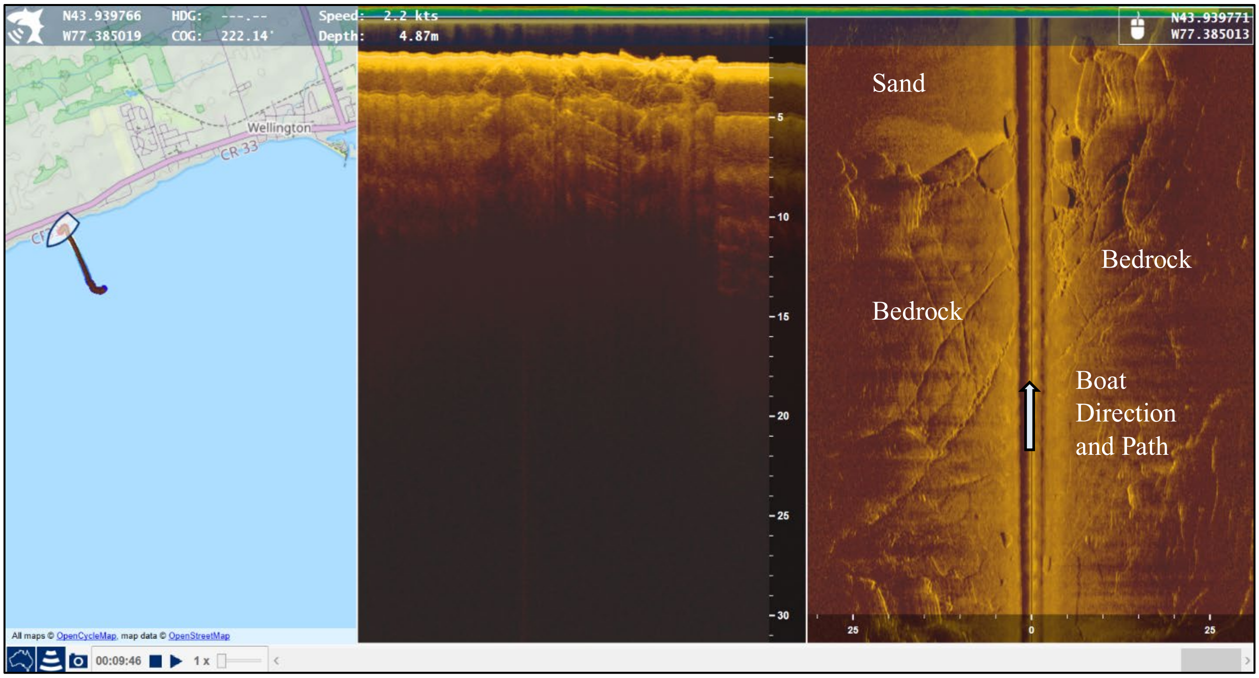


Figure 3.17 Sonar imaging of lake bottom near Wellington

3.4 Topographic Data

Several sources of topographic LiDAR were leveraged for the technical work and mapping.

3.4.1 2009 LiDAR

Topographic LiDAR was collected in 2009 for provincial and municipal partners and is referred to as the Lidar Eastern Acquisition Project (LEAP). This dataset and derivative products are available to download through the Ontario GeoHub. The Ontario GeoHub is an open data website containing numerous freely available products and is managed by the Province.

The 2009 LiDAR acquisition is the most recent LiDAR collection that provides nearly complete coverage of the Lake Ontario shoreline and the Bay of Quinte within the QC jurisdiction. Derivative bare-earth Digital Terrain Model (DTM) rasters were downloaded from the GeoHub and mosaiced into one raster covering shorelines within the study area (Figure 3.18). The DTM's have a resolution of 1 metre and elevations are referenced to the Canadian Geodetic Vertical Datum of 1928 (CGVD28). The DTM mosaic was converted to an IGLD'85 vertical datum by adding 5 cm to all elevations within the DTM. Refer to Section 3.4.3 for additional information on vertical datum conversions.

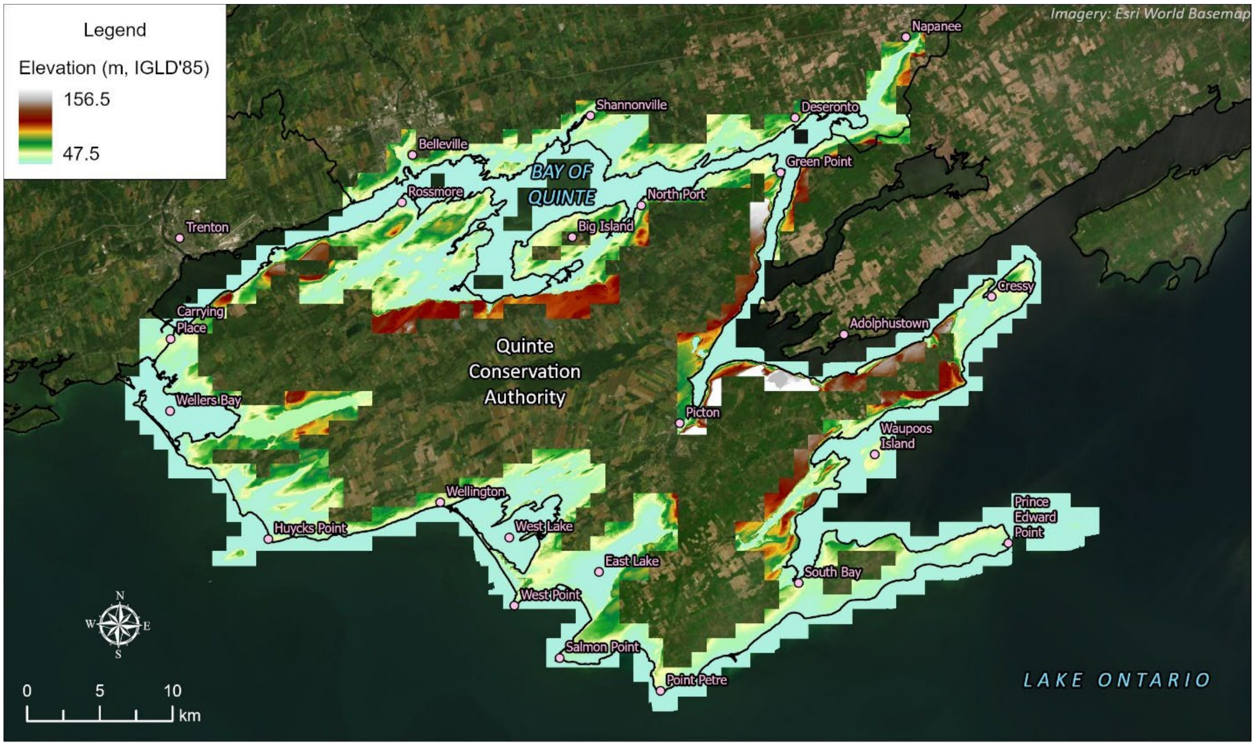


Figure 3.18 LEAP 2009 DTM grid mosaic

3.4.2 2021 LiDAR

Topographic LiDAR was collected in November 2021 for the vicinity of Wellers Bay and provided as raster tiles to Zuzek Inc. by QC. The raster tiles have a resolution of 1 metre and elevations are referenced to the Canadian Geodetic Vertical Datum of 2013 (CGVD2013). The raster tiles were mosaiced into a single raster, then converted to IGLD’85 vertical datum by adding 40 cm to all elevations within the DTM (Figure 3.19). Refer to Section 3.4.3 for additional information on vertical datum conversions.

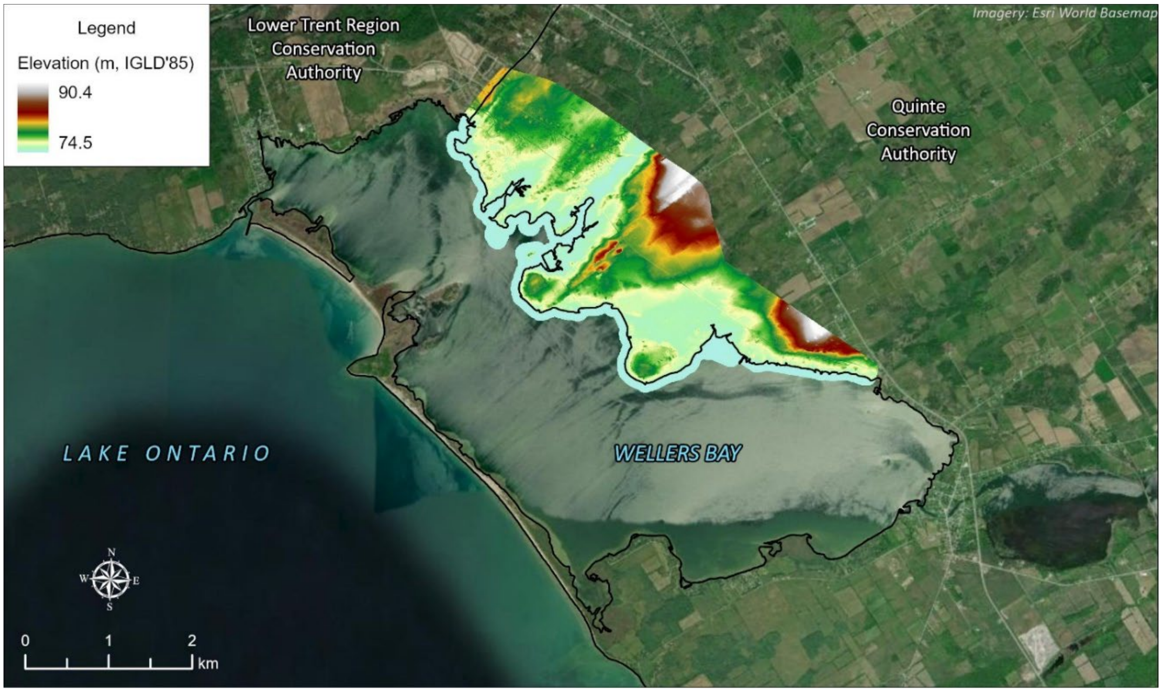


Figure 3.19 2021 Wellers Bay LiDAR grid mosaic

3.4.3 Differences in Vertical Datums CGVD28, CGVD2013 and IGLD'85

Passive control network data from Natural Resources Canada provides elevations for markers and benchmarks across Canada. The elevations are given in CGVD2013, CGVD28 and IGLD'85. Nine data locations near shorelines within Quinte Conservation were used to calculate the differences in elevations for each vertical datum. Refer to Table 3.1. The IGLD'85 datum is an average of 40 cm higher than the CGVD2013 datum. The IGLD'85 datum is an average of 5 cm higher than the CGVD28 datum, as noted in Table 3.1. These values were used when converting elevation products to IGLD'85.

Table 3.1 Differences in elevations for passive control network locations

		Coordinates		Elevations			Difference (m)	Difference (m)
Control No.	Location	Easting	Northing	CGVD2013 (m)*	CGVD28 (m)	IGLD85 (m)	IGLD85 - CGVD13	IGLD85 - CGVD28
67U125	Wellers Bay	295598	4876478	76.87	77.24	77.28	0.41	0.04
67U136	Wellington	311684	4869275	82.76	83.12	83.16	0.40	0.05
67U3001	Point Petre	326134	4857043	75.52	75.87	75.92	0.40	0.05
67U167	Adophustown	339332	4880493	79.09	79.44	79.49	0.40	0.05
67U159	Picton	328740	4875048	76.09	76.44	76.48	0.39	0.05
67U115	Desoronto	336743	4895672	77.68	78.03	78.08	0.40	0.05
67U119	Napanee	342582	4899086	79.61	79.96	80.01	0.40	0.05
16U003	Belleville	309458	4892405	76.12	76.47	76.52	0.40	0.05
67U082	Trenton	293907	4886537	75.44	75.80	75.84	0.41	0.04
						Average Difference (m):	**0.40**	**0.05**

Passive control network data can be obtained here: https://webapp.geod.nrcan.gc.ca/geod/data-donnees/passive-passif.php

3.5 Slope Stability Assessment

Published information on bedrock characteristics and collected field observations to assess the stability of rock banks and bluffs found throughout the study area shoreline were reviewed by Terraprobe. The majority of the shoreline has formed the physiographic region known as the Napanee Plain (Chapman and Putnam, 1984) and the limestone bedrock is covered by relatively shallow soil deposits. As noted in Section 3.2.1, the three bedrock units include the Verulam Formation, lower Lindsay, and upper Lindsay Formations. While more erosion resistant than glacial sediment or unconsolidated glacial outwash found throughout Lake Ontario, these limestone units and interbedded shale seams do erode and form low banks or high bluffs when exposed to wave activity on Lake Ontario and the Bay of Quinte.

Given the erodibility of the bedrock shore materials, a long-term stable slope is required to map the erosion hazard limit for the study area. However, classic slope stability approaches for soils are not directly applicable to the erodible bedrock banks and bluffs. Therefore, the long-term stability of the rock slopes was established based on local knowledge, existing publications, and site observations of rock type, strength, composition, and resistance to weathering. The approach followed was consistent with the guidance in the Geotechnical Principles for Stable Slopes (Terraprobe, 1998).

The long-term stable slope inclination for the rock banks and bluffs in the study area is 1.75 horizontal to 1.0 vertical (1.75H:1.0V). This stable slope setback, converted to a horizontal distance, was applied to all banks higher than 2 m as a component of the erosion hazard mapping (refer to Section 5.1).

4.0 TECHNICAL ANALYSIS

The technical analysis completed for the SMP is summarized in Section 4.0.

4.1 Reach Boundaries

Sixteen shoreline reaches were defined for the Quinte Conservation shoreline following the field work in the Summer of 2021. See attached map in Figure 4.1. Boundaries were based on exposure to wave energy, shoreline and nearshore geology, shoreline morphology, physical processes such as erosion and sediment transport, development density, and sensitive ecological habitat.

Figure 4.1 Reach boundaries for SMP

- **Reach 1 – Wellers Bay**: Reach 1 features a shallow embayment sheltered from Lake Ontario waves by a continuous 6 km barrier beach. The barrier was protected in 1978 as a National Wildlife Area due to its significant beach, dune, and wetland habitat. The remainder of the bay shoreline features dense shoreline development and a wide range of shoreline protection structures. The focus of the SMP is the bay shoreline, however, the long-term stability of the barrier system will also be addressed in the management recommendations.

- **Reach 2 – Stinson Block Road to Huycks Point:** Reach 2 features prominent bedrock headlands that anchor sandy barrier beaches at North Point Provincial Park and Huycks Bay. The barrier beaches in turn protect extensive coastal wetlands and shallow warm water habitat. There is limited new sediment to supply the barrier beaches, so sediment management to ensure their stability will be addressed in the SMP.

- **Reach 3 – Huycks Point to Wellington:** Huycks Point to Wellington features a bedrock cliff shoreline and a steep shelving bedrock nearshore. Beaches are largely absent due to the shoreline orientation and exposure to Lake Ontario waves from the southwest, except for the fillet beach adjacent to the navigation channel jetties into West Bay. The shoreline features a row of lakefront development, some shore protection, and is backed by agricultural lands.

- **Reach 4 – East and West Lake:** The barrier beaches associated with Sandbanks Provincial Park are not part of the study, as they are not regulated by the CA. However, the large sheltered embayments associated with East and West Lake are included and form Reach 4. The embayments feature a mix of natural wetland shoreline and cottage/residential development.

- **Reach 5 - Salmon Point Lighthouse to Point Traverse Lighthouse:** Reach 5 is a low-plain bedrock shoreline that features cobble/shingle beaches and several large crescentic barrier beach wetland complexes. The majority of the shoreline is undeveloped and in a natural state. Reach 5 is features moderate wave-energy (see Figure 4.2).

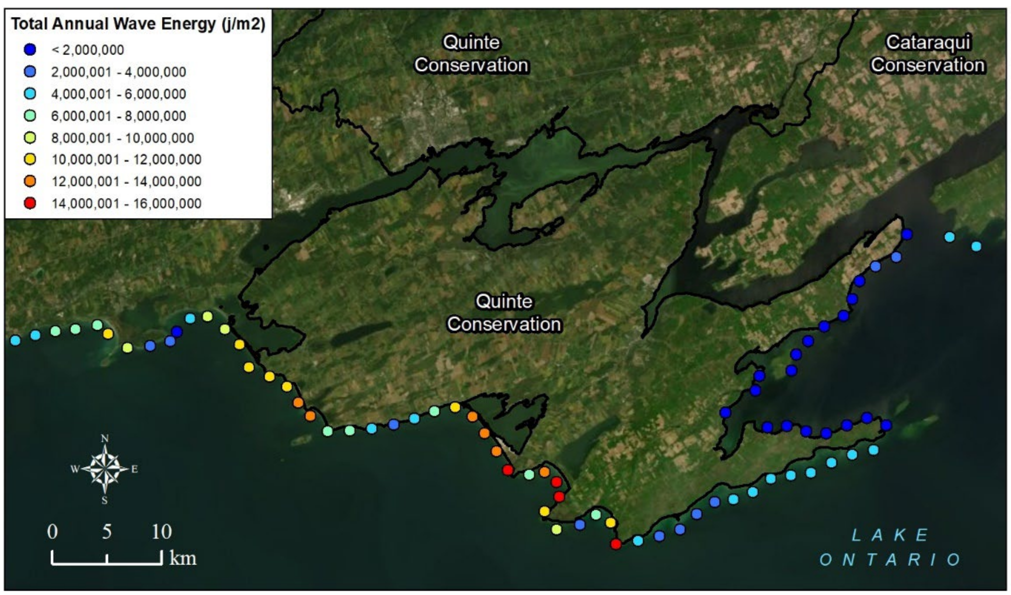


Figure 4.2 Average Annual Wave Energy Density for Lake Shoreline

- **Reach 6 – Long Point Road to South Bay:** Long Point Road to South Bay is sheltered from Lake Ontario waves that propagate from the long fetch to the west but partly exposed to the shorter northeastern fetches of the Kingston Basin. The majority of the shoreline features sparse development and natural land cover. South Bay features extensive coastal wetlands.

- **Reach 7 – Black River Mouth to Point Pleasant Lane:** Reach 7 features a sinuous shoreline with extensive coastal wetlands at the Black River mouth and in the lee of Waupoos Island. It is exposed to waves from the Kingston Basin and the southeast. The shoreline from Waupoos to Point Pleasant Lane is sparsely developed and features large tracks of natural shoreline.

- **Reach 8 – Adolphus Reach:** The Adolphus Reach covers the south shoreline of the entrance to the Bay of Quinte. The width of the bay varies from 900 m at Glenora to 3 km at Conway and is generally very deep (over 25 m offshore of Glenora). The shoreline features moderate development density.

- **Reach 9 – Picton Bay:** The bay is 5 km in a north-south direction with the community of Picton surrounding the southern limits. The shoreline features moderate development density. The sheltered conditions result in dense beds of submerged aquatic vegetation along the shoreline.

- **Reach 10 – Hayward Long Reach:** Reach 10 also features a north-south orientation and the west banks of Hayward Long Reach are regulated by Quinte Conservation. The east banks of the bay are regulated by the Cataraqui Region Conservation Authority. The majority of the reach features a steep bluff that extends right to the waters edge. Beaches are largely absent and waves are generated in the north-south channel and by boat wakes.

- **Reach 11 – Kimball Lane to Robinson Cove:** Reach 12 covers approximately 20 km of the Bay of Quinte from the Quinte Skyway Bridge to Muscote Bay. The shoreline features moderate development density and is exposed to wind generated waves during storms from the west or east.

- **Reach 12 – Muscote Bay:** The bay has a short fetch that generates small waves during winds from the north, which occur infrequently. The sheltered conditions have resulted in the creation of three large riverine wetland complexes. The majority of the shoreline is in a natural state with the exception of some development along Highway 14.

- **Reach 13 – Grave Island to Carrying Place:** Reach 13 is roughly 25 km in length and features dense shoreline development and a wide variety of shoreline treatments and protection structures. The majority of the shoreline slopes upward away from the lake and flood risk is minimal. Bedrock exposures were observed in select locations where nature shoreline conditions exist (i.e., not covered in shore protection).

- **Reach 14 – Belleville:** The community of Belleville was mapped as Reach 14 and extends roughly 8 km in an east west direction. Due to the limited wave exposure, the nearshore areas feature dense beds of submerged aquatic vegetation. The shoreline is densely developed and the majority features some form of shoreline protection.

- **Reach 15 – Mohawks of the Bay of Quinte to Deseronto:** Reach 15 covers roughly 30 km of the north shore of the bay, from the First Nations Community to Deseronto. The shoreline features a variety of natural and developed conditions.

- **Reach 16 – Napanee River:** The east and west banks of the Napanee River, from the bay to Highway #2 were mapped as Reach 16. This section of the river is influenced by water level fluctuations in the bay and was thus included in the Shoreline Management Plan.

4.2 Shoreline Change Analysis

Shoreline change rates can be measured at different temporal and spatial scales. For this study, the focus was long-term rates that are representative of the trend over many decades (i.e., greater than 35 years as outlined in MNR, 2001a, where possible) to support the hazard assessment. Short-term rates or trend reversals are not relevant for regulatory erosion hazard mapping. The methods and results from the shoreline change analysis within the study area are described in the sections that follow.

4.2.1 Georeferencing Historical Aerial Photographs

Quinte Conservation provided 119 digital (scanned) historical aerial photographs for various locations for 1978, 1985 and 1993. An additional 16 historic aerial photos were purchased from the National Air Photo Library in Ottawa. Quinte Conservation also provided 2018 orthophoto coverage of the entire shoreline within the study area (Figure 4.3). These orthophotos had a spatial resolution of 16 cm.

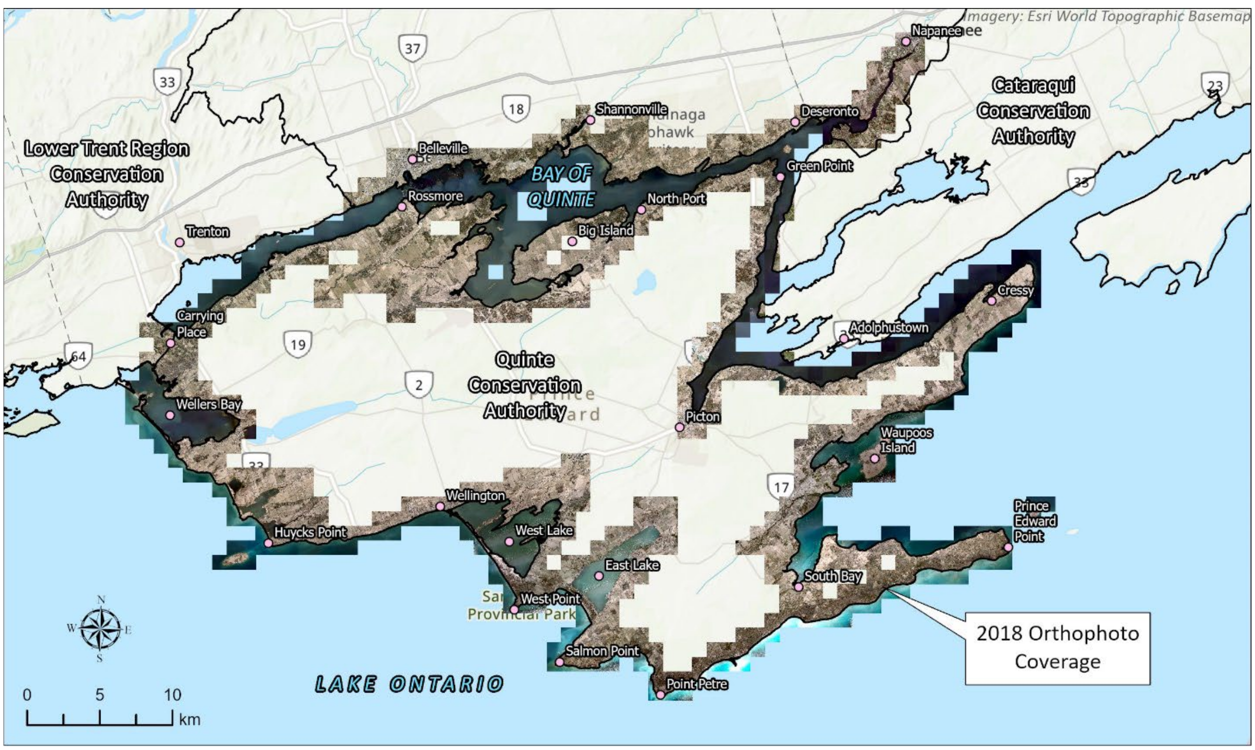


Figure 4.3 2018 orthophoto coverage

A total of 135 air photos were geo-referenced with ArcGIS software using 2018 orthophotographs as the base imagery. Root Mean Square (RMS) errors were used to quantify a maximum potential horizontal positional error in the geo-referenced photos, which is reported during the geo-referencing process with GIS software. The maximum RMS errors are summarized in Table 4.1. It is important to note that technical studies (Crowell et al, 1991) have shown the actual horizontal error in geo-referenced aerial images and maps is generally much lower than the RMS error (in other words, RMS error is a conservative estimate).

To assess the influence of the potential RMS error in Table 4.1, the horizontal error is divided by the temporal period of the shoreline change analysis. For example, the 1.6 m RMS error for the 1978 photo series in Reach 1 translates to a potential annualized error of 0.04 m/yr when comparing shoreline positions to the 2018 orthophotograph. Provided the rate of change from 1978 to 2018 is greater than 0.04 m/yr, there is confidence in the rate. If the RMS error for a specific photograph, once annualized to a rate of change, was greater than the actual erosion measurement between the photos (e.g., 1978 to 2018), the photograph was not used in the shoreline change analysis.

Table 4.1 Maximum RMS errors per reach by photo year

	PHOTO YEAR											
	1948		1951		1962		1978		1985		1993	
Reach	No. of Photos	Maximum RMS Error (m)	No. of Photos	Maximum RMS Error (m)	No. of Photos	Maximum RMS Error (m)	No. of Photos	Maximum RMS Error (m)	No. of Photos	Maximum RMS Error (m)	No. of Photos	Maximum RMS Error (m)
1	--	--	--	--	2	3.4	12	1.6	--	--	--	--
2	--	--	--	--	1	~1	2	1.5	4	1.7	--	--
3	--	--	--	--	2	3.1	--	--	9	1.3	--	--
4	--	--	--	--	1	~1	--	--	14	2	--	--
5	--	--	3	1	--	--	21	2.1	--	--	--	--
6	--	--	1	2.7	--	--	8	2	--	--	--	--
7	2	~1	--	--	--	--	--	--	13	2.3	--	--
8	--	--	--	--	--	--	--	--	--	--	5	1.5
9	--	--	--	--	--	--	--	--	--	--	2	1.7
10	--	--	--	--	--	--	--	--	--	--	2	1.5
11	--	--	--	--	--	--	--	--	--	--	5	2.1
12	--	--	--	--	--	--	--	--	--	--	6	2.5
13	--	--	--	--	1	1.8	6	2.3	--	--	1	1.4
14	--	--	--	--	--	--	--	--	--	--	2	1.5
15	--	--	--	--	2	3.8	--	--	--	--	5	1.5
16	1	1.5	--	--	--	--	--	--	--	--	2	1.6

An example of a historical aerial photo during the registration process is illustrated in Figure 4.4. The yellow arrows point to the ground control used, which are the red Xs. Ground control represents features that are visible in both the historic aerial and the base imagery. To minimize horizontal positional errors in georeferenced imagery, ground control points were well distributed across the aerial, an appropriate transformation method was applied, and routine visual checks against base imagery were completed.

Figure 4.4 Ground control selection during photo registration

4.2.2 Long-term Recession and Accretion Rates

The project shoreline was reviewed in GIS to identify areas suitable for measuring long term erosion rates. This involved visual checks of possible shoreline and land use changes between historic aerial photos and the 2018 orthophotos. When a suitable area was found, a common feature such as a top of bank line was digitized in both photo series. Using on-screen measuring tools, the change in horizontal position was assessed. If a change in horizontal position was observed, then a more detailed approach was applied.

Using semi-automated tools in GIS, transects were drawn between the common features digitized in each photo (e.g., top of bank) at a spacing of 10 m. The individual transect lengths in the population were calculated, then divided by the number of years between photos to obtain an annualized recession rate. For example, if the transect length between the 1978 and 2018 photos was 5 m, then the annualized rate is 0.13 m (5 / (2018-1978)).

The Average Annual Recession Rate (AARR) was then determined by calculating the average of the annualized rates for a given population of transects. To account for the spatial variability of the transect s (i.e., the variance), the standard deviation of the erosion transect AARRs was also calculated. The long-term recession rate for an area was based on the sum of the AARR and one annualized standard deviation. An example of erosion transects for a location of eroding bank in Reach 2 is presented in Figure 4.5. Here, the 22 transects featured an AARR of 0.10 m/yr and an annualized standard deviation of 0.05 m/yr. The long-term recession rates for mapping the erosion hazard was therefore 0.15 m/yr.

Figure 4.5 Transects between the 1985 and 2018 back of beach line

This process was repeated throughout the study area to establish a long-term recession rate for each shoreline reach and, in some cases, two rates per reach. Stable areas, such as pocket beaches are not mapped for the erosion hazard. See Figure 4.6 for an overview of all areas considered during this recession rate calculation task. Additional maps of erosion sites are provided in Appendix B. As expected, erosion was more common and more significant in Reaches 1 to 7 where there is greater exposure to Lake Ontario waves.

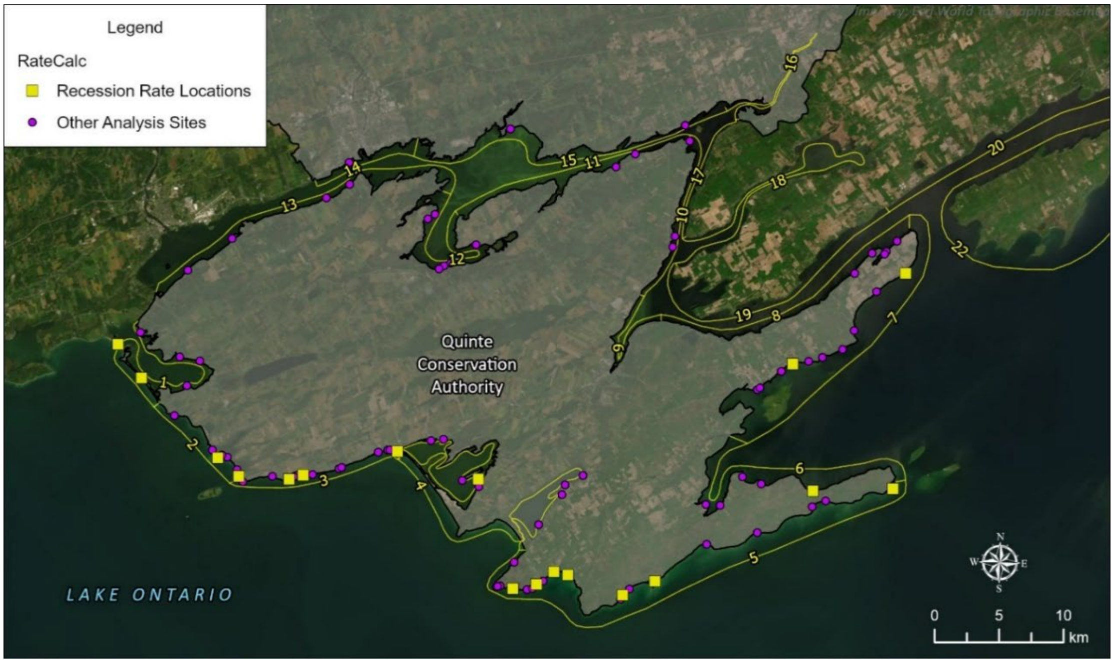


Figure 4.6 Recession rate analysis locations

The recession rate selected for mapping the erosion hazard within each reach is presented in Table 4.2. For Reaches 1, 8 to 16, and all embayments (e.g., East and West Lake), a fixed 100-year recession rate of 0.1 m/yr was used (10 metres over 100 years). These locations have historically featured low recession rates and are protected from the erosive wave climate on Lake Ontario. The recession rates presented in Table 4.2 below do not consider the impacts of a changing climate.

Table 4.2 Recession rate by reach

Reach	Recession Rate (m/yr)	100-year Recession
1	fixed	10
2	0.16	16
3	0.19	19
4. Bwn E and W Lake	0.19	19
5. Reach 4 to Salmon Pt.	0.21	21
5. Soup Harbour	0.42	42
5. Point Petre to Reach 6	0.21	21
6	0.15	15
7	0.15	15
8	fixed	10
9	fixed	10
10	fixed	10
11	fixed	10
12	fixed	10
13	fixed	10
14	fixed	10
15	fixed	10
16	fixed	10

4.3 Water Level Analysis

A critical component in the assessment of coastal hazards for Great Lakes shorelines is the determination of the 100-year flood level. The 100-year flood level is defined as the water level reached through a combination of static lake level and local storm surge, having a combined probability of occurrence of 1% in any given year. To assess the 100-year flood level therefore requires independent statistical analyses of static lake levels and local storms surges, followed by a joint probability analysis (JPA).

Water levels on the Great Lakes fluctuate over a broad range across various time scales. Fluctuations over the course of hours or a few days are generally the result of intense rainfall or snowmelt events, or storm surges generated by major wind events. The most familiar fluctuations occur seasonally, with higher water supply in the spring and early summer resulting in higher lake levels, typically peaking in May or June for Lake Ontario. Longer-term fluctuations in lake levels can also occur over decades due to climatic factors (e.g., wet and dry periods) and more recently due to climate change. To assess the 100-year flood level therefore requires statistical analyses of static lake levels and storm surges over the longest period of data available, accounting for seasonal variations, and using the best available statistical analyses techniques.

Historically, 100-year flood levels for most Great Lakes shorelines were based on work completed by the Ministry of Natural Resources (now the Ministry of Northern Development, Mines, Natural Resources and Forestry – NDMNRF) in the 1980's and published in a report titled "Great Lakes System Flood Levels and Water Related Hazards" (MNR, 1989). Since the MNR publication, more than 30 years of high-resolution water level data has been logged at numerous water level gauges around the Great Lakes. Measured monthly mean lake levels from a coordinated network of water level gauges around Lake Ontario are now available covering a period of more than 120 years. Figure 4.7 below presents monthly mean lake levels for Lake Ontario from 1900 to 2021, inclusive.

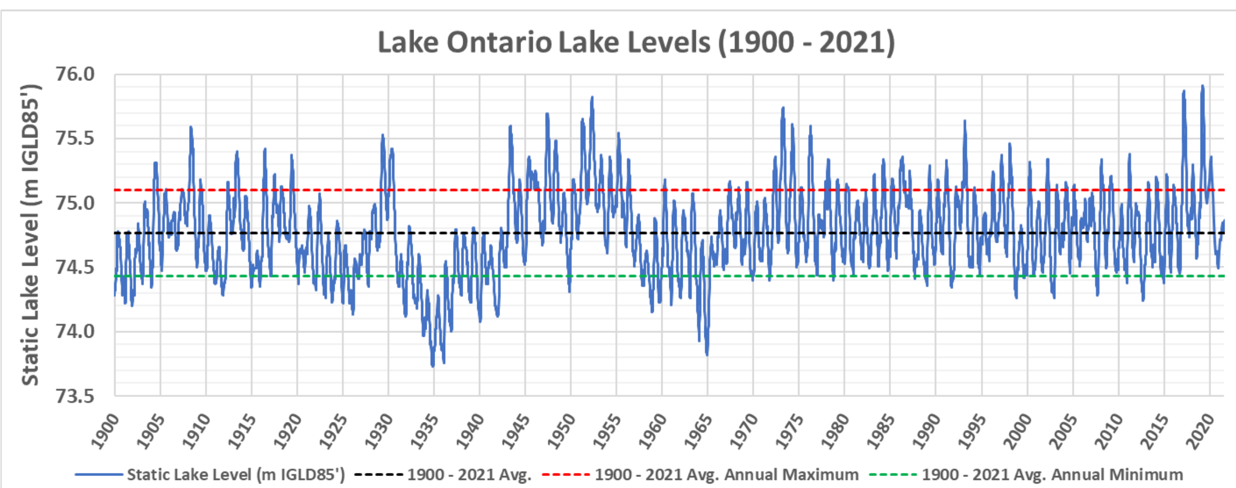


Figure 4.7 Monthly mean lake levels for Lake Ontario from 1900 – 2021, inclusive

4.3.1 Water Level Regulation

In addition to natural water level fluctuations, some influence on water levels is created by man-made control structures and the policies surrounding the operation of those structures. The Great Lakes basin is a chain of five lakes which forms the largest surficial freshwater system on earth with a combined drainage basin of more than 500,000 square kilometres. Lake Ontario is the furthest downstream of the five lakes, therefore receiving flows from the other four. Lake Ontario water levels are influenced by a regulation plan for the Moses-Saunders Power Dam in Cornwall, Ontario. Of the water flowing out of Lake Ontario via the dam, approximately 85% by volume is from upstream sources (i.e. Lake Erie via the Niagara River). The remaining 15% is direct contributions to the Lake Ontario drainage basin. In addition to water flowing into the St. Lawrence River through the operation of the dam, evaporation plays a significant role in the amount of water leaving the system.

Up until the mid-twentieth century, Lake Ontario was unregulated with outflow flowing freely via the St. Lawrence River. In the mid 1950's the St. Lawrence Seaway and Power Project was introduced including the construction of navigation channels to facilitate the movement of goods and the Moses-Sunders Power Dam at Cornwall for the generation of hydro-electricity. These changes increased the outflow capacity of the St. Lawrence River and provided the ability to moderate water levels both upstream and downstream through the control of the dam. As a result, a water level regulation plan was developed in the late 1950's and further adapted in the early 1960's with the intention of keeping water levels on Lake Ontario and the St. Lawrence River within an acceptable range to mitigate both upstream and downstream flooding while encouraging recreational boating, the safe transport of goods and the production of hydro-electricity. This plan was referred to as Plan 1958-D and was the official water level regulation plan adopted by the International Joint Commission (IJC) from 1960 to 2016.

Between 2000 and 2014 the IJC examined alternative regulation plans to better balance the various upstream and downstream interests and to update water level regulation practices in light of decades of shoreline development and fluctuations in water supply. Recognizing that Plan 1958-D had not considered the impacts of water levels on ecosystem health, the new plan, termed Plan 2014, considered impacts on coastal wetland environments and the protection of natural processes within the shoreline environment. Plan 2014 included guidance on releases at the dam that would occasionally allow for slightly higher highs during periods of high water supply, and lower lows during periods of drought. The new water level regulation plan was implemented in 2017. Inflow to Lake Ontario has historically been unregulated and remains so under the new plan, with no control structures in place between Lake Erie and Lake Ontario. Figure 4.8 shows monthly mean lake levels for Lake Ontario during the period of water level regulation only (post-1963), from which it can be seen that water level regulation has generally been effective in limiting lake levels to a narrower range than was observed historically (compared to Figure 4.7).

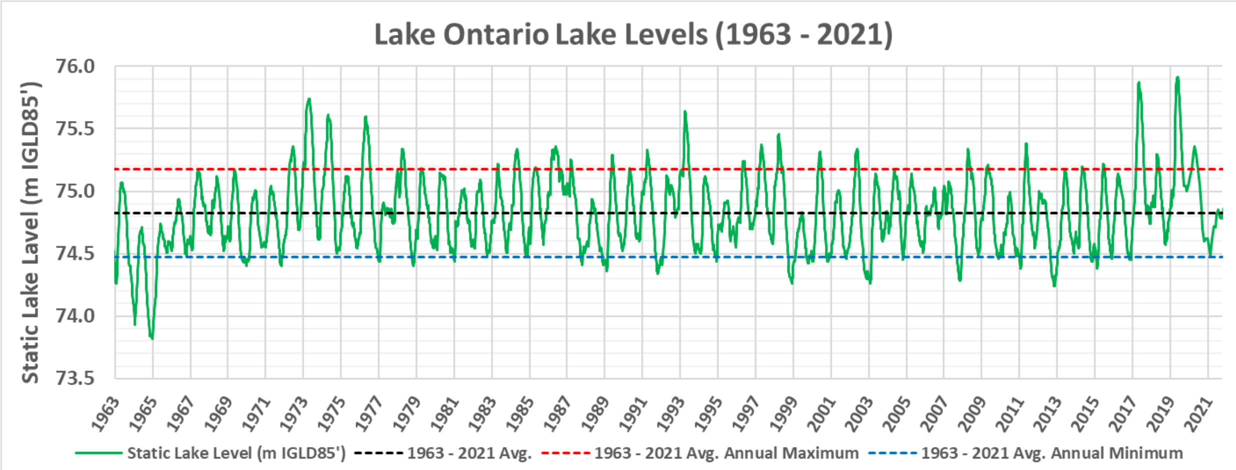


Figure 4.8 Monthly mean lake levels for Lake Ontario since the construction of the St. Lawrence Seaway and implementation of water level regulation policies, from 1963 – 2021, inclusive

Modelling completed for the IJC has shown that the present configuration of the St. Lawrence Seaway and water level regulation as per Plan 2014 has resulted in maximum water levels being on the order of 0.3 m lower than would have been realized under pre-project (natural, historical) conditions. In periods of extreme water supply such as those experienced in 2017 and 2019, the IJC has deviated from Plan 2014 to better balance the interests of shoreline landowners upstream and downstream while providing acceptable conditions (depths, currents, and ice breakup) for safe navigation through the St. Lawrence Seaway to maintain the movement of essential goods. In 2020, the IJC announced increased investment in reviewing the performance of Plan 2014 during periods of extreme water supply by the Great Lakes Adaptive Management Committee (GLAM). Review of Plan 2014 is ongoing at the time of this writing.

4.3.2 Static Lake Levels

Modelled and measured historical static lake level data courtesy of Environment and Climate Change Canada (ECCC) were used in the analysis of the 100-year flood level for this study. Performing statistical analysis of measured water levels alone dating back to 1900 would not be an accurate assessment of present day conditions, as the measured data reflects periods of no water level regulation (pre-1960s), regulation as per Plan 1958-D (1960s to 2016), and regulation as per Plan 2014. As such, a dataset of modelled static lake levels for Lake Ontario was used in the analysis, whereby historical measured water supplies were routed through ECCC's calibrated Great Lakes routing model assuming outflow control as per Plan 2014 for the entire historical period up to 2008. The routing model has been calibrated to historical data and is the most accurate prediction tool available for assessing water levels resulting from various water supply scenarios and outflow decisions at the Moses-Saunders Dam. Measured lake level data from 2009 to 2021 was added to the dataset to create a synthetic dataset containing more than 120 years of monthly mean lake levels for Lake Ontario.

Of the 120+ years of data contained in the static lake level dataset, only the period from 2009 – 2016 did not account for the influence of Plan 2014, as the former regulation plan (1958-D) was in effect when the measured data was logged. However, water supplies and water levels during this period were generally within the typical expected range for which both water level regulation plans perform similarly (refer to Figure 4.8). As such, the impact this would have on the analyses of the 100-year flood level is expected to be negligeable.

A seasonal statistical analysis of monthly mean lake levels was completed by first separating the 120+ year dataset into 12 monthly datasets. Each monthly dataset was subsequently ranked from the highest to lowest monthly values on record, and fitted to several statistical distributions. The distribution providing the highest overall correlation coefficient to the data was selected, and static lake levels corresponding to a variety of average recurrence intervals (ARIs) were output for each month of the year. Table 4.3 provides a summary of 100-year static lake levels for Lake Ontario by month, based on water levels from 1900 – 2021 and accounting for the influence of Plan 2014.

Table 4.3 Seasonal static lake levels for Lake Ontario corresponding to a variety of average recurrence intervals (in metres above IGLD85')

	Predicted Monthly Static Lake Level - Plan2014 (m IGLD85')												
Tr	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	MAX Annual
1.5	74.54	74.56	74.66	74.87	74.97	74.99	74.96	74.88	74.78	74.65	74.56	74.53	74.99
2	74.66	74.69	74.79	75.00	75.10	75.10	75.06	74.98	74.87	74.74	74.65	74.64	75.10
5	74.91	74.94	75.02	75.25	75.36	75.36	75.30	75.19	75.05	74.89	74.82	74.82	75.36
10	75.03	75.07	75.13	75.37	75.50	75.50	75.44	75.31	75.13	74.96	74.90	74.92	75.50
20	75.13	75.16	75.22	75.48	75.62	75.63	75.55	75.40	75.20	75.02	74.96	74.99	75.63
25	75.16	75.19	75.24	75.51	75.65	75.66	75.59	75.43	75.21	75.03	74.97	75.01	75.66
50	75.24	75.27	75.31	75.59	75.75	75.77	75.68	75.51	75.27	75.08	75.02	75.06	75.77
100	75.31	75.34	75.36	75.66	75.83	75.86	75.78	75.58	75.31	75.11	75.06	75.11	75.86
200	75.38	75.40	75.41	75.73	75.91	75.95	75.86	75.64	75.35	75.14	75.09	75.15	75.95
MAX Obs.	75.30	75.34	75.48	75.70	75.86	75.91	75.88	75.69	75.34	75.26	75.22	75.23	75.91

As is illustrated in Table 4.3, based on an extreme value analysis that considers current water level regulation policies (Plan 2014) and historical water supplies for more than 120 years, the governing 100-year static lake level for Lake Ontario is +75.86 m IGLD85', most likely occurring in the month of June. This value is 20 cm higher than the 100-year static lake level published by the MNR in 1989. Should the present water level regulation plan (Plan 2014) be replaced or updated, the 100-year static lake level should be re-evaluated.

4.3.3 Measured Storm Surges

Storm surge is the temporary rise in water levels during a storm resulting from a combination of barometric pressure gradients and wind setup. On large inland lakes the influence of pressure variations is generally smaller compared to the impacts of wind setup, which can be substantial. Setup occurs when wind-induced shear stress at the water-air interface pushes water in the same direction as the wind. When winds are in an onshore direction this will cause water levels to increase along the shoreline. For the case of inland lakes, this temporary increase in water level at one side of the lake will be offset by a temporary decrease at the opposite end of the lake. The amplitude of a storm surge event at a given location is dependent on the wind speed, duration, direction, fetch (open water distance over which the wind is blowing), the geometry of the lake, and the lake bathymetry (depth and slope of the lakebed).

There are several water level gauges around Lake Ontario that log data at sufficient temporal resolution to capture, identify and measure the magnitude of storm surge events, which typically last on the order of 12 to 24 hours. The closest water level gauges to the project shoreline are at Cobourg to the west (ID 13590), and Kingston to the east (ID 13988). Both datasets cover the period from 1962 to present day. Statistical analyses of measured storm surges at both gauge locations were therefore completed for the 60 year period from 1962 to 2021, inclusive.

Storm surge events were isolated from static lake levels in each dataset by first calculating background lake levels as a 5-day moving average with the central 36 hours removed. The residual between a specific data point (water level) and the background static level is then calculated. Large, positive residuals represent potential storm surge events, with the residual being equal to the magnitude of surge experienced at the gauge location. Significant events were plotted at a high temporal resolution to ensure the validity of the surge event and to confirm that the peak of the event was being captured by the analysis. Figure 4.9 presents a timeseries of water levels recorded at the Kingston water level gauge during the largest storm surge event on record, which occurred on November 13, 1992, and featured a surge magnitude of approximately 64 cm. For comparison, the largest event on record at the Cobourg water level gauge was 35 cm, occurring on November 24, 1979.

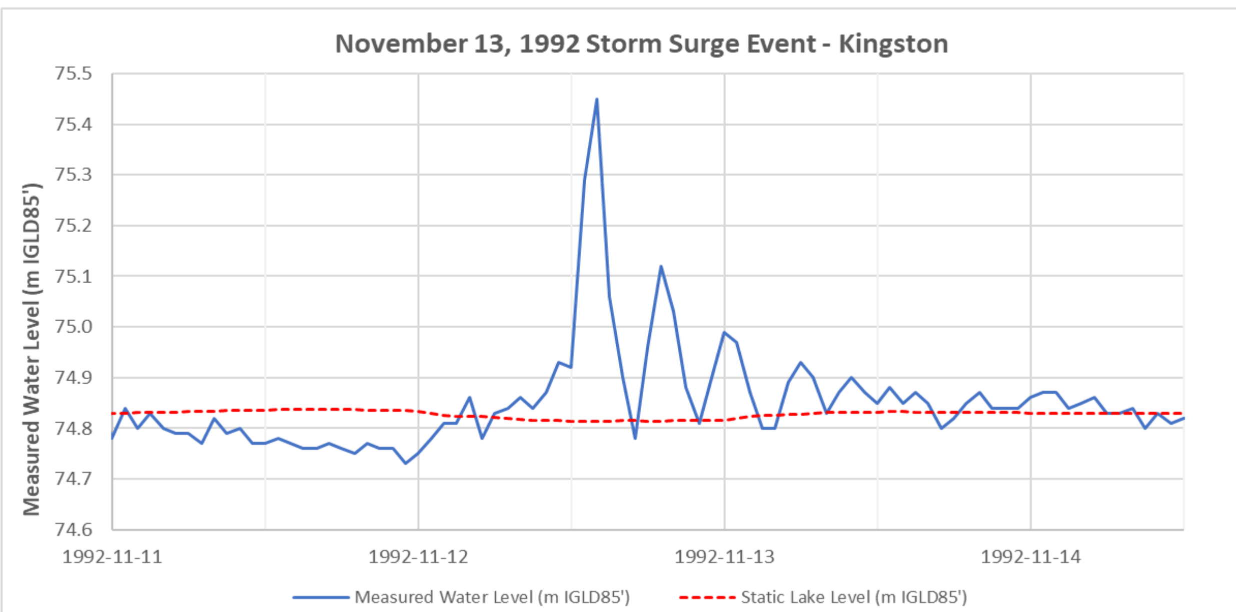


Figure 4.9 November 13, 1992, storm surge event, recorded at the Kingston water level gauge

Maximum residuals (surge magnitude) from identified surge events at each gauge location were ranked and separated into 12 monthly datasets to capture seasonality. In general, storm surge events are more frequent and severe during the fall and winter months. Since storms are random occurrences, an event that occurred on March 31st could conceivably have occurred on April 1st instead. To remove this potential bias, the 12 monthly datasets were compiled to include surge events measured during the specified month and those occurring in the month before and after (i.e. the April surge dataset included historical events during the period from March to May).

Each “monthly” dataset of ranked surge events was subsequently fit to several statistical distributions, with the best fitting distribution based on correlation coefficient being selected. Storm surge magnitudes corresponding to a variety of average recurrence intervals could then be predicted for each water level gauge location, with results provided in Table 4.4 and Table 4.5 for Cobourg and Kingston, respectively.

Table 4.4 Seasonal storm surge magnitudes at Cobourg for a variety of recurrence intervals (m)

	Predicted Monthly Storm Surge Magnitude - Cobourg (m)												
(years)	Jan (Dec-Feb)	Feb (Jan-Mar)	Mar (Feb-Apr)	Apr May)	May (Apr-Jun)	Jun (May-Jul)	Jul (Jun-Aug)	Aug (Jul-Sep)	Sep (Aug-Oct)	Oct Nov)	Nov (Oct-Dec)	Dec (Nov-Jan)	Max Annual
1.5	0.15	0.14	0.14	0.14	0.13	0.11	0.11	0.12	0.12	0.14	0.15	0.15	0.15
2	0.16	0.15	0.15	0.15	0.14	0.12	0.11	0.12	0.13	0.15	0.16	0.16	0.16
5	0.18	0.18	0.18	0.18	0.17	0.15	0.13	0.15	0.15	0.18	0.19	0.19	0.19
10	0.20	0.20	0.20	0.20	0.19	0.17	0.15	0.16	0.17	0.21	0.22	0.22	0.22
20	0.23	0.22	0.22	0.23	0.22	0.20	0.16	0.17	0.19	0.24	0.26	0.26	0.26
25	0.23	0.22	0.23	0.24	0.23	0.21	0.17	0.18	0.20	0.25	0.27	0.27	0.27
50	0.26	0.24	0.25	0.27	0.26	0.25	0.19	0.19	0.22	0.29	0.30	0.30	0.30
100	0.28	0.26	0.27	0.30	0.29	0.28	0.20	0.20	0.24	0.34	0.34	0.34	0.34
200	0.30	0.29	0.30	0.33	0.32	0.32	0.22	0.21	0.26	0.38	0.38	0.37	0.38
MAX Obs.	0.29	0.26	0.26	0.30	0.30	0.30	0.20	0.20	0.24	0.35	0.35	0.35	0.35

Table 4.5 Seasonal storm surge magnitudes at Kingston for a variety of recurrence intervals (m)

	Predicted Monthly Storm Surge Magnitude - Kingston (m)												
ARI (years)	Jan (Dec-Feb)	Feb (Jan-Mar)	Mar (Feb-Apr)	Apr (Mar-May)	May (Apr-Jun)	Jun (May-Jul)	Jul (Jun-Aug)	Aug (Jul-Sep)	Sep (Aug-Oct)	Oct (Sep-Nov)	Nov (Oct-Dec)	Dec (Nov-Jan)	Max Annual
1.5	0.27	0.25	0.21	0.19	0.16	0.13	0.12	0.14	0.19	0.23	0.25	0.28	0.28
2	0.29	0.28	0.23	0.20	0.17	0.13	0.12	0.16	0.20	0.25	0.26	0.30	0.30
5	0.37	0.36	0.30	0.24	0.21	0.15	0.15	0.20	0.24	0.31	0.32	0.37	0.37
10	0.42	0.41	0.35	0.29	0.26	0.18	0.17	0.23	0.26	0.36	0.38	0.42	0.42
20	0.47	0.47	0.42	0.35	0.32	0.22	0.19	0.26	0.29	0.43	0.44	0.48	0.48
25	0.48	0.49	0.44	0.37	0.34	0.24	0.20	0.27	0.29	0.45	0.46	0.50	0.50
50	0.53	0.54	0.51	0.44	0.42	0.31	0.22	0.30	0.32	0.53	0.54	0.56	0.56
100	0.57	0.59	0.59	0.52	0.50	0.40	0.24	0.33	0.34	0.61	0.61	0.62	0.62
200	0.62	0.63	0.69	0.61	0.59	0.52	0.26	0.36	0.36	0.69	0.70	0.68	0.70
MAX Obs.	0.49	0.49	0.50	0.51	0.51	0.51	0.22	0.33	0.33	0.64	0.64	0.64	0.64

As is illustrated in Table 4.4 and Table 4.5, based on an extreme value analysis of recorded storm surges from 1962 – 2021, the predicted 100-year storm surge magnitude at the Cobourg and Kingston water level gauges are 34 cm and 62 cm, respectively. These values are 10 cm and 4 cm lower than those presented by the MNR in 1989 (it is noted that the MNR analyses were completed using only 30 years of data).

4.3.4 Joint Probability Analysis of 100-year Flood Level

In order to assess the 100-year flood level, a seasonal joint probability analysis must be performed to assess the joint occurrence of static lake levels and storm surge events. In the seasonal joint probability analysis, static lake level and storm surge are treated as independent variables X and Y. These variables are populated using their respective monthly probability distributions, as was determined in Sections 4.3.2 and 4.3.3 above. The convolution formula is then used to determine the joint probability of a combined water level "Z" (where Z = X + Y). The joint probability equation for "Z" can be expressed as:

$$P(Z) = \sum_{Rx} P(X) \cdot P(Z - X)$$

Assessing the above formulation for the full range of possible combined flood elevations (Z) at each water level gauge location and for each month of the year results in a series of monthly cumulative joint probability distributions of combined flood levels. Figure 4.10 shows one such cumulative joint probability distribution for the month of June at Cobourg. The 100-year combined flood level is the value that corresponds to a cumulative probability of occurrence of 1% (i.e. 1 – 0.01 = 0.99 on the Y-axis). The complete results of the joint probability analysis are presented in Table 4.6 and Table 4.7, for Cobourg and Kingston respectively, for each month of the year and for a variety of recurrence intervals.

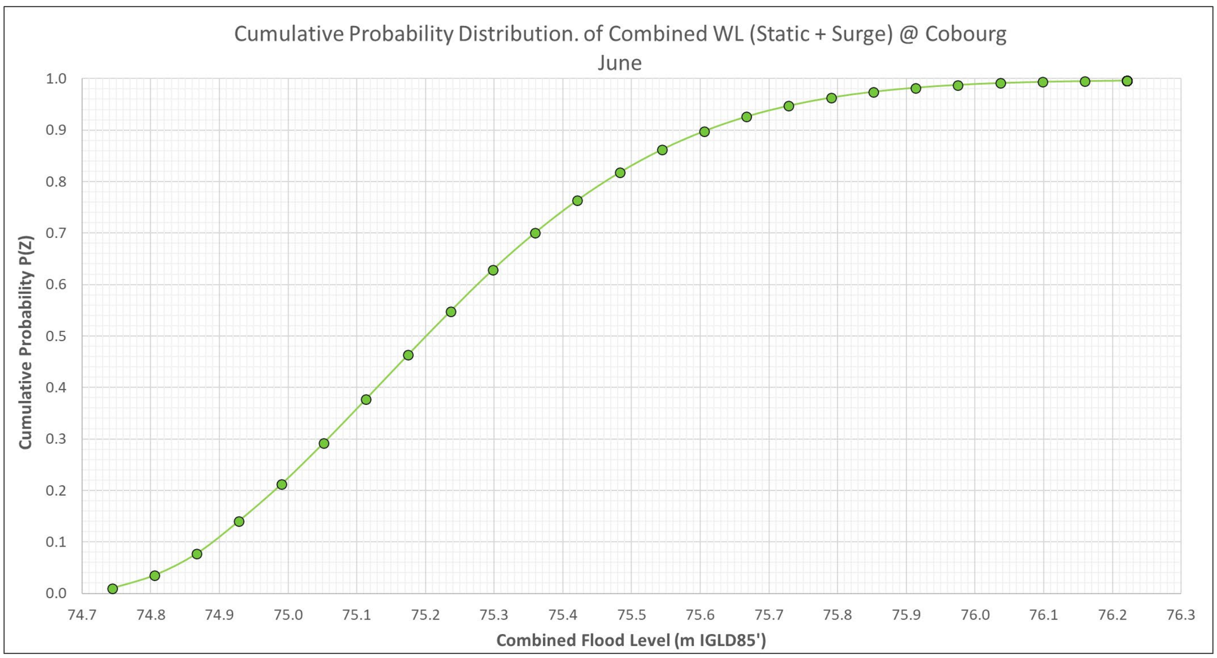


Figure 4.10 Cumulative joint probability distribution of combined flood levels (static water level and storm surge) at Cobourg for the month of June

Table 4.6 Seasonal combined flood levels at Cobourg for a variety of recurrence intervals (in metres above IGLD85')

	Predicted Joint Probability Flood Levels - Cobourg (m IGLD85')												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Max
(years)	Feb)	(Jan-Mar)	(Feb-Apr)	May)	(Apr-Jun)	(May-Jul)	(Jun-Aug)	(Jul-Sep)	(Aug-Oct)	Nov)	(Oct-Dec)	(Nov-Jan)	Annual
1.1	74.43	74.40	74.48	74.73	74.83	74.87	74.87	74.81	74.68	74.58	74.47	74.44	74.87
2	74.81	74.83	74.93	75.13	75.21	75.20	75.17	75.10	75.00	74.88	74.81	74.79	75.21
5	75.06	75.09	75.17	75.39	75.49	75.47	75.41	75.32	75.18	75.05	74.98	74.99	75.49
10	75.19	75.21	75.28	75.52	75.64	75.62	75.55	75.43	75.26	75.12	75.06	75.09	75.64
20	75.29	75.32	75.37	75.63	75.76	75.75	75.67	75.53	75.33	75.18	75.13	75.16	75.76
25	75.33	75.35	75.40	75.66	75.80	75.79	75.71	75.56	75.35	75.20	75.15	75.19	75.80
50	75.42	75.44	75.48	75.76	75.91	75.91	75.82	75.64	75.41	75.25	75.22	75.25	75.91
100	75.50	75.52	75.56	75.86	76.02	76.03	75.93	75.73	75.47	75.31	75.27	75.31	76.03
200	75.63	75.63	75.64	75.98	76.17	76.19	76.08	75.84	75.54	75.39	75.34	75.40	76.19
MAX Obs.	75.31	75.30	75.50	75.78	75.96	75.94	75.91	75.70	75.43	75.27	75.20	75.17	75.96

Table 4.7 Seasonal combined flood levels at Kingston for a variety of recurrence intervals (in metres above IGLD85').

	Predicted Joint Probability Flood Levels - Kingston (m IGLD85')												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Max
(years)	Feb)	(Jan-Mar)	(Feb-Apr)	May)	(Apr-Jun)	(May-Jul)	(Jun-Aug)	(Jul-Sep)	(Aug-Oct)	Nov)	(Oct-Dec)	(Nov-Jan)	Annual
1.1	74.56	74.52	74.55	74.80	74.88	74.89	74.89	74.84	74.74	74.67	74.59	74.57	74.89
2	74.96	74.97	75.02	75.20	75.27	75.22	75.18	75.14	75.07	74.99	74.93	74.94	75.27
5	75.22	75.24	75.26	75.47	75.54	75.49	75.42	75.35	75.25	75.16	75.11	75.14	75.54
10	75.35	75.37	75.39	75.59	75.69	75.65	75.56	75.47	75.34	75.24	75.20	75.24	75.69
20	75.46	75.48	75.49	75.71	75.81	75.78	75.69	75.57	75.41	75.32	75.27	75.33	75.81
25	75.49	75.51	75.52	75.73	75.85	75.82	75.72	75.60	75.43	75.34	75.30	75.35	75.85
50	75.59	75.61	75.60	75.84	75.96	75.94	75.83	75.69	75.49	75.42	75.37	75.43	75.96
100	75.69	75.70	75.70	75.94	76.09	76.07	75.95	75.78	75.55	75.50	75.44	75.51	76.09
200	75.81	75.84	75.87	76.09	76.24	76.24	76.09	75.90	75.63	75.68	75.61	75.65	76.24
MAX Obs.	75.52	75.38	75.53	75.76	75.90	75.98	75.87	75.70	75.42	75.28	75.56	75.23	75.98

As illustrated in Table 4.6 and Table 4.7, based on joint probability analyses of static lake levels and measured storm surges, the predicted 100-year flood level at Cobourg and Kingston is n p bbv +76.03 and +76.09 m IGLD85', respectively. These values are 23 cm and 10 cm higher than those presented by the MNR in 1989 for the two locations, and are most likely to occur during the months of May or June.

4.3.5 Storm Surge Modelling to Establish Longshore Gradients

Although the static lake level component of the joint probability analysis of flood levels is consistent, the storm surge component varies for different locations along the shoreline. Therefore, to evaluate the 100-year flood level at locations along the QC and CRCA shorelines between the two gauging stations (Cobourg and Kingston) requires numerical modelling of storm surge gradients. To address this, DHI have developed a storm surge model for Lake Ontario featuring a high-resolution grid from Prince Edward County to Kingston, including the entire Bay of Quinte. The model was developed in DHI's MIKE21 FM HD modelling environment and uses triangular and quadrangular flexible mesh elements to resolve the bathymetry of Lake Ontario and the Bay of Quinte. The mesh is depicted in Figure 4.11 and contains 179,077 nodes and 187,559 elements. Model bathymetry was obtained from the Canadian Hydrographic Service (CHS) non-navigational (NONNA) bathymetric data portal and supplemented with single-beam bathymetric data collected by Zuzek Inc. in the summer of 2021 at areas of interest throughout the model domain. The model bathymetry for Lake Ontario is presented in Figure 4.11 below.

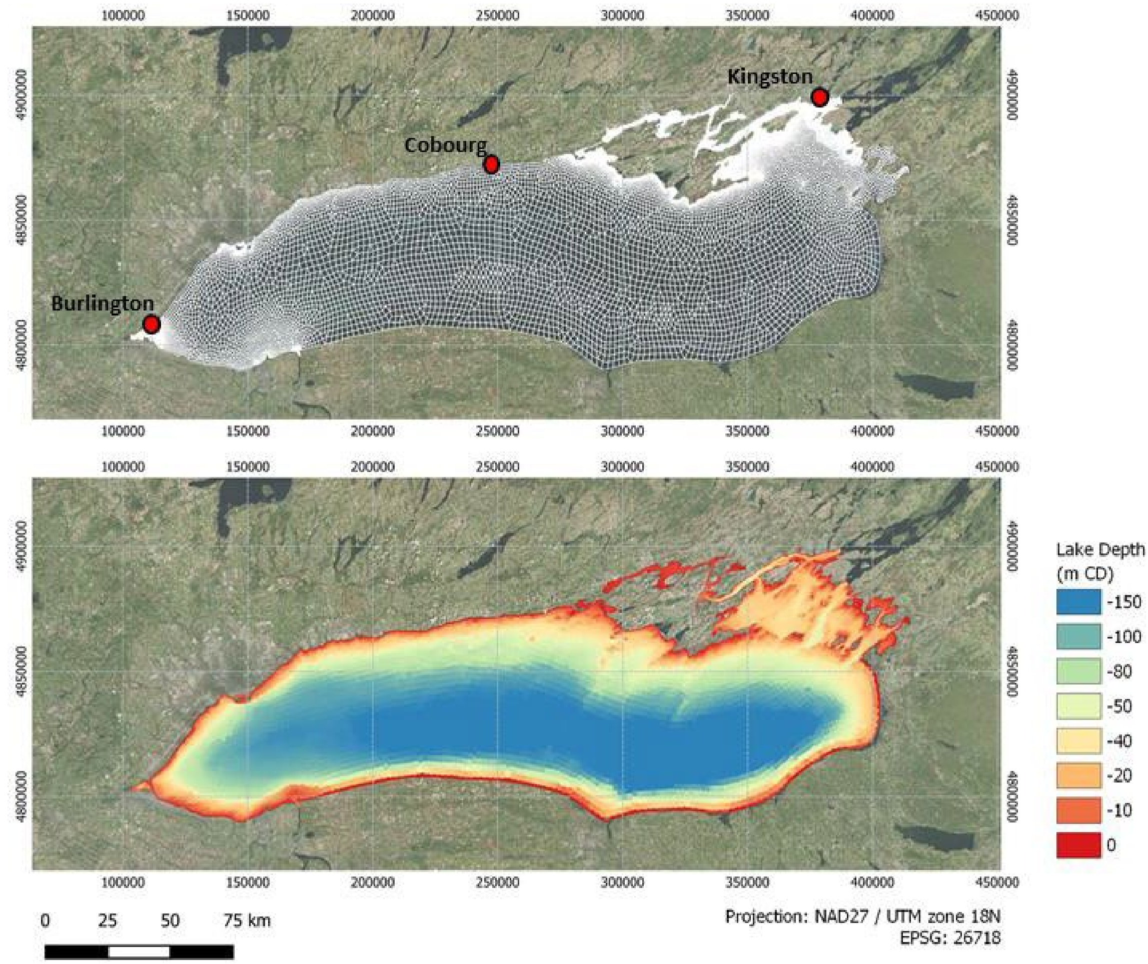


Figure 4.11 Lake Ontario surge model mesh (top) and interpolated bathymetry (bottom)

The adopted mesh resolution (i.e. size and number of mesh elements) is a necessary compromise between desired resolution and model runtimes, with model simulation times increasing with more and smaller mesh elements. The size/length of mesh elements range from several hundred meters to less than five meters within the Bay of Quinte itself, at specified locations of interest. The high-quality bathymetric data available throughout the majority of the Bay of Quinte, combined with the high-resolution model domain, improves the ability of the model to capture locally generated storm surge gradients. Mesh resolution at specific areas of interest within the Bay of Quinte is depicted in Figure 4.12 for Trenton, Wellers Bay, Belleville Bay Bridge, Quinte Skyway Bridge, Deseronto, and Glenora.

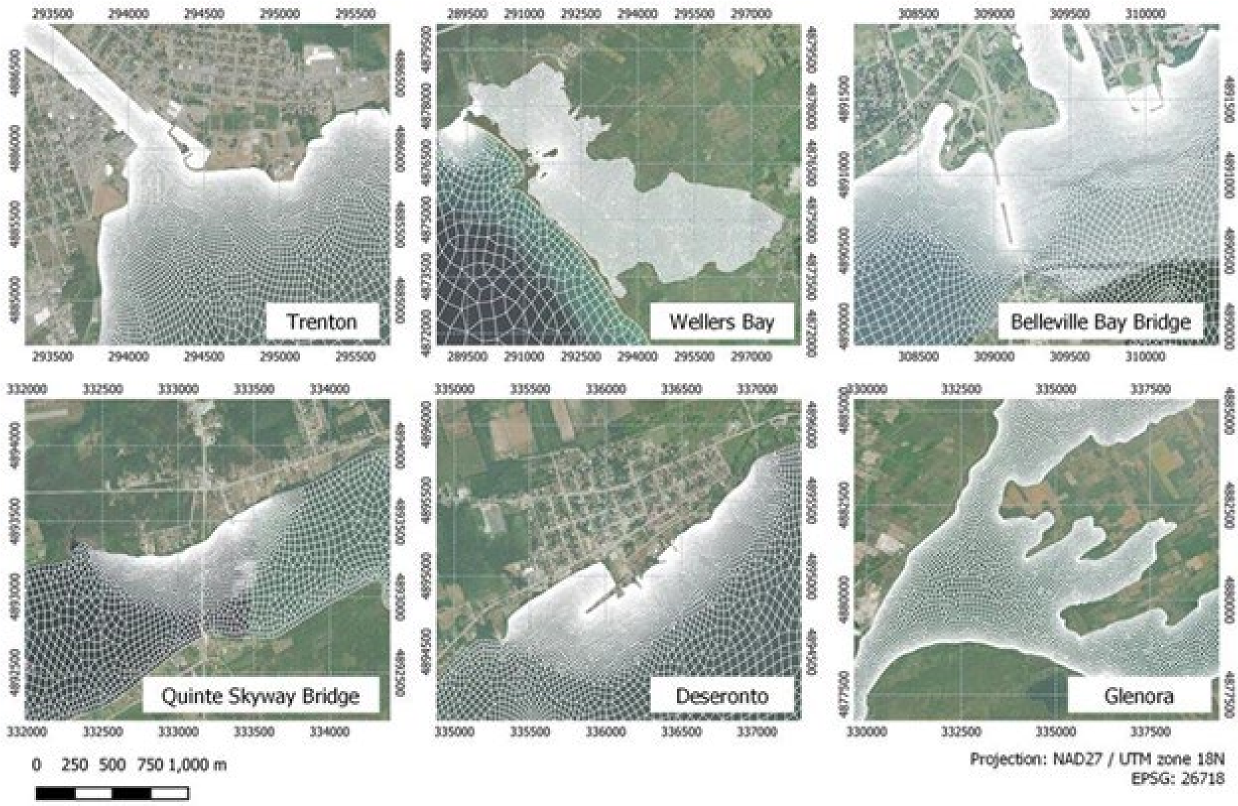


Figure 4.12 Mesh detail at specific locations of interest within the Bay of Quinte

Spatially and temporally varying atmospheric data to drive hydrodynamic processes regionally and locally on Lake Ontario were sourced from the Climate Forecast System Reanalysis (CFSR) project, supplied by NOAA's National Center for Environmental Prediction (NCEP). The CFSR project uses an assimilated global, high resolution, coupled atmosphere-ocean-land surface-sea ice modelling system. The CFSR data is available from 1970 onwards at hourly intervals with a spatial resolution of 0.30° x 0.30° through 2010 and 0.20° x 0.20° from 2011 onwards. Wind velocity components 10 m above the ground and atmospheric pressure at Mean Sea Level were downloaded from the CFSR hindcast at a 1-hour time interval and post-processed into a model-compatible format. CFSR wind and pressure data was compared to measured data around the lake at ECCC meteorological stations at St. Catherine's, Hamilton, Toronto, Trenton and Kingston, Lake Ontario ECCC buoys (45139, 45159 and 45135), and US Coast Guard stations at Rochester and Oswego. A comparison of observed versus CFSR hindcast pressure and wind components is depicted in Figure 4.13 at Kingston for March and April 1979. A significant surge event occurring on April 6th is indicated with a dashed line, where high wind speeds, and low pressure associated with the storm surge event are captured by the CFSR hindcast data. The timeseries comparison of measured and modelled data indicates a strong agreement between the CFSR hindcast data and local observations. Some bias corrections were made to the CFSR data as necessary (e.g. pressure reduction ~10hPa for March and April in 1979) on a spatially varying grid, using observation data, to improve the modelled CFSR hindcast data applied in the modelling.

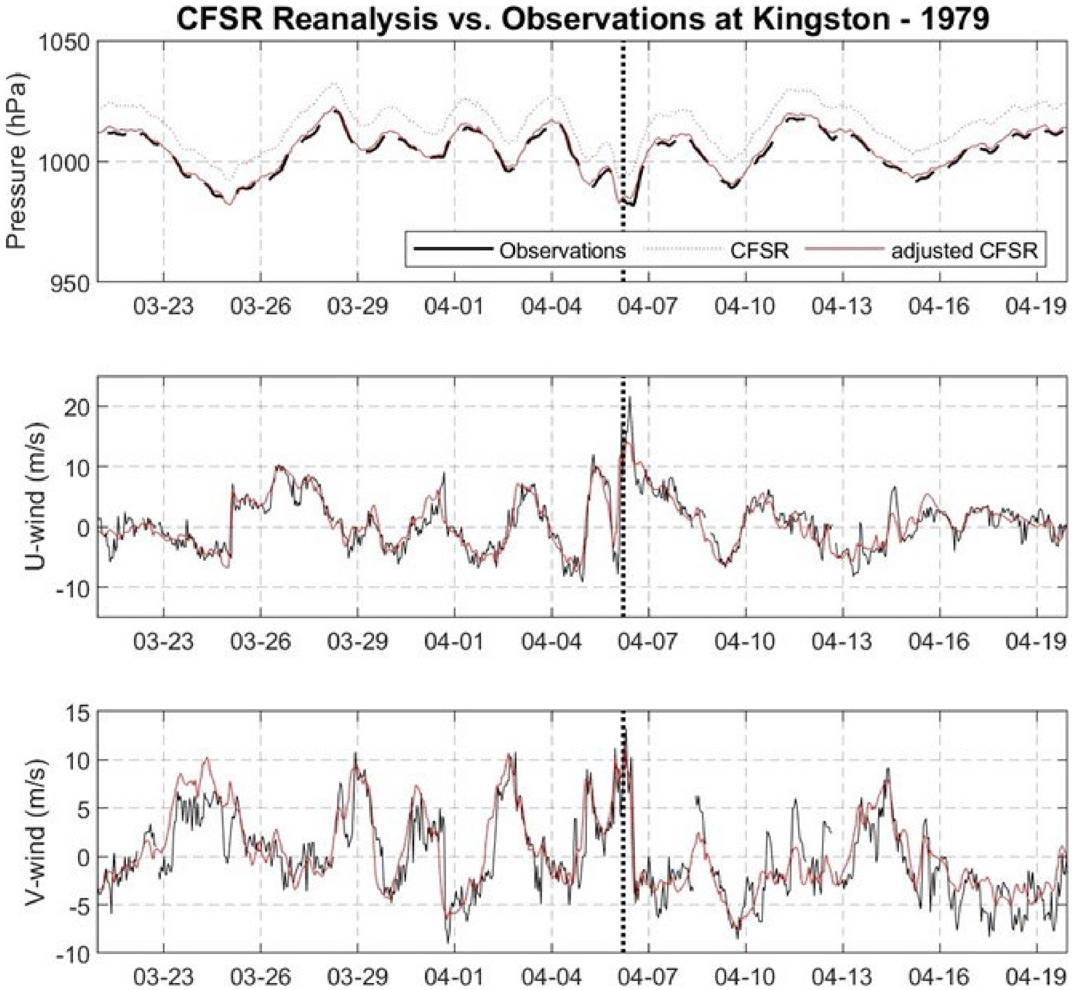


Figure 4.13 Comparison of CFSR and measured winds at Kingston for March and April, 1979

Four historical storm events were simulated using the DHI storm surge model, with each event summarized as follows:

1. **April 6, 1979:** the 4th largest surge event on record at the Kingston water level gauge, having generated a 25-year return period surge. This is the largest recorded event from the beginning of the record to the 1990s and falls within the CFSR hindcast period. During the event, prevailing westerly winds were sustained for a continuous 24-hour period, thereby generating surge at the eastern extents of Lake Ontario.

2. **November 13, 1992:** the largest surge event on record at Kingston, corresponding to an approximately 100-year event. During the event prevailing westerly winds were sustained for a continuous 24-hour period, thereby generating surge at the eastern extents of Lake Ontario.

3. **May 4, 2018:** the 3rd largest surge event on record at Kingston, corresponding to an approximately 25-year event. The event was unique in that it occurred during the month of May, coinciding with seasonally high baseline lake levels for a significant combined water level event. During the event prevailing westerly winds were sustained for a

continuous 24-hour period, thereby generating surge across the eastern extents of Lake Ontario.

4. **December 19, 2007:** the largest surge event recorded at the Burlington water level gauge at the west end of Lake Ontario in the last 45-years. During this event, high easterly winds were sustained for more than 24-hours, resulting in a surge gradient along the lake from east to west. This event has been incorporated in the modelling to understand storm surge potential at the western extents of the Bay of Quinte caused by easterly winds.

Background static lake levels, storm surge magnitudes and total combined water levels reached at the Cobourg and Kingston gauging stations for each of the simulated events described above are summarized in Table 4.8.

Table 4.8 Simulated historical storm surge events

ID	Date	Total Water Level (m IGLD85')		Storm Surge Residual (m)		Avg. Static Lake Level (m IGLD85')
		Kingston	Cobourg	Kingston	Cobourg	
1	April 6, 1979	75.47	75.12	0.50	0.15	74.97
2	November 13, 1992	75.45	75.03	0.62	0.20	74.83
3	May 4, 2018	75.67	75.29	0.50	0.12	75.17
4	December 16, 2007	74.46	74.46	0.10	0.10	74.36

The storm surge model has two (2) open boundaries at the Niagara River and the St. Lawrence River near Kingston. At each of these boundaries discharge conditions are included in the model, where the Niagara River flows into the model domain, and the St. Lawrence flows out of the domain. The river discharge applied in the model for each event are described in Table 4.9. To select an initial static lake level for the beginning of each simulation, a 7-day central moving average filter was applied to measured lake levels. The model is started 14-days prior to the storm event to allow for sufficient model spin-up. The initial water level conditions for Lake Ontario applied at the onset of the simulation are summarized in Table 4.9.

Table 4.9 Surge model boundary and initial conditions

ID	Date	Initial Water Level (m IGLD85')	Niagara River Discharge (m^3/s)	St. Lawrence River Discharge (m^3/s)
1	April 6, 1979	75.05	7,504	-7,759
2	November 13, 1992	74.82	8,184	-8,127
3	May 4, 2018	75.26	7,646	-7,589
4	December 16, 2007	74.32	5,210	-6,003

Each storm surge simulation was run for a period of 3-weeks, where 2-weeks were used to spin-up the model, and 1-week included at the end of each storm to verify that the model is stable after the passage of the event. The 2D hydrodynamic model is driven by the bias corrected CFSR atmospheric pressure and wind, where the surface elevation of the lake responds to temporally and spatially varying meteorological forcing. Storm event 1 (April 9, 1979) was used to calibrate the model to hourly observations at Kingston and Cobourg. The hourly observations (discrete red points in Figure 4.14) are compared to the continuous model output (black line in Figure 4.14). The peak surge at Kingston is reproduced by the model, where the peak modelled and measured water level above IGLD85' are very close, at +75.49 m and +75.47 m IGLD85', respectively. There is a shift in the timing of the peak observed and modelled water levels that could be attributed to differences in measured and CFSR applied atmospheric forcing, where prior to 2011 the CFSR data resolution is lower (0.30° x 0.30°). Given that the objective of the modelling is to reproduce the peak of the storm surge, and not necessarily the time at which this occurs, the model performance to capture the peak storm surge is satisfactory at both locations.

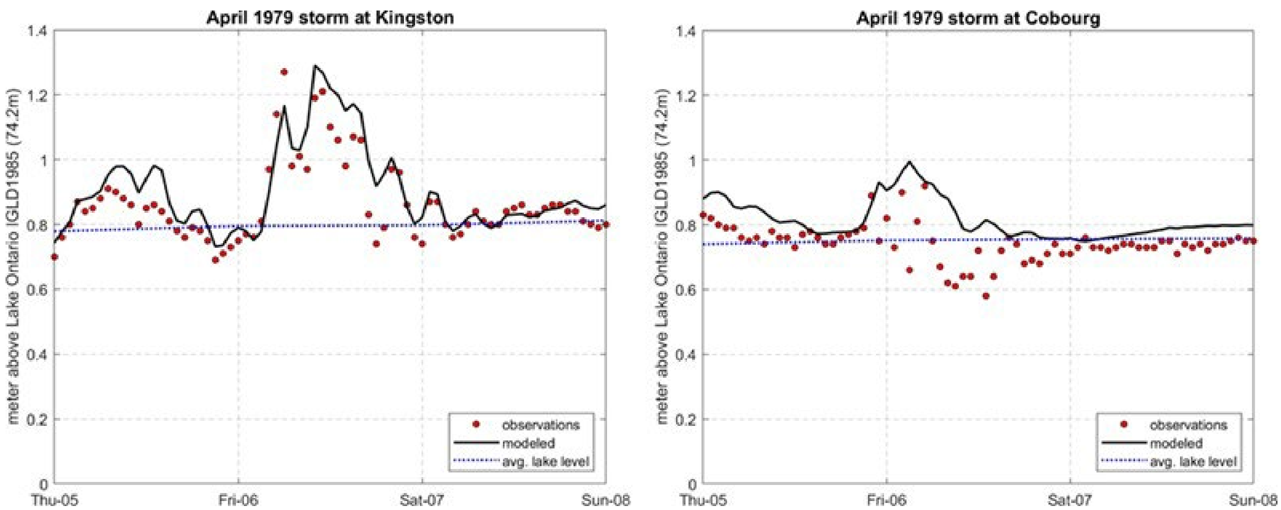


Figure 4.14 Measured (red dots) versus modelled (continuous black line) water levels at Kingston (left) and Cobourg (right) during the April, 1979 storm surge event (in metres above Chart Datum)

The maximum water level recorded during the April, 1979 storm event across the entire model domain is presented below in Figure 4.15. As expected, a distinct water level gradient exists along the north shore of Lake Ontario from west to east (direction of dominant westerly winds), with higher water levels in the narrow and shallow bays on the eastern extent of the Bay of Quinte (e.g. Napanee).

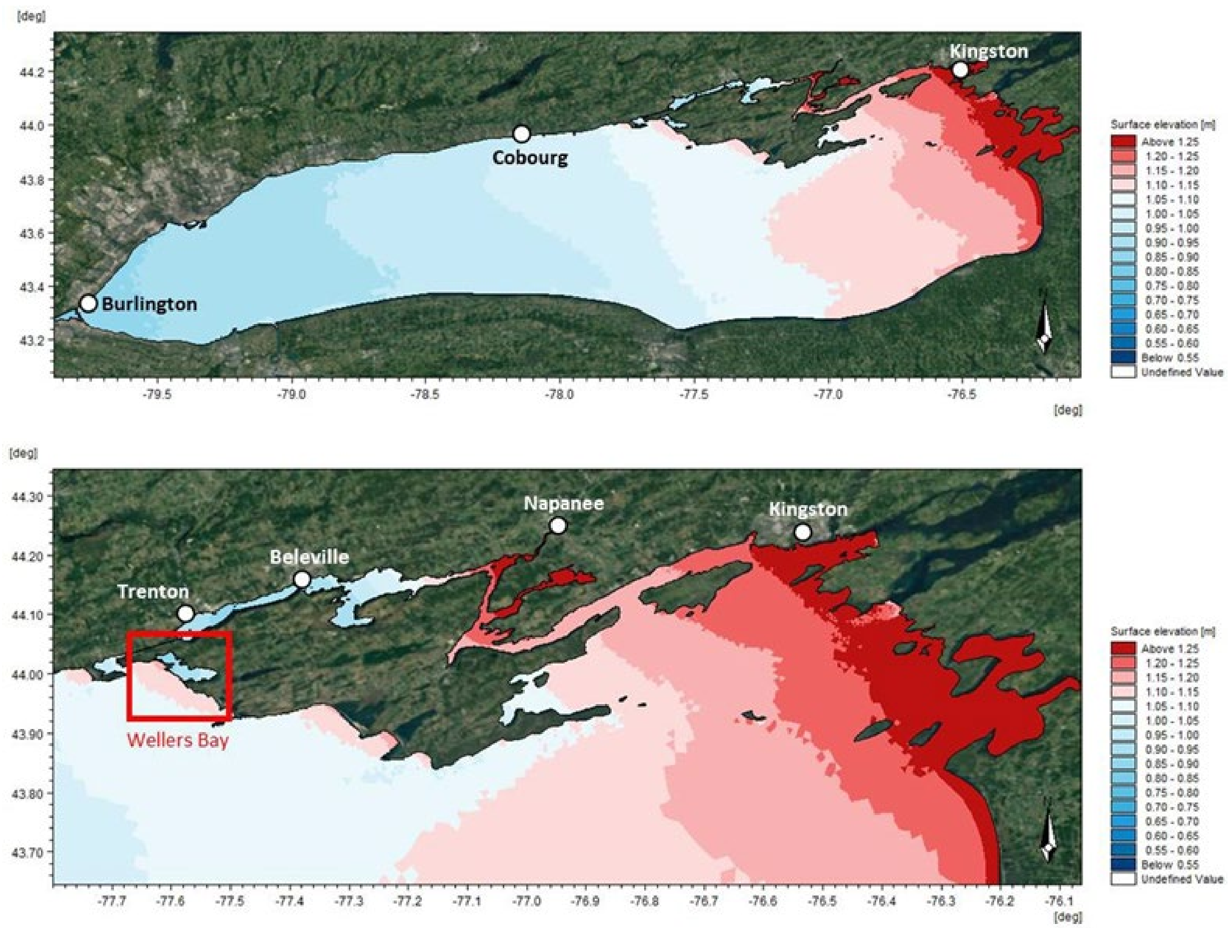


Figure 4.15 Model output showing maximum water levels across Lake Ontario (top) and the project region (bottom) during the April 6, 1979 storm surge event (in metres above Chart Datum)

Storm surge penetrating through narrow constrictions, channels and along shallow bodies of water connected directly or in-directly to Lake Ontario are a concern when identifying flood risks for low-lying areas. Wellers Bay was selected as a sample location to investigate the potential for storm surge to penetrate into a sheltered embayment through a narrow channel opening. Wellers Bay shares similar characteristics with nearby North Bay, Pleasant Bay, Huycks Bay, West Lake and East Lake, and is therefore indicative of storm surge potential within any of these small, enclosed, southwest-facing bodies of water.

The channel between Wellers Bay and Lake Ontario was resolved at a high resolution in the surge model (< 5.0 m). For this simplified investigation, the barrier beach between the Wellers Bay and Lake Ontario was assumed to be closed, with no exchange of water possible over the low-lying beach. The model results shown in Figure 4.16 indicate that only some storm surge penetration through the channel mouth would occur during the simulated events, resulting in a surge gradient from west to east within the embayment of no more than 20 cm. Local surge along the outer shoreline (i.e. lakeside) of the barrier beach is about 25 cm higher than the water level inside Wellers Bay during the April 6, 1979, storm. The elevation of the barrier beach should be taken into consideration in the event of future higher lake levels to determine whether the barrier beach would be overtopped and breached by a large surge event.

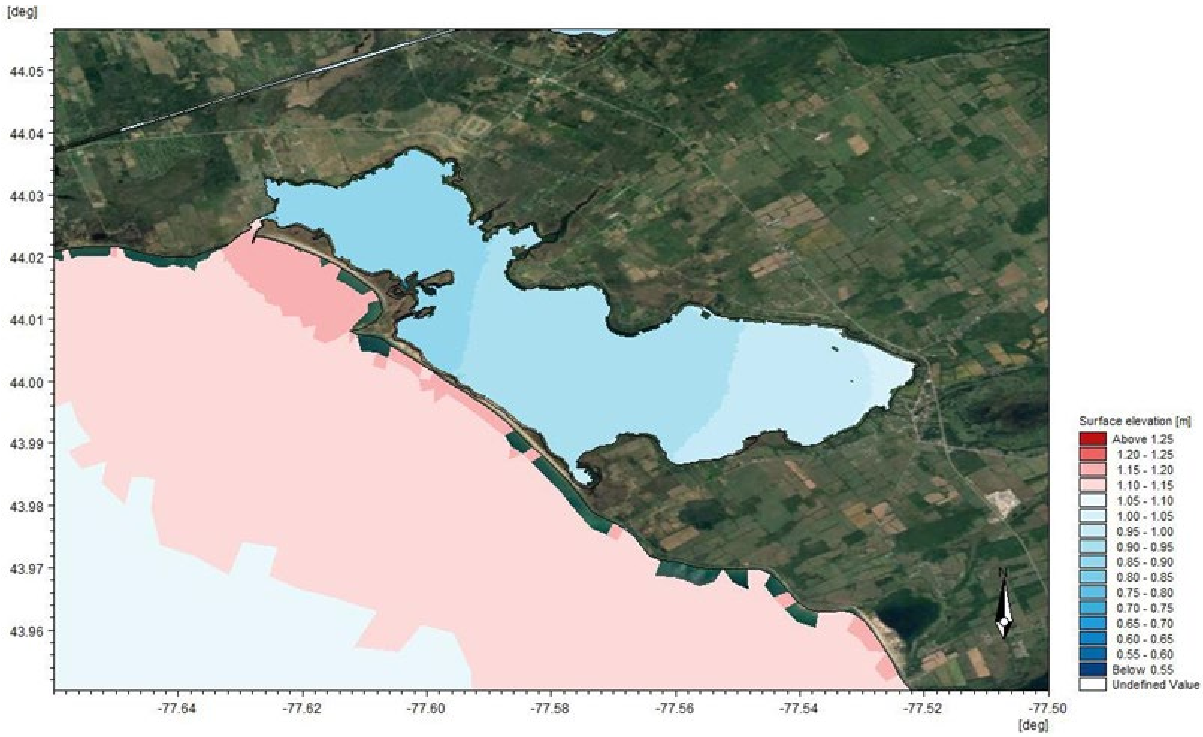


Figure 4.16 Simulated storm surge gradient within Wellers Bay during the April 6, 1979, storm event (in metres above Chart Datum)

The model was used to simulate the December 16, 2007 event to investigate storm surge potential in the western extent of the Bay of Quinte during strong easterly winds. The storm surge event was validated at the Burlington water level gauge, and also compared to water levels observed at Kingston and Cobourg. A comparison of modelled and measured water levels during the surge event is provided in Figure 4.17 at Burlington (left) and Kingston (right). The observed discrepancy in the event peak at the Burlington gauge is likely due to the very short duration of the event itself, which is difficult to capture in the model. Importantly, the model is able to capture the water level draw-down at Kingston, attributed to a lake-wide seiching effect, where lake water accumulates at the western extent of the lake due to the surge effect, reducing water levels along the eastern extent of the lake. The ability of the model to capture lake-wide seiching and variable water levels at locations throughout Lake Ontario during the December 16, 2007, storm event validates the model's ability to replicate lake wide storm surge conditions.

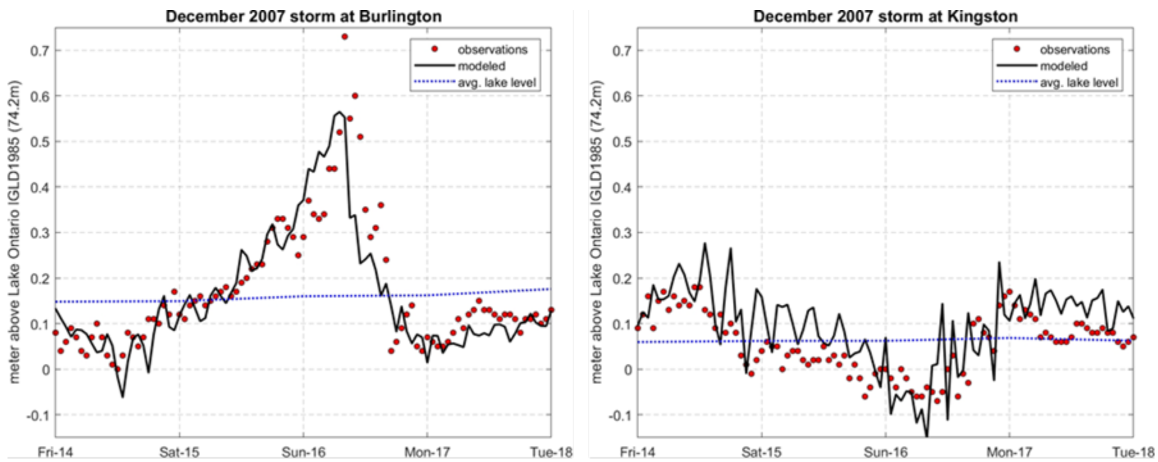


Figure 4.17 Model validation at Burlington (left) and Kingston (right) during the December 16, 2007, storm surge event (in metres above Chart Datum).

The maximum water levels simulated within the Bay of Quinte during the December 2007 storm event are illustrated in Figure 4.18 below. The model results confirm that a surge gradient from east to west occurs within the Bay of Quinte during significant surge events on Lake Ontario associated with westerly winds, resulting in elevated water levels at the west end of the Bay (near Carrying Place and Trenton).

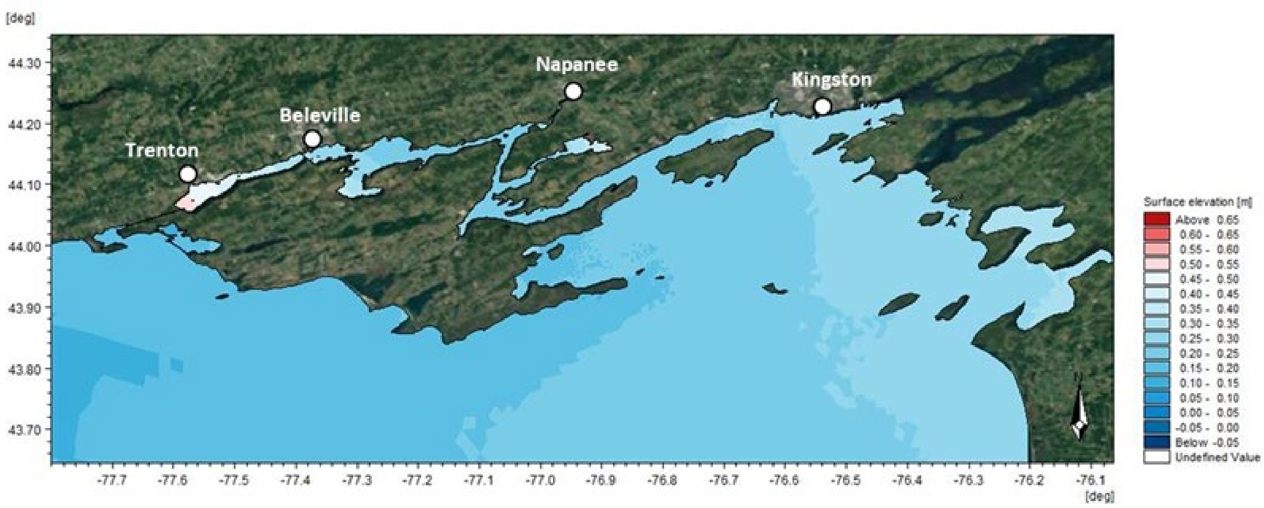


Figure 4.18 Maximum modelled storm surge within the project region during the December 16, 2007, storm surge event (in metres above Chart Datum)

Modelled maximum storm surge levels throughout the entire project region and for all four (4) simulated storm events are summarized graphically in Figure 4.19 below. All model results were found to be within 10 cm of measured water levels at Cobourg and Kingston throughout the surge events. The contours (surge magnitudes) shown in Figure 4.19 are the maximum water level recorded at each model node over a 24-hour period surrounding the peak of the storm. The maps provided in Figure 4.19 therefore depict the primary storm surge gradient associated with the event peak, as well as secondary and tertiary surge gradients associated with rapidly shifting wind directions that can occur during extreme surge events.

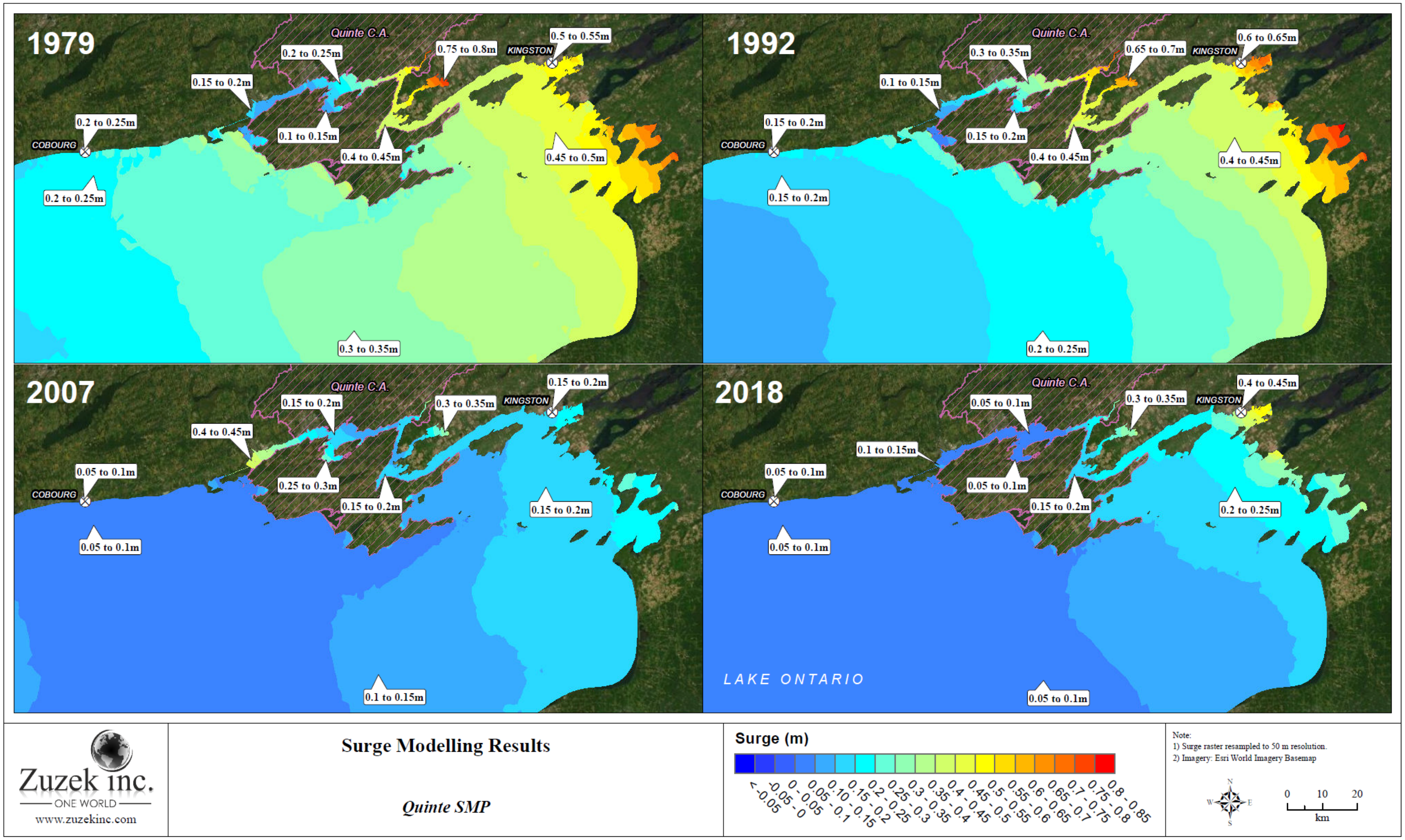


Figure 4.19 Maximum surge magnitude (in metres) experienced throughout the model domain during the four (4) simulated surge events

The storm lists of surge events at Cobourg and Kingston were manually scaled to be representative of surge magnitudes at other locations based on modelled storm surge gradients presented in Figure 4.19 above. For example, surges on the order of 40 cm to 45 cm were determined to be possible during extreme historical westerly wind events within Reach 1 at the west end of the project (i.e. at Wellers Bay Barrier Beach). These same events were generally shown to produce surges at Cobourg on the order of 30 cm to 35 cm. As such, the measured surge events at Cobourg were scaled by a factor of 1.25 to create a synthetic surge dataset at that location. Statistical analyses described in Section 4.3.2 through 4.3.4 including the extreme value analysis of storm surge events and the joint probability analysis of static lake levels and storm surge were repeated using the scaled storm surge data for the month of June (included events from May – July) as this period was shown to produce the governing 100-year flood level at Cobourg. Following this methodology a 100-year flood level of +76.07 m IGLD85' was determined for Reach 1 at the west end of the project. Figure 4.20 shows the probability distribution of storm surge events at Cobourg for the month of June (left) and the probability distribution at the west end of the project that resulted from scaling the surge events at Cobourg (right).

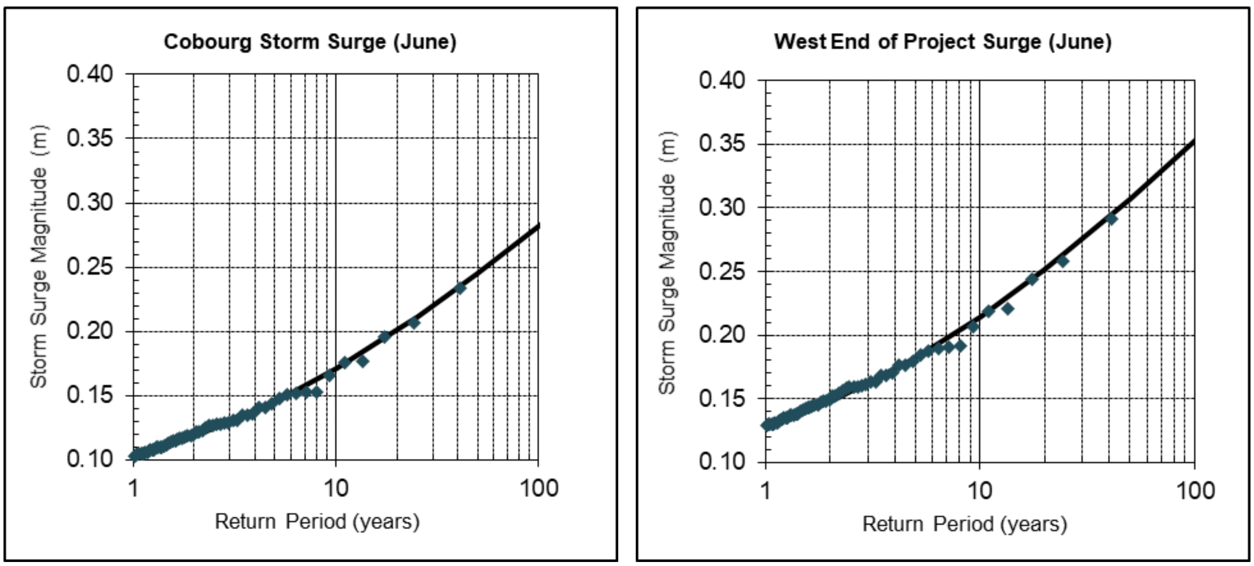


Figure 4.20 Probability distributions for storm surge at Cobourg (left – measured data) and for Reach 1 at the west end of the project (right – scaled data)

The same methodology was followed to estimate the 100-year flood level at the west and east ends of the Bay of Quinte, where surges on the order of 45 cm and 80 cm were determined to be possible during significant easterly and westerly wind events, respectively (refer to Figure 4.19). At the east end of the Bay of Quinte for example (i.e. Napanee), surges of 75 cm to 80 cm were shown to be possible during surge events that produced surges of 60 cm to 65 cm at Kingston. The Kingston surge dataset was scaled accordingly, and the joint probability analysis repeated for the east end of the Bay of Quinte using the scaled surge data. The resulting 100-year flood level at Napanee and within Hay Bay (near Galt's Corner) was estimated at +76.15 m IGLD85'. A map illustrating recommended 100-year flood levels for the entire project geography within both Quinte Conservation and the Cataraqui Region Conservation Authority's jurisdictions is provided as Figure 4.21 below.

Figure 4.21 100-year flood levels for entire project geography based on updated joint probability analyses of measured static lake levels (1900 – 2021) and storm surge (1962 – 2021) at Cobourg and Kingston, scaled to other locations using DHI's high-resolution storm surge model

4.4 Wave Climate

Section 4.4 reviews the Lake Ontario and Bay of Quinte offshore wave climates affecting the project region, nearshore wave transformation modelling to assess wave conditions along the shoreline, and wave uprush calculations completed to inform the determination and delineation of the flooding hazard.

4.4.1 Existing Offshore Wave Data

To determine wave conditions for the Quinte-Cataraqui Lake Ontario shoreline, long-term historical wave data was downloaded from the Wave Information Study (WIS) database. The WIS is a United States Army Corps of Engineers (USACE) sponsored project led by the Coastal and Hydraulics Laboratory Engineering Research and Development Center providing hourly wave climatologies for all major shorelines throughout the United States. Included in this study was a 35-year wave hindcast for Lake Ontario covering the period from 1979 to 2014. In a wave hindcast, historical wind fields are used to drive a wave generation and propagation model to produce a timeseries of historical waves. The model is calibrated to measured wave buoy data where available. The WIS database is the most accurate and complete wind-wave dataset available for Lake Ontario at the time of writing.

The WIS database includes wave data output at more than 50 locations offshore of the project shoreline, as illustrated in Figure 4.22. The output points are generally located a distance of 3 to 4 km offshore due to the limited spatial resolution of the hindcast model. Twelve (12) output points were selected for analysis, spaced out evenly around the project geography. Stations analysed for this study are listed in Table 4.10.

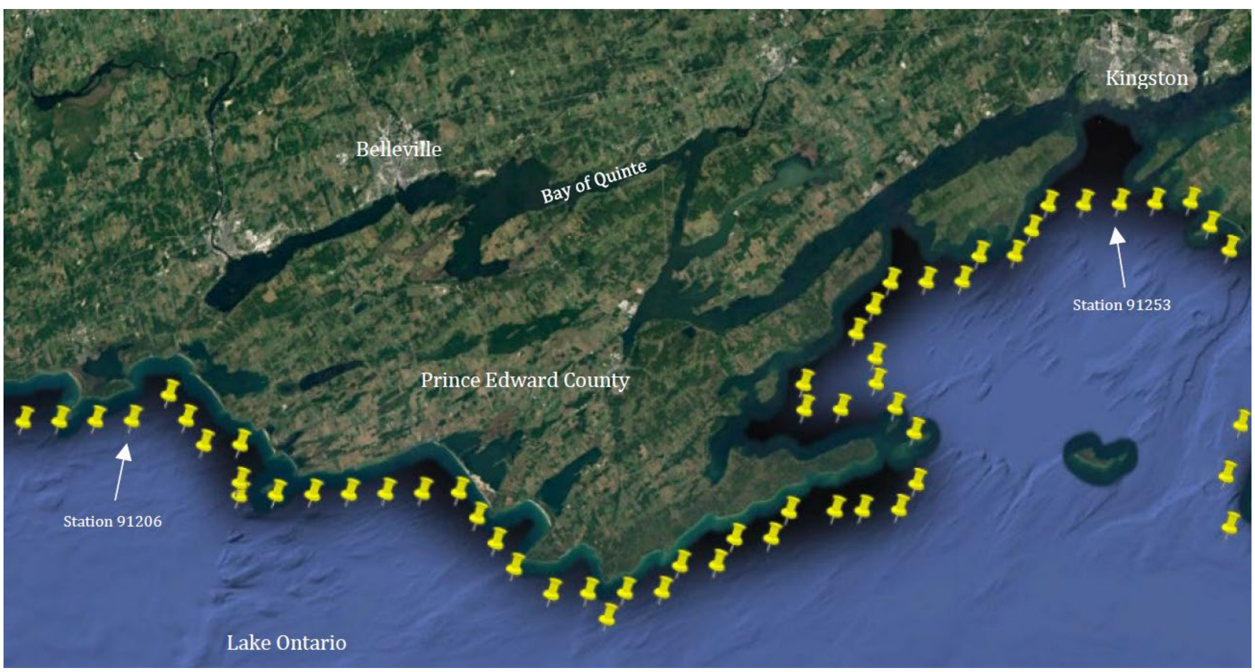


Figure 4.22 Wave output locations from the WIS study located within the project geography (USACE)

The 35-year timeseries of hourly wave data at each of the twelve (12) selected output points was subjected to statistical analyses to determine storm wave conditions corresponding to various average recurrence intervals (5-year, 25-year, 100-year, etc.). Assessed wave parameters included significant wave height (defined as the highest 1/3 of individual wave heights), peak wave period and mean wave direction. Storm lists were first generated for each selected output location, ranked by significant wave height, and subjected to extreme value analyses. Several probability distributions were fit to the data, with the best-fitting distribution based on visual assessment and correlation coefficient selected. Wave heights corresponding to a variety of return period events were subsequently evaluated at each WIS location based on the best-fitting statistical distribution. Where two distinct directional bins were present in the data, each bin was analysed separately and wave conditions for both primary and secondary storm directions were determined.

Plots of significant wave height versus wave period and wave direction were generated for all storm events within the storm lists to assess the maximum wave period and range in wave directions associated with each average recurrence interval event. Refer to Figure 4.23 which presents the relationship between wave height and wave period at Station 91212. Table 4.10 summarizes 25-year and 100-year wave conditions at each analysed WIS output location. The 25-year conditions were used in the determination of wave uprush which influences the regulatory flooding hazard. 100-year wave conditions are more commonly used in the design of coastal structures.

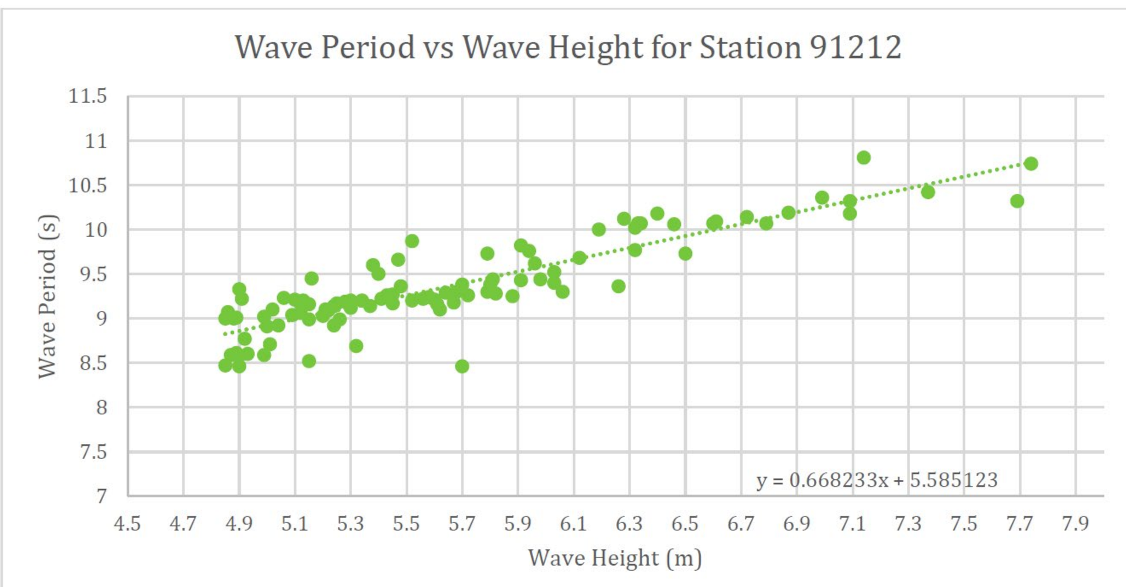


Figure 4.23 Relationship between significant wave height (Hs) and wave period (Tp) for top 100 storm events at WIS Station 91212

Table 4.10 25-year and 100-year wave conditions at WIS output locations

Station ID	ARI (years)	Primary Wave Direction			Secondary Wave Direction		
		Significant Wave Height (m)	Peak Wave Period (s)	Wave Direction (deg TN)	Significant Wave Height (m)	Peak Wave Period (s)	Wave Direction (deg TN)
91206	25	6.4	10.5	230 – 245	-	-	-
	100	7.0	11.0	230 – 245	-	-	-
91209	25	6.9	10.7	235 – 250	-	-	-
	100	7.5	11.1	235 – 250	-	-	-
91212	25	7.6	10.7	240 – 255	-	-	-
	100	8.3	11.1	240 – 255	-	-	-
91214	25	6.7	10.6	235 – 250	-	-	-
	100	7.2	11.1	235 – 250	-	-	-
91217	25	7.0	10.8	240 – 250	-	-	-
	100	7.5	11.2	240 – 250	-	-	-
91220	25	7.2	10.9	245 – 260	-	-	-
	100	7.8	11.4	245 – 260	-	-	-
91224	25	7.8	11.1	250 – 260	-	-	-
	100	8.2	11.4	250 – 260	-	-	-
91228	25	5.9	10.6	235 – 245	4.8	9.0	150 – 180
	100	6.3	11.0	235 – 245	5.1	9.3	150 – 180
91234	25	6.9	10.8	235 – 245	4.9	10.0	160 – 190
	100	7.6	11.3	235 – 245	5.2	10.9	160 – 190
91242	25	3.7	7.7	135 – 170	3.7	6.0	230 – 255
	100	4.1	8.0	135 – 170	4.1	6.4	230 – 255
91247	25	4.6	8.2	160 – 185	3.7	7.8	210 – 235
	100	5.1	8.6	160 – 185	4.0	8.0	210 – 235
91253	25	4.8	8.5	215 – 235	4.5	8.0	165 – 195
	100	5.1	8.7	215 – 235	4.8	8.6	165 – 195

4.4.2 Numerical Modelling of Nearshore Waves

The numerical wave model CMS-Wave was used to transform the offshore 25 and 100-year WIS storm waves shown in Table 4.10 to the project shoreline. CMS-Wave is a two-dimensional, phase-averaged, spectral transformation model that employs a forward-marching, finite-difference method to solve the wave action conservation equation. It simulates all major nearshore wave transformation processes including wave refraction, shoaling, diffraction and breaking over complex bathymetries.

Six separate wave model grids were setup to cover the exposed Lake Ontario shorelines within the project geography. Each model grid featured a cell resolution of between 10 x 10 m and 15 x 15 m, and contained at least one of the analyzed WIS output locations within the model domain, near the offshore boundary. This facilitated the calibration of each model to the 25 and 100-year wave conditions listed in Table 4.10. The general location, orientation, and size of the six CMS-Wave models is shown in Figure 4.24. Analyzed offshore wave locations (WIS output locations) are shown in the figure as yellow dots.

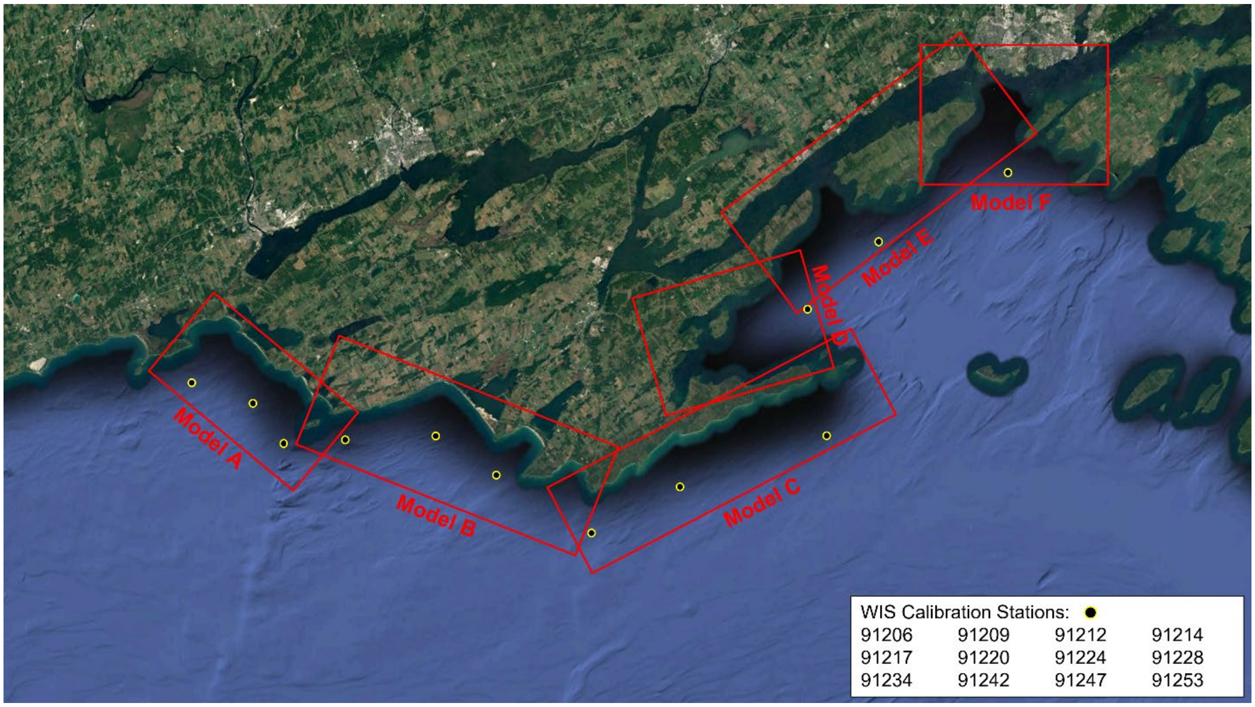


Figure 4.24 Location, size, and orientation of each of the six (6) numerical wave models used to transform 25-year and 100-year offshore waves to the project shoreline

Bathymetry used in the nearshore wave models was obtained from the CHS non-navigational (NONNA) bathymetric data portal and supplemented with single-beam bathymetric data collected by Zuzek Inc. in the fall of 2021 at areas of interest. This is the same bathymetric dataset that was used in the DHI storm surge modelling described in Section 4.3.5. Land boundaries used in the model were delineated manually from 2018 satellite imagery. The model domain and bathymetric contours for Model B are shown in Figure 4.25. Model B includes project Reaches 3, 4 and part of 5, including all Lake Ontario shoreline from Huyck's Point to Point Petre.

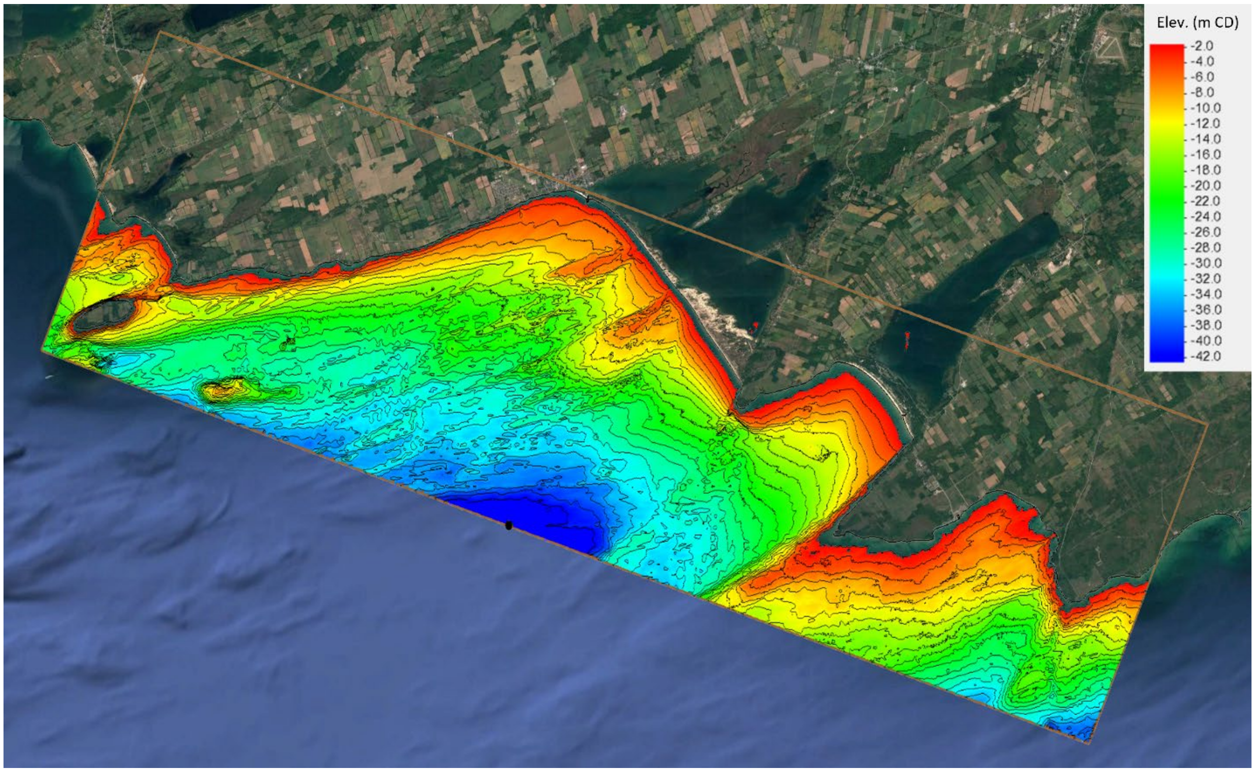


Figure 4.25 Nearshore wave model (CMS-Wave) domain and bathymetric contours for Model B, from Huyck's Point to Point Petre

Offshore storm waves were input at each of the model boundaries and adjusted (calibrated) such that the WIS conditions listed in Table 4.10 for the 25-year and 100-year events were reproduced at the location of the WIS output point(s) within each model domain. In general, wave heights at the WIS point closest to the offshore boundary of each model were reproduced with an accuracy of +/- 2%. For models where multiple analysed WIS points fell within the model domain, all other WIS locations were reproduced with an accuracy of +/- 5% for the 25-year and 100-year wave events.

Once calibrated, each of the six (6) models was run for the 25-year and 100-year storm events, with the water level set at the 100-year flood level for the shoreline (+76.07 for Models A, B, and C, +76.08 for Models D and E, and +76.09 for Model F – refer to Figure 4.21). Wind-wave generation was included in the model, with the input wind speed and direction being commensurate with the average recurrence interval and direction of the wave event. 25-year and 100-year wind speeds were analysed for a variety of directional bins from measured wind data at the Trenton Air Base, as discussed further in Section 4.4.3 below.

Nearshore wave information was output from the numerical models at various locations around the shoreline where wave uprush calculations would be made. This is discussed further in Section 4.4.4. Figure 4.26 presents a contour plot of 25-year wave heights for Model A, which covers the Lake Ontario shoreline from Wellers Bay to Huyck's Point. Vectors indicate the direction of wave propagation throughout the model domain during the 25-year event.

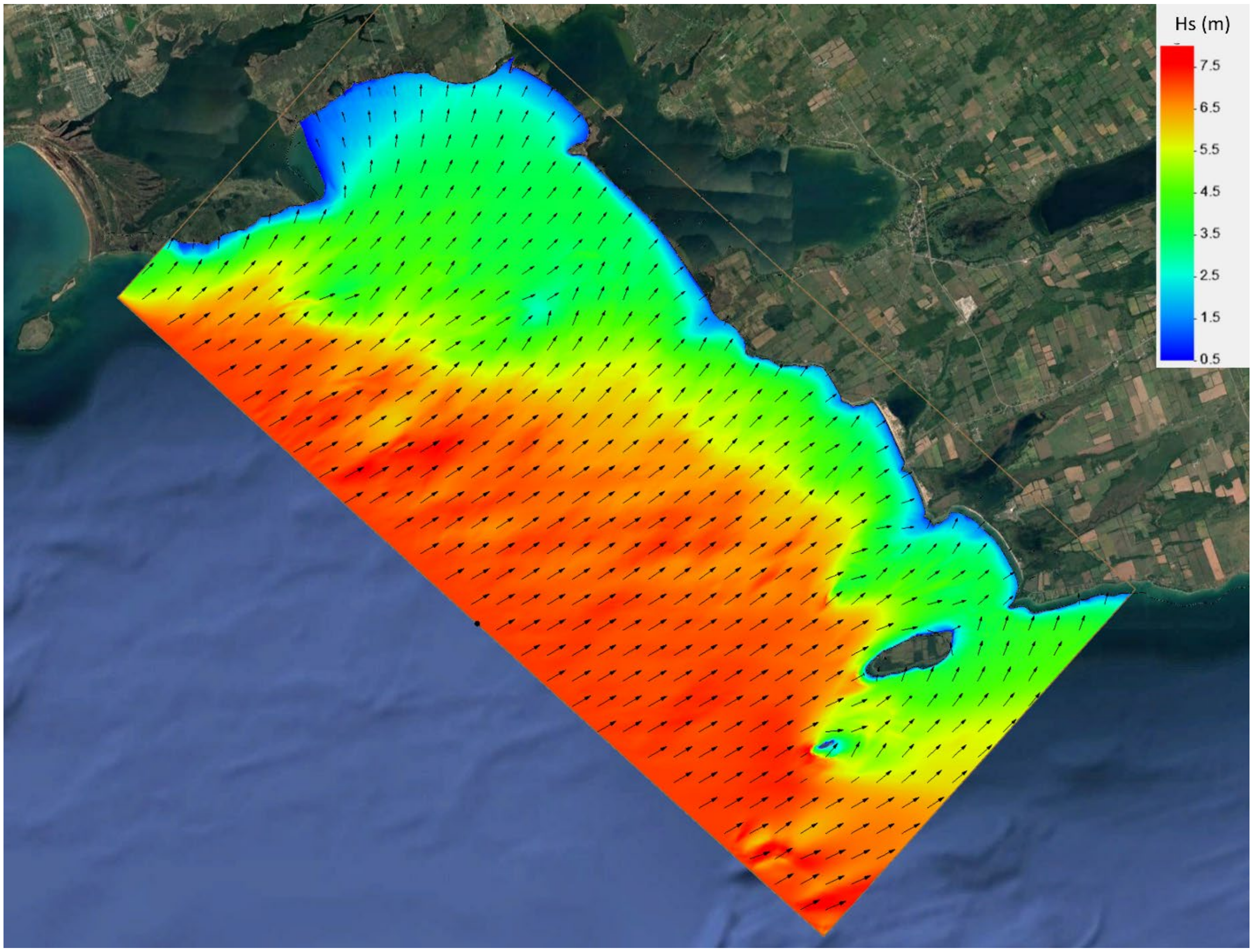


Figure 4.26 Modelled significant wave height (colour contours) and direction of wave propagation (vectors) for the 25-year event from Wellers Bay to Huyck's Point (Model A)

4.4.3 Wave Generation in Bay of Quinte and Sheltered Embayments

Given that no wave database is available for the Bay of Quinte, a parametric wind-wave hindcast was performed to assess the wave generation potential within each portion of the embayment. In a parametric hindcast, empirical equations for wave growth are applied to determine the wave heights that may be realized during significant wind events. Wave growth equations are based primarily on wind speed, duration of sustained winds, fetch (open-water distance over which the wind is blowing) and available water depths. The hindcast performed herein generally follows the procedures and methodology found in the Shore Protection Manual (USACE, 1984).

Hourly wind data was downloaded at both the Trenton Airforce Base (1953 – 2021) and Kingston Airport (1967 – 2021), courtesy of Environment and Climate Change Canada. Both wind datasets were filtered to isolate maximum wind speeds within moving 72-hour periods. Peak winds were subsequently ranked and checked for independence. The datasets were further disseminated into 18 directional bins, and storm lists of ranked wind events were produced for each direction. Only the top 69 and 54 wind events were retained in the storm lists for Trenton and Kingston respectively, commensurate with the number of years in the datasets (one event per year, on average).

Storm lists for each directional bin and for both locations were subjected to an extreme value analysis and fit to a number of statistical distributions. The best fitting distributions for each directional bin based on the calculated correlation coefficient were used to assess the 25-year and 100-year wind speeds from each direction, at both locations. Table 4.11 presents the results of this analysis.

Table 4.11 25-year and 100-year wind conditions for 18 directional bins at Trenton Air Force Base and Kingston Airport

Wind Direction (+/- 5 degrees TN)	Trenton (1953 – 2021)		Kingston (1967 – 2021)	
	25-year Wind Speed (m/s)	100-year Wind Speed (m/s)	25-year Wind Speed (m/s)	100-year Wind Speed (m/s)
0 – 10	13.2	14.4	15.4	17.5
20 – 30	13.7	14.5	13.9	15.8
40 – 50	15.1	17.7	13.5	14.3
60 – 70	13.2	15.1	12.8	16.5
80 – 90	11.1	13.3	10.9	12.3
100 – 110	11.3	12.3	8.3	9.8
120 – 130	9.5	11.0	10.1	11.4
140 – 150	13.9	17.6	14.8	16.9
160 – 170	14.6	16.4	17.7	19.4
180 – 190	13.9	16.3	18.0	19.2
200 – 210	16.1	19.7	17.4	20.6
220 – 230	21.2	23.0	17.9	19.6
240 – 250	22.5	27.0	21.1	23.3
260 – 270	19.7	20.8	19.1	21.8
280 – 290	19.1	21.1	16.2	19.4
300 – 310	15.5	17.2	13.1	14.4
320 – 330	17.5	19.9	13.0	14.1
340 – 350	15.2	17.2	14.7	18.8

As can be seen from Table 4.11, 25-year and 100-year wind speeds based on available records at the two locations are generally similar, with both locations featuring the highest wind speeds from the 240 – 250 directional bin. Given the similarities between the two datasets, only winds at Trenton were used for the Bay of Quinte hindcast discussed below. Trenton is both closer in proximity to the majority of the Bay of Quinte and features generally higher wind speeds from the critical directions that align with the orientation of the Bay.

The Bay of Quinte was separated into sub-reaches within which wave growth potential could be evaluated. Wave growth potential was also simulated for several sheltered embayments on the southwest side of Prince Edward County, including Wellers Bay, North Bay, West Lake, and East Lake. Figure 4.27 presents a graphical summary of the sub-reaches used in the analysis of wave growth potential (coloured boxes).

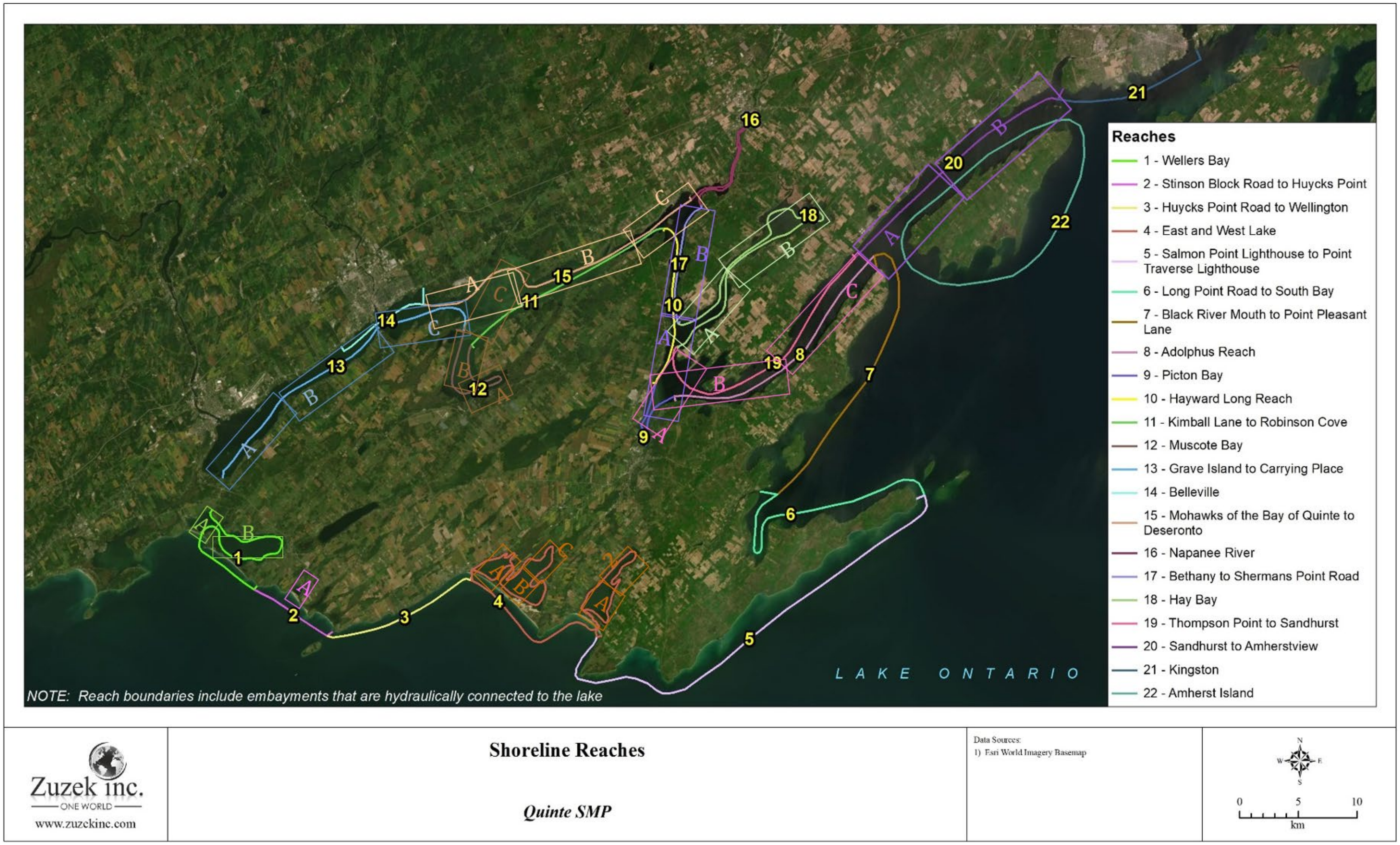


Figure 4.27 Project reaches (yellow numbers) and sub-reaches (coloured boxes and letters) used in the analysis of wave growth potential for sheltered and interior embayments including the Bay of Quinte

For each sub-reach shown in Figure 4.27, the available fetch and average water depth across the fetch from all 18 directions was documented. Water depths were based on the 100-year flood levels shown in Figure 4.21 and bathymetry previously described in Section 4.3.5. Average water depths in Wellers Bay and West Lake were sourced from navigational charts, while depths in North Bay and East Lake were assumed. Wave growth calculations were subsequently completed for each sub-reach and from all directions in which a notable fetch was present, using the corresponding directional 25-year and 100-year wind speeds shown in Table 4.11. Wind speed adjustments to account for over-water versus over-land effects were only applied where they resulted in an increase in the windspeed (Resio and Vincent, 1977). In general, wave growth was fetch limited and was governed by winds arriving from the 240 – 250 degree directional bin (i.e. the strongest wind direction). Notable exceptions to this are listed as follows:

- Reach 12 (sub-reach B, Muscote Bay): wave growth governed by 40 – 50 degree winds
- Reach 10/17 (sub-reach A, Long Reach): wave growth governed by 20 – 30 degree winds
- Reach 10/17 (sub-reach B, Long Reach): wave growth governed by 200 – 210 degree winds

Governing significant wave heights and wave periods achieved within each analysed sub-reach during the 25-year wind event are summarized graphically as Figure 4.28 and Figure 4.29. The results were subsequently used in the estimation of wave uprush throughout the Bay of Quinte and other sheltered embayments, as discussed further in Section 4.4.4.

Although not explicitly used in this study, wave growth potential corresponding to the 100-year wind event was also evaluated throughout the Bay of Quinte and other sheltered embayments. The 100-year event would produce wave conditions more commonly used in the design of coastal infrastructure. 100-year wave heights and periods throughout the Bay of Quinte and other sheltered embayments are summarized graphically in Figure 4.30 and Figure 4.31 below.

It is noted that the analysis of wave growth potential presented herein is meant to be a conservative approach applied at a regional scale. For site specific wave conditions to be used in the assessment of lot-level shoreline hazards or the design of coastal infrastructure, a site-specific assessment of the design wave condition along the shoreline should be completed.

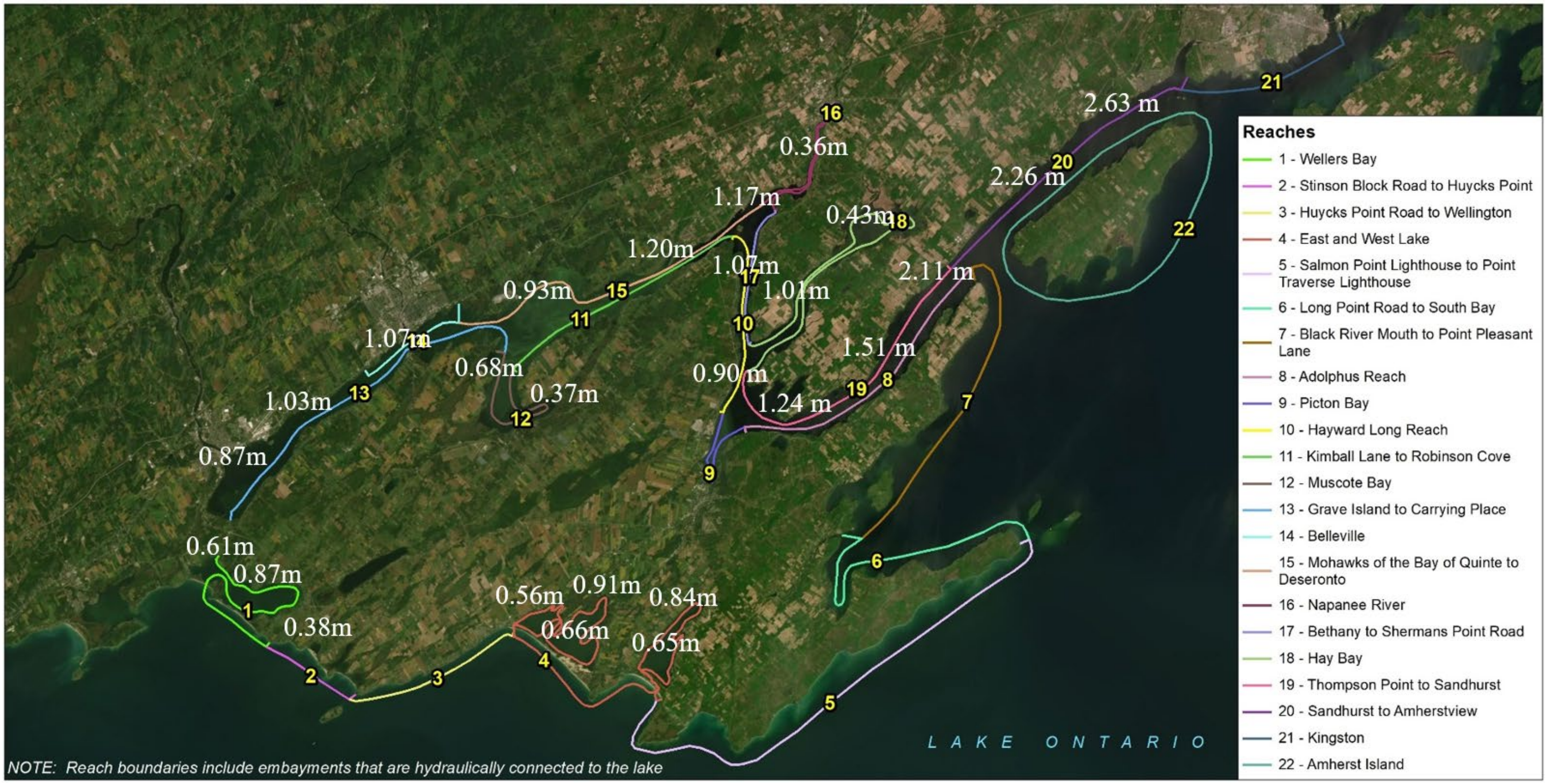


Figure 4.28 Estimated 25-year significant wave height (meters) throughout the Bay of Quinte and other sheltered embayments

Figure 4.29 Estimated 25-year wave period (seconds) throughout the Bay of Quinte and other sheltered embayments

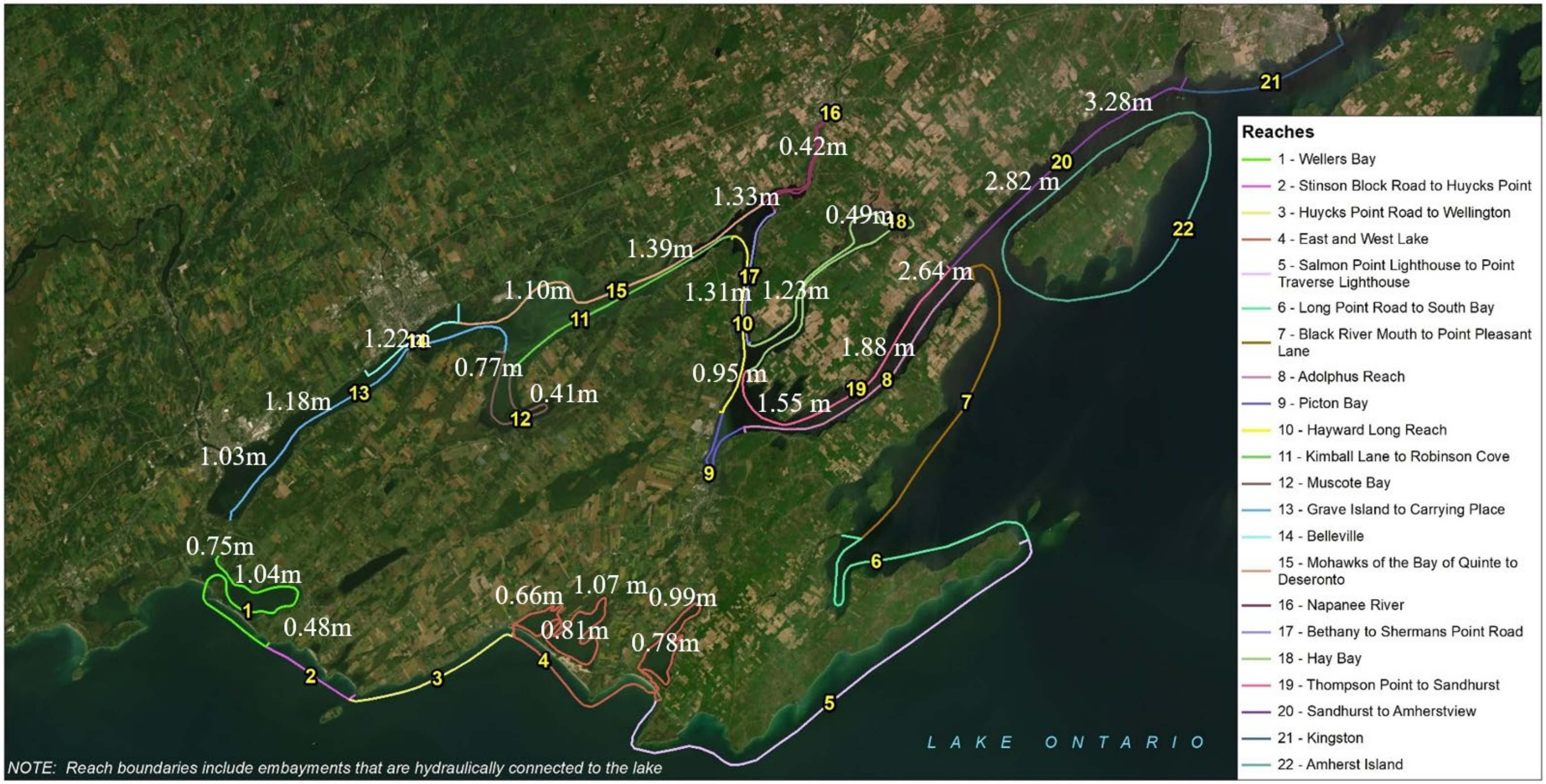


Figure 4.30 Estimated 100-year significant wave height (meters) throughout the Bay of Quinte and other sheltered embayments

Figure 4.31 Estimated 100-year wave period (seconds) throughout the Bay of Quinte and other sheltered embayments

4.4.4 Wave Uprush Analysis

As discussed in detail in Section 5.2, determining an appropriate horizontal distance landward from the waterline that may be impacted by wave action is a critical component of both the flooding hazard and dynamic beach hazard definitions. To address this, wave uprush was assessed at 77 locations along the QC and CRCA shorelines. Wave uprush describes the process by which waves break along a shoreline and surge up the shoreline to an elevation higher than the static water level. A definition sketch of wave uprush is provided in Figure 4.32 below.

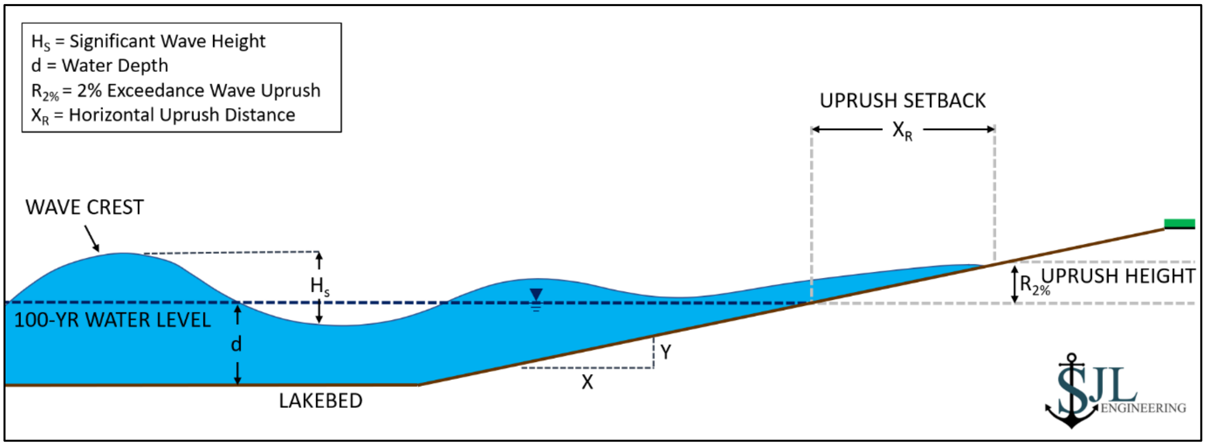


Figure 4.32 Wave uprush on a gentle sloping shoreline – definition sketch

The water level used in the wave uprush analyses was the 100-year flood level (refer to Figure 4.21) with wave conditions corresponding to the 25-year wave event, commensurate with the guidance provided in the Great Lakes Technical Guide (MNR, 2001). Figure 4.33 presents a map of locations for which wave uprush was estimated. Note that uprush was assessed at both ends of profiles 27, 36-49 and 51-56, resulting in 77 separate uprush calculations.

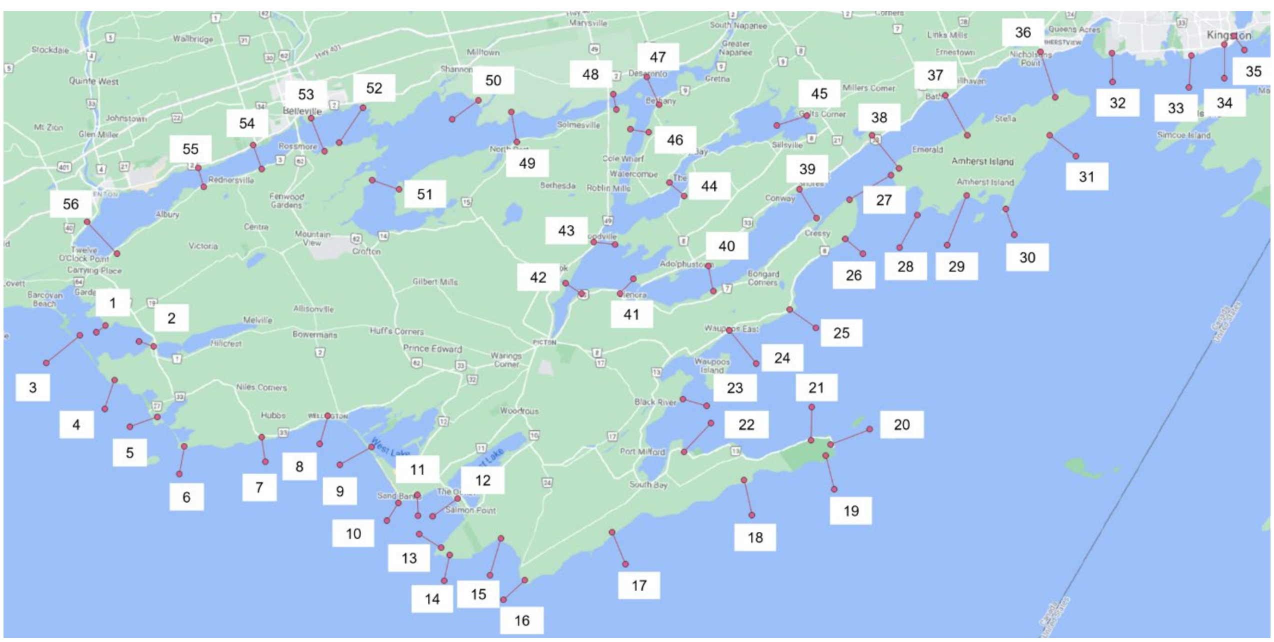


Figure 4.33 Location of wave uprush profiles

Wave uprush elevations were estimated using an in-house composite slope uprush tool, which calculates the equivalent slope uprush at specified intervals along a given nearshore profile based on input wave conditions and using a variety of wave uprush formulations. For regional scale mapping studies, the Upper Bound Method published in the Technical Guide for Great Lakes – St. Lawrence River Shorelines is an appropriate formulation for the estimation of wave uprush, and was selected for use in this study (as per MNR, 2001a). In the composite-slope uprush calculation, the 2% exceedance uprush elevation is first calculated based on wave conditions at the lakeward end of the bathymetric/topographic profile. The tool then calculates the uprush resulting from progressively smaller wave heights moving landward across the profile (i.e., through the surf zone). At each calculation point, the uprush solution is iterated for an equivalent straight line slope drawn from that location on the profile to the predicted limit of wave uprush (on the portion of the profile above the waterline). The resulting uprush elevation is therefore associated with a specific point on the topographic portion of the profile, from which a horizontal distance from the waterline can also be determined.

For shorelines featuring a low bank with a well defined crest, wave uprush may exceed the crest elevation and becoming wave overtopping. This scenario is illustrated in Figure 4.34. Although the composite slope approach does provide an uprush elevation and horizontal distance estimate for low-bank shorelines, it may be less accurate due to the overtopping processes that occur as wave action surpasses the bank crest. For these types of shorelines, Cox and Machemehl (1986) present a simplified equation for the prediction of the overland propagation of wave action that overtops a low-bank or bluff shoreline. Inputs to the equation include the wave period, runup elevation on the bank (assuming an infinite bank height) and freeboard (elevation of bank crest above the static water level). Where low-bank/cliff/bluff shorelines were encountered throughout the project geography, both the composite-slope uprush and the Cox and Machemehl methods were evaluated, with the greater horizontal uprush distance between the two methods being selected.

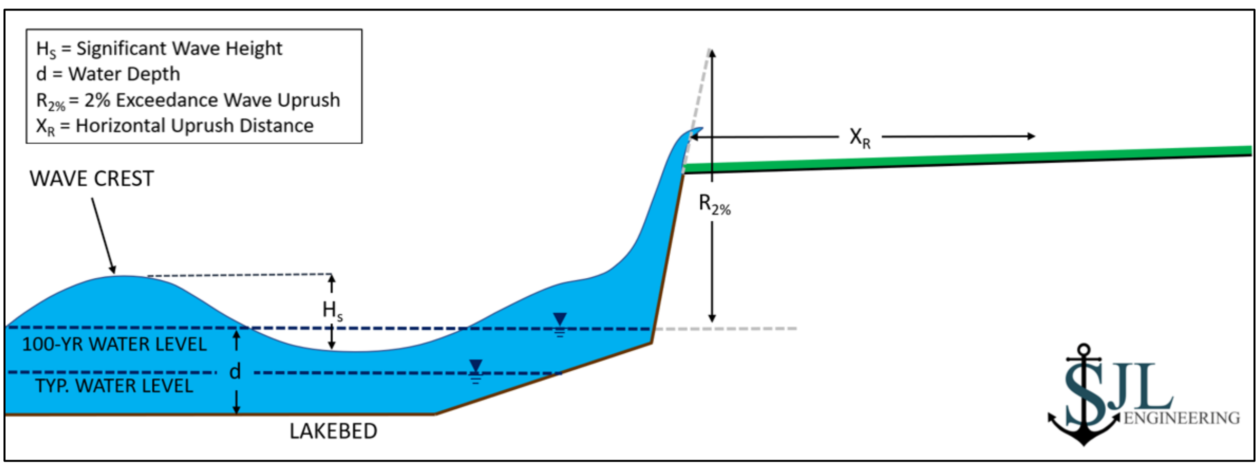


Figure 4.34 Wave uprush on a steep bank or cliff resulting in overtopping of the bank crest

Given that wave uprush elevations can vary significantly over short distances of shoreline due to changes in nearshore depth and shoreline geometry (primarily slope and roughness), estimating an uprush elevation and mapping it to a topographic contour is not an appropriate means for delineating the zone that may be impacted by wave uprush except for over very short distances.

The preferred approach for local and regional scale mapping is to calculate uprush at several locations within each project reach, to determine the horizontal distance from the waterline associated with the calculated uprush elevation at each profile, and to choose a conservative horizontal setback for each reach accordingly.

The standard wave uprush allowance for Great Lakes shorelines, as stipulated in the Great Lakes Technical Guide, is 15 m measured horizontally from the 100-year flood level. Generally, this allowance is not reduced unless detailed wave uprush calculations reveal it to be over-conservative. The standard 15 m uprush allowance can be increased, should site-specific uprush calculations confirm a larger horizontal setback may be required. This is most often the case for gentle sloping shorelines, such as for sandy, low-lying, headland-bay beaches (e.g. Outlet Beach in Reach 4). In general, the horizontal component of wave uprush was determined to be less than 15 m for all evaluated profiles on the exposed Prince Edward County shoreline and throughout the Bay of Quinte. The sole exception to this was for gentle-sloping beach shorelines (e.g. Pleasant Bay Barrier Beach), where the horizontal component of uprush was found to generally be between 15 and 25 m, measured from the 100-year water line. The application of the wave uprush results in the determination and delineation of the shoreline flooding and dynamic beach hazards is discussed in Sections 5.2 and 5.3.

Table 4.12 below provides a summary of governing uprush elevations within each project reach. Wave uprush results presented herein are commensurate with the level of detail required for a regional-scale hazard mapping study. For a lot-by-lot level assessment, the calculation of wave uprush should be completed on a site-specific basis using appropriate nearshore bathymetry, shoreline topography and nearshore wave conditions.

Table 4.12 Governing wave uprush elevations for each project reach and sub-reach shoreline type (where appropriate)

Project Reach	Conservation Authority	100-year WL (m IGLD85')	Calculated Uprush Elevation (m IGLD85')	Sub-Reach Shoreline Type
1	QC	76.07	76.7	Wellers Bay
			78.1	Barrier Beach
			79.0	-
2	QC	76.07	77.7	Barrier Beach
			79.0	-
3	QC	76.07	79.2	-
4	QC	76.07	76.7	East/West Lake
			77.7	Main Barrier Beach
			78.0	County Rd. 12
			77.1	Outlet Barrier Beach
5	QC	76.07	77.8	SW Side
			77.5	SE Side
			76.6	Sheltered Marsh
6	QC	76.08	80.0*	High/Steep Bank
			77.5	-
7	QC	76.08	80.0*	High/Steep Bank
			77.5	-
8	QC	76.08	77.5	-
9	QC	76.10	76.9	Picton Bay
			78.8	Port of Picton
10	QC	76.10	78.8	-
11	QC	76.10	77.1	-
12	QC	76.10	77.0	-
13	QC	76.10	77.1	-
14	QC	76.10	77.1	-
15	QC	76.10	77.1	-
16	QC	76.15	76.8	-

*Near-vertical cliff typically exceeds uprush elevation

4.5 Projected Impacts of Climate Change

The projected impacts of climate change on air and lake temperatures, ice cover, wave climate, and future lake levels is reviewed based on published information and technical work completed for this study.

4.5.1 Warming Due to Climate Change

In Canada's Changing Climate report by Bush and Lemmen (2019), Chapter 4 on temperature and precipitation states that it is virtually certain Canada's climate will continue to warm in the future, with the projected increase in mean temperature in Canada being about twice the global estimate (Zhang, X. et al, 2019). The results presented specifically for Ontario, project an increase in annual mean surface air temperature from 1.5 to 2.3 degrees Celsius by 2030-2050 (Zhang, X. et al, 2019) relative to 1986 to 2005. The projected increases in the winter air temperature for Representative Concentration Pathway (RCP) 2.6 and 8.5 are much greater and presented in Figure 4.35 for mid-century (2031 to 2050) and late century (2081 to 2100). By late century, winter temperatures for RCP8.5 are projected to be 5 to 7 degrees Celsius warmer in Southern Ontario relative to 1986 to 2005.

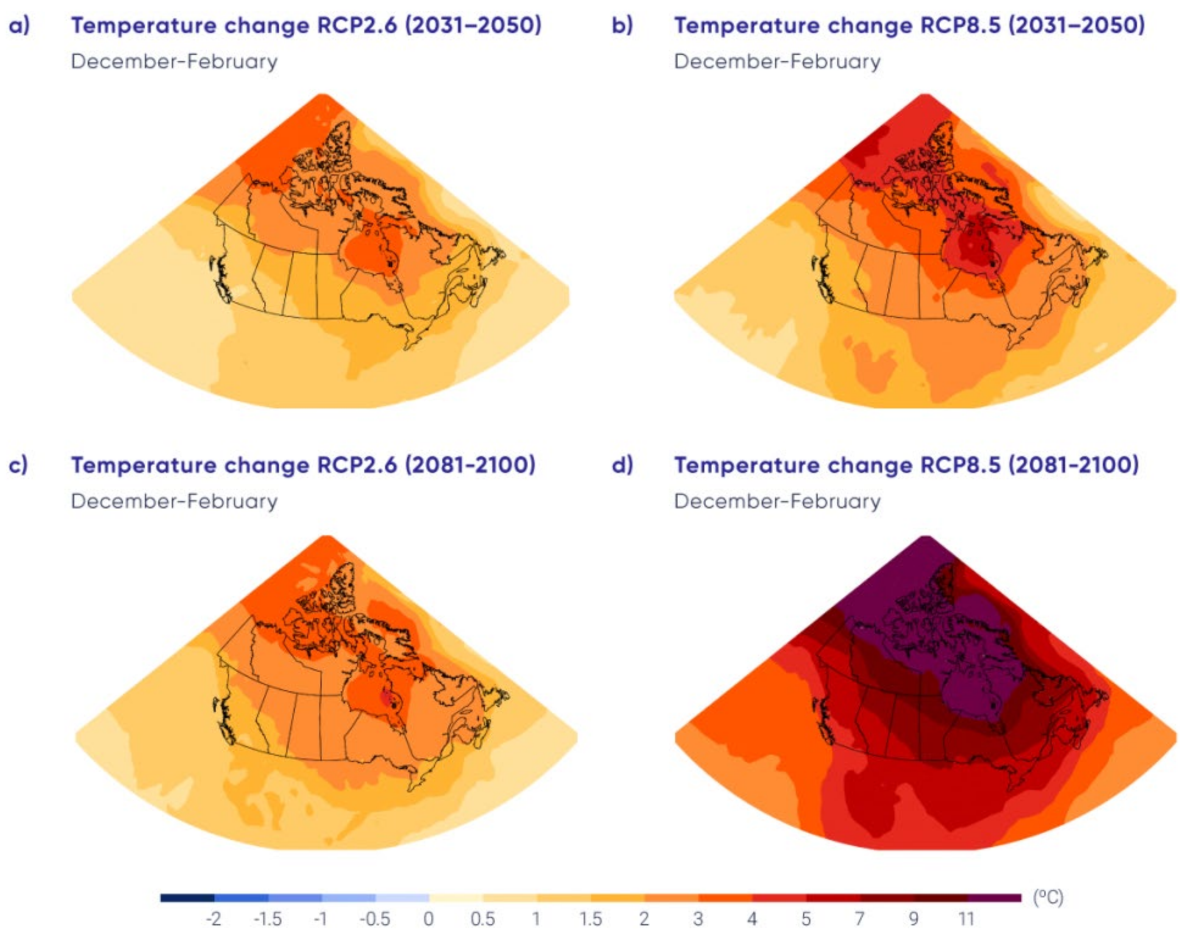


Figure 4.35 Winter warming in Canada for mid- and late-century (from Bush and Lemmen, 2019)

4.5.2 Ice Cover Trends and Projections Due to Warming

Ice cover in the Great Lakes has been decreasing since 1973 (Wang et al, 2012) with similar trends documented across the northern hemisphere (Sharma et al, 2019). The projected warming will continue to increase land and lake temperature, resulting in further reductions in ice cover in the future. Figure 4.36 provides a conceptual diagram of these potential changes for Lake Ontario with extensive ice cover in the eastern basin (left-hand panel), coverage limited to the Kingston Basin in the middle image, and no ice coverage in the open lake for the winter image in the right-hand panel.

Figure 4.36 Schematic diagram of reduced Lake Ontario ice coverage

Zuzek Inc. recently developed a tool to investigate and quantify changes in the historical nearshore ice cover on the Great Lakes for Environment and Climate Change Canada (Zuzek Inc., 2022). The GIS based tool leverages a daily ice concentration dataset developed by NOAAs Great Lakes Environmental Research Laboratory (GLERL) from 1973 to present. A sample of the basin wide coverage on February 14, 2018, is presented in Figure 4.37. Each coloured polygon represents ice cover with a different concentration (e.g., 31 to 40%).

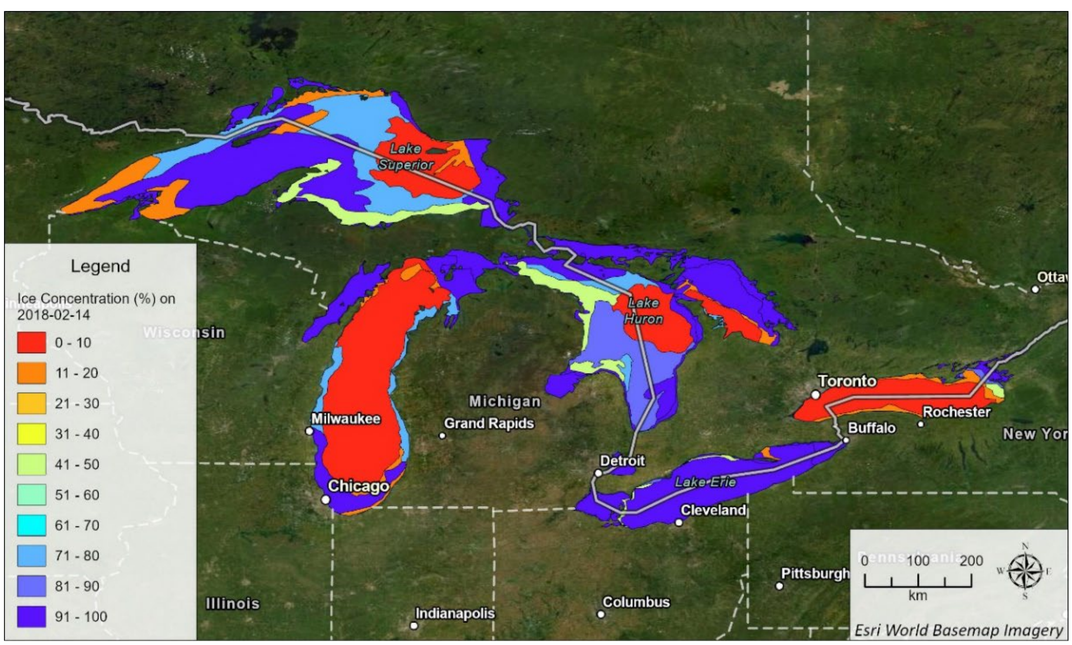


Figure 4.37 Sample of NOAA GLERL basin wide ice cover data (Feb. 14, 2018)

The ice tool was applied to four locations throughout the study area, including the Lake Ontario shoreline with western, southern, and southeastern exposure, and four locations within the Bay of Quinte. Refer to Figure 4.38. For the lake shoreline locations, four grid cells were selected to evaluate changes in a cross-shore direction. Each cell is 1.8 by 1.8 km.

Figure 4.38 Locations of historical ice analysis for study area

The number of ice days per winter season, from October to May, is summarized for Points 1 to 4 in Reach 2 (southwest shoreline). Historically, there has been considerable year to year variability in the number of ice days per season. Refer to Appendix C for the results in the Bay of Quinte.

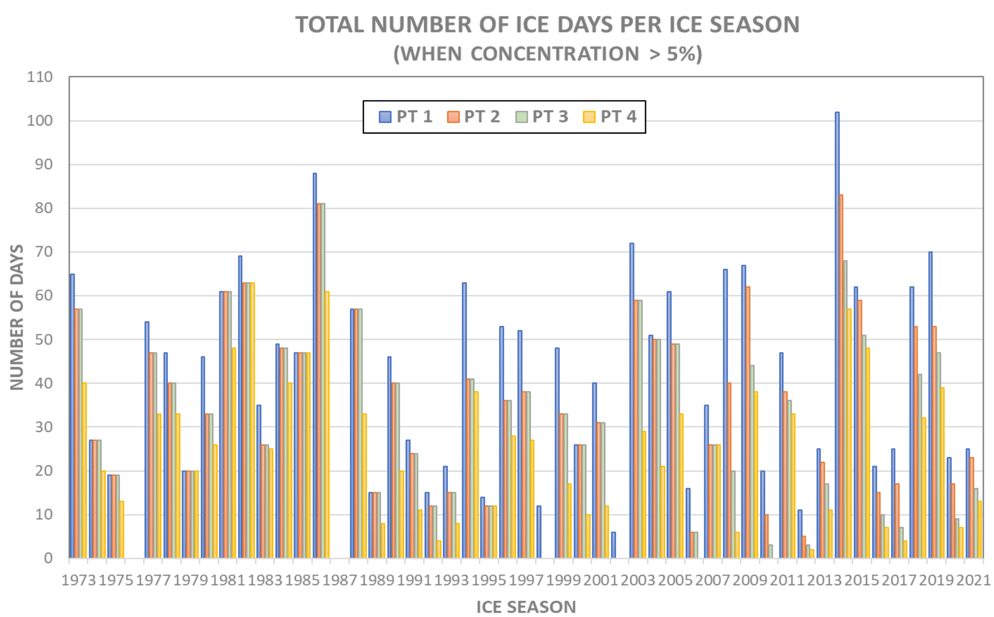


Figure 4.39 1973 to 2021 ice days at Point 1 to 4 in Reach 2

When the historical period from 1977 to 1986 is compared to the last ten years from 2012 to 2021, a reduction in the duration of the winter ice season is more apparent, as shown in Figure 4.40. Interestingly, the 2014 and 2015 ice seasons appear to be outliers, as the number of ice days at Point 1 were very high. This is particularly true for 2014, when Point 1 featured the highest number of ice days across the entire dataset from 1973 to 2021. These years correspond to winters when a weak jet stream developed and allowed artic low-pressure systems to setup over the Great Lakes Region, bringing unusually cold air mases during the winter (polar vortex). A stable jet stream circles the northern polar region in a counter-clockwise direction, with low pressure systems generally confined to the north (refer to Figure 4.41). More research is required on the future impacts of climate change on the jet stream, but 2014/2015 suggest a weakened system could disrupt the long-term warming trends from year to year and result in some winters with significant ice-cover seasons.

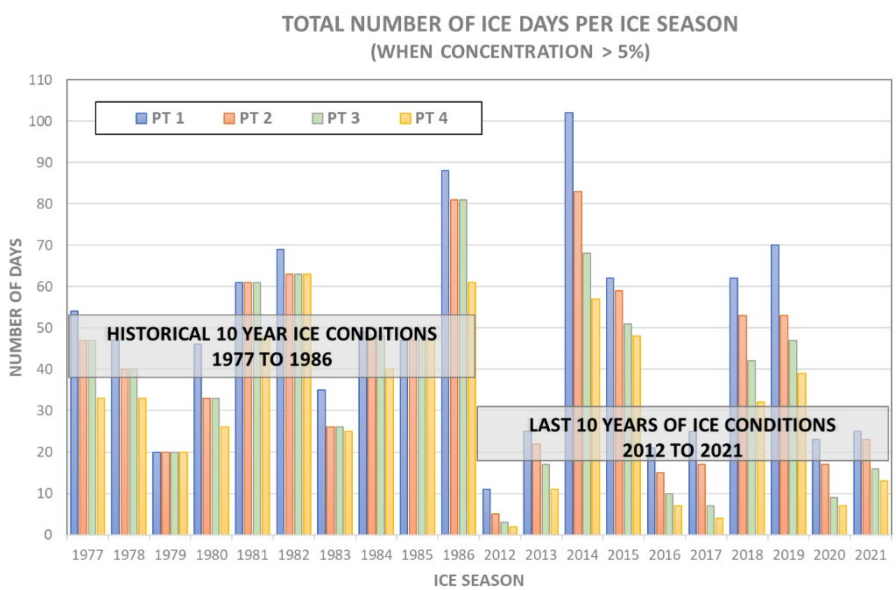


Figure 4.40 1977 to 1986 versus 2012 to 2021 at Points 1 to 4 (Reach 2)

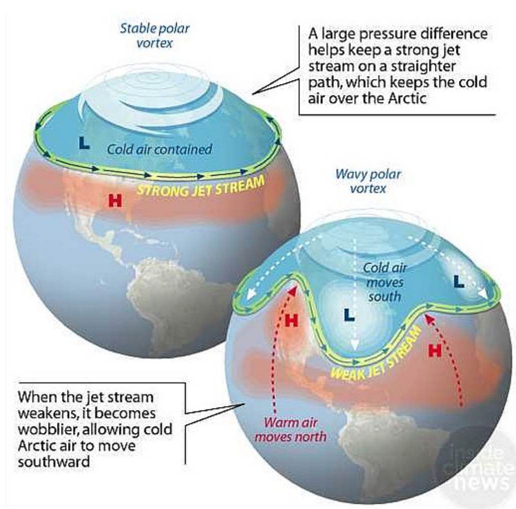


Figure 4.41 Example of polar vortex in the Northern Hemisphere

Using 1968 to 2005 as a baseline, projected increases in lake surface temperature across the Great Lakes for mid-century (2040-2059) and late-century (2080-2099) were recently evaluated with data from the Canadian Regional Climate Model Version 5 (CRCM5) with boundary conditions provided by four Global Climate Models, including CanESM2, NCRM-CM5, MPI-ESM-LR and GFDL-ESM2M (Seglenieks and Temgoua, 2021). The results for the CRCM5/CanESM2 simulation are presented in Figure 4.42. The range for winter Lake Ontario surface temperature increases is 1.0 to 3.0 degrees Celsius by the mid- and late century for the two emission scenarios.

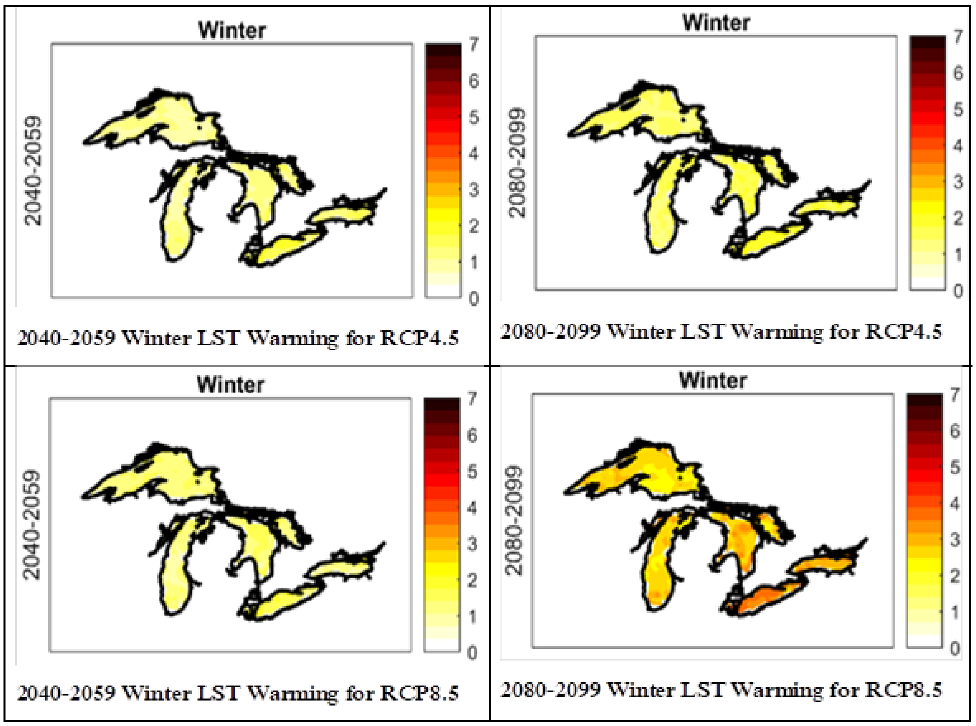


Figure 4.42 Mid- and late-century lake surface temperature warming for RCP4.5 (top) and RCP8.5 (bottom) simulations from CRCM5/CanESM2 relative to 1986-2005 (Seglenieks and Temgoua, 2021)

The trends and projections presented above for future warming and its impacts on winter ice cover are consistent with the findings of a recent Great Lakes climate investigation by RWDI (2020). In the study, future land and lake temperatures were extracted from the Weather Research and Forecasting (WRF) model for a late century RCP8.5 simulation. With winter lake temperatures projected to be several degrees warmer than the historical baseline, significant reductions in ice cover and the occurrence of ice-free winters were projected for the future.

4.5.3 Changes in Wave Climate and Storm Surge Magnitude

The impacts of climate change on future wave heights, and storm surges was recently evaluated for Lakes Erie and Ontario (Baird, 2019) as part of the NRCan supported study Adapting to the Future Storm and Ice Regime (Zuzek Inc., 2019). A wave height analysis was completed by selecting the top 15 wave events on Lake Ontario from 2000 to 2013 and comparing the predicted wave heights for the same storms for a late-century RCP8.5 emission scenario. The results did not produce any consistent trends on the potential impacts of climate change on future wave heights (e.g., larger or smaller wave heights in the future). The analysis did, however, highlight the importance of lake ice cover on the generation of deep-water waves and propagation of those waves into the shoreline in the winter.

In the second part of the analysis, an hourly wind-wave hindcast was completed using spatially varying winds across Lake Ontario for the historical baseline period (2000 to 2013) with actual ice-cover. The same weather was then simulated for late-century with the RCP8.5 emission scenario and a zero ice-cover assumption for Lake Ontario. For each grid cell in the wave model, hourly wave energy density was calculated for the 13-year wave hindcast. The results from the historical hindcast were subtracted from the future (late century) simulation to estimate the potential increase in wave energy due to climate change. The results are summarized in Figure 4.43. In the Kingston basin at the northeastern end of the lake, the loss of winter ice cover resulted in a 100% increase in the amount of winter wave energy reaching the coast between mid-December and mid-March each year. For the coast around Prince Edward County, the increase in winter wave energy was estimated to be 60% to 70%. The wave model was not extended into the Bay of Quinte. This finding may not increase the severity of future flood risks, since the winter months typically feature the lowest seasonal water levels on the Great Lakes, it may result in more winter flooding events. It may increase future erosion rates, as more wave energy will strike the shoreline during winter months, compared to the past.

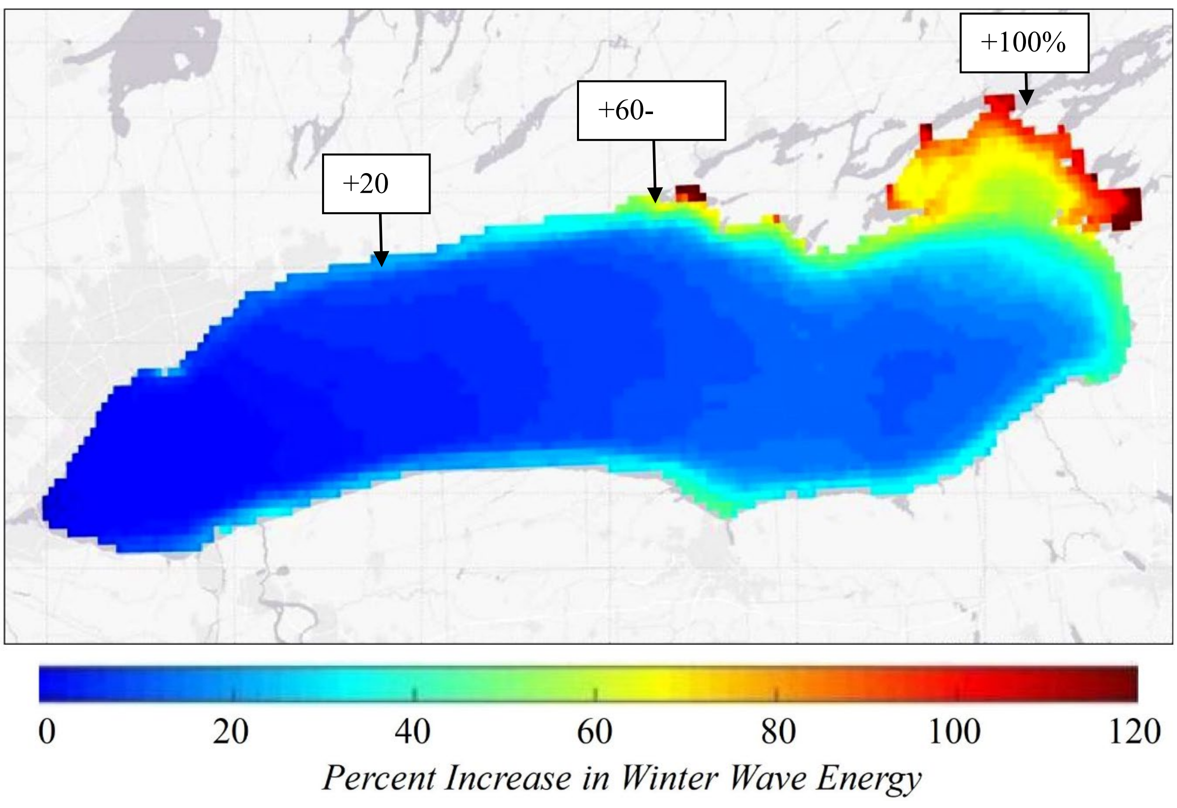


Figure 4.43 Projected increase in winter wave energy for RCP8.5 (late century)

When peak storm surge conditions from the baseline period of 2000 to 2013 were compared to the peak surge heights for the future late-century RCP8.5 emission scenario (Baird, 2019), no significant changes were observed. In other words, at this time, there is no conclusive evidence to suggest that storm surge magnitude will increase in the future due to stronger wind fields or pressure gradients that track across the lake. However, as mentioned previously, there could be more winter flooding events due to reduced ice cover.

4.5.4 Future Lake Levels

In a recent report from Environment and Climate Change Canada (Seglenieks and Temgoua, 2021), projections of future Great Lakes water levels were summarized for global temperature increases of 1.5 to 3.0 degrees Celsius. Data on precipitation, evaporation, and runoff for the analysis was extracted from 13 pairs of Global and Regional Climate Models from the Coupled Model Intercomparison Project Phase 5 (CMIP5). The historical variability in measured lake levels is projected to continue (i.e., periods of highs and lows). However, due to increases in precipitation with a warming climate, both mean lake levels and extreme highs are projected to increase in the future across the lakes. Refer to Figure 4.44, reproduced from Seglenieks and Temgoua (2021), which plots the time series of future water level projections for the 13 combinations of Global and Regional Climate Models, compared to the historical baseline period from 1961 to 2000. The 13 scenarios are presented for four global mean temperature change scenarios (1.5, 2.0, 2.5 and 3.5 degrees Celsius of warming, respectively, versus the baseline period).

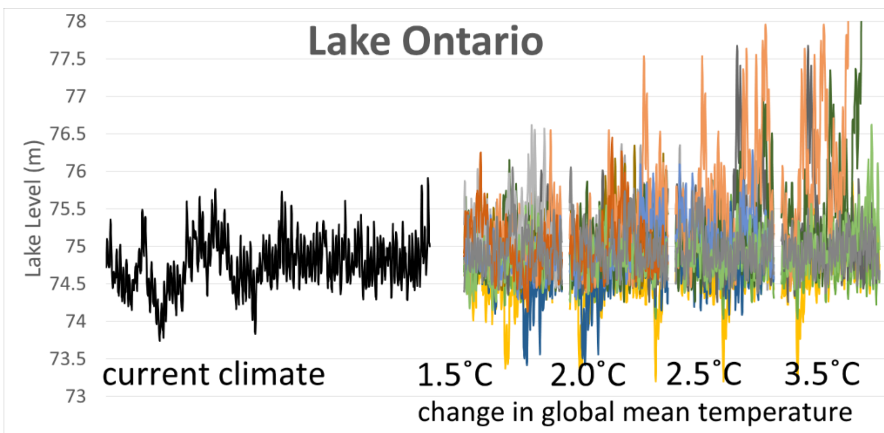


Figure 4.44 Projected future Lake Ontario levels for different global warming trends and GCM-RCM simulations (from Seglenieks and Temgoua, 2021)

Future climate change simulations have uncertainties associated with the inputs, predictive capability of the models, and outputs. Therefore, it is important to recognize that future water levels presented in Figure 4.44 represents projections, not predictions. How the projected extreme water supply scenarios under 2.5 and 3.5 degrees of warming, in particular very wet years in the future, would flow through the Great Lakes and connecting channels given the physical constraints of the system is not fully known. As such, the information in Figure 4.44 is considered indeterminate for those extreme warming scenarios (i.e., 2.5 and 3.5 degrees Celsius).

It is also important to note that since the historical baseline period was 1961 to 2000, the modelled future lake levels are not being compared to the recent record highs in 2017 and 2019. And finally, deviations from Plan 2014 controlling the operation of the Moses-Saunders Dam during periods of extreme water supply are not represented in the routing model and subsequent water level projections. During the record high water supplies experienced in 2019, for example, the International Lake Ontario-St. Lawrence River Board did deviate from the rules in Plan 2014 and increased discharge at the dam to mitigate high water levels on Lake Ontario. As such, there is some uncertainty in the extreme high water level projections shown in Figure 4.44 above for 1.5 and 2.0 degrees Celsius of future warming.

The projected future lake levels from the ECCC study are also summarized as probability of exceedance for the future scenarios, relative to the historical baseline condition from 1961 to 2000. The results for the 1% and 50% exceedance for increases in global mean temperatures from 1.5 and 2.0 degrees Celsius are summarized in Table 4.13. These data indicate that as temperatures in the Great Lakes Basin continue to increase in the future, mean lake levels may increase slowly over time (refer to the 50% exceedance results in Table 4.13). The 1% exceedance, which is indicative of the 100-year static lake level, is projected to increase 0.39 m with 1.5 degrees of global warming. If realized, this would contribute to a significant increase in the 100-year flood level established for this study and used in the flood hazard mapping. However, without knowing if the IJC would deviate from their regulation plan during future periods of extreme water supply, it is difficult to integrate this information into the SMP at this time.

Table 4.13 Projected change in future lake level extremes (from Seglenieks and Temgoua, 2021)

Percent Exceedance	Projected Increase in Lake Ontario Water Levels from the Historical Baseline	
	1.5 C of Warming	2.0 C of Warming
1%	0.39 m	0.63 m
50%	0.07 m	0.12 m

Regardless of the uncertainties associated with these future lake level projections, the recent 2018 report from the Intergovernmental Panel on Climate Change (IPCC) puts these projected increases in global warming in context by presenting a timeline of historical CO_2 emission and future scenarios. There is high confidence that global mean temperatures will surpass 1.5 degrees Celsius between 2030 and 2052 if CO_2 emissions continue to increase at the current rate (refer to Figure 4.45). In a 2021 publication by Hébert et al., it was stated that warming of 1.5 degrees Celsius by 2038 was extremely likely (>95%).

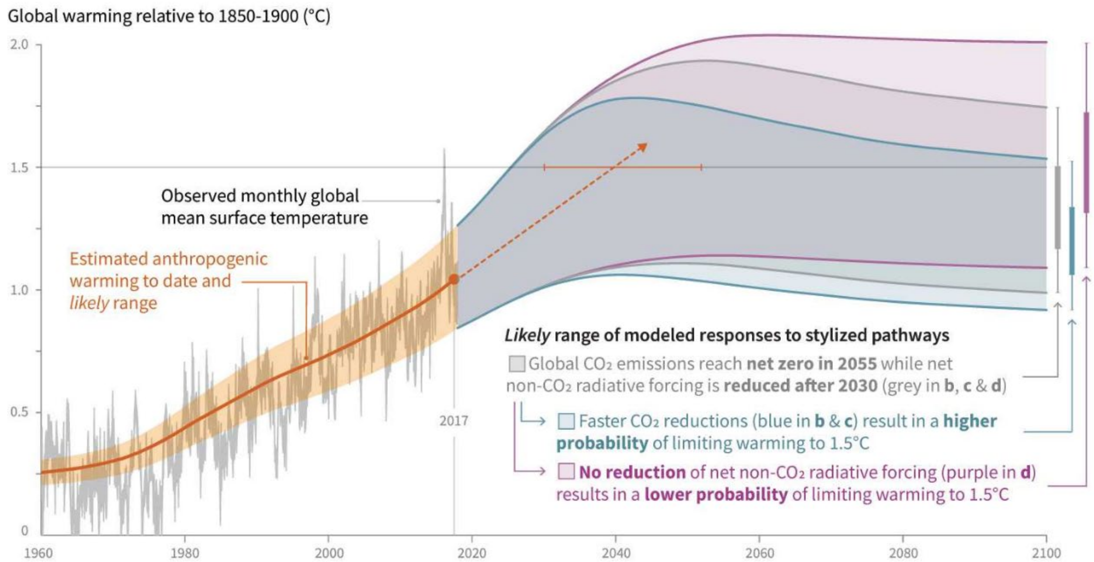


Figure 4.45 Observed global temperature change and projected increases for different CO2 emission scenarios (IPCC, 2018)

In summary, climate change is projected to have significant impacts on factors and physical processes that influence the hazard mapping generated for this study. Higher atmospheric and lake temperatures may lead to less ice cover in the future, more storm exposure, higher recession rates, and possibly higher lake levels than the recent record established in 2019.

5.0 MAPPING HAZARDOUS LANDS

Section 5.0 summarizes the approach to mapping hazardous lands in the SMP, the presentation of the draft mapping using a webmapping platform, and future considerations for updating the mapping outputs.

5.1 Erosion Hazard Limit

The erosion hazard setback is defined in the Guidelines for Developing Schedules of Regulated Areas (Conservation Ontario and MNR, 2005) as a 100-year erosion allowance plus a stable slope allowance measured horizontally from the existing stable toe of slope. When the CAs identify their regulated area, an additional allowance of up to 15 metres can be added. A schematic of the setback methodology is provided in Figure 5.1.

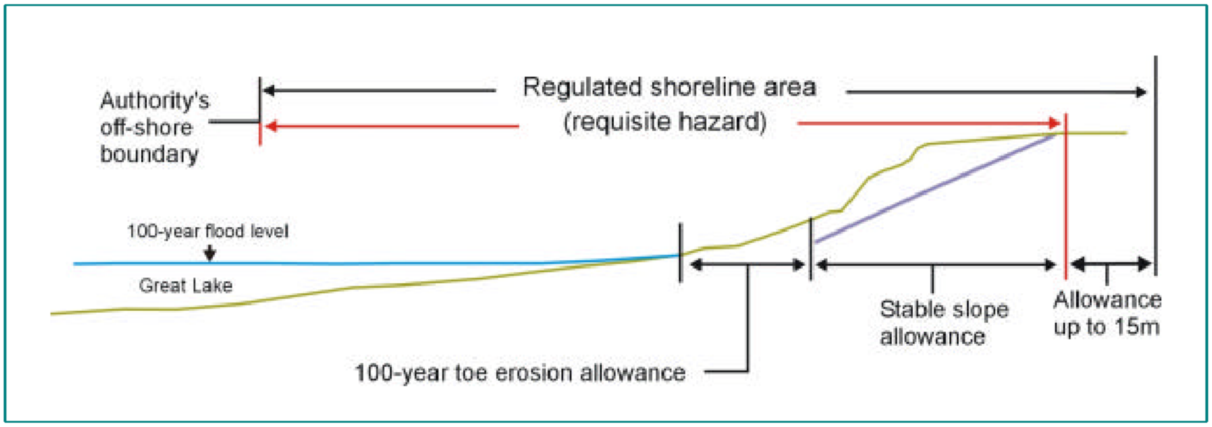
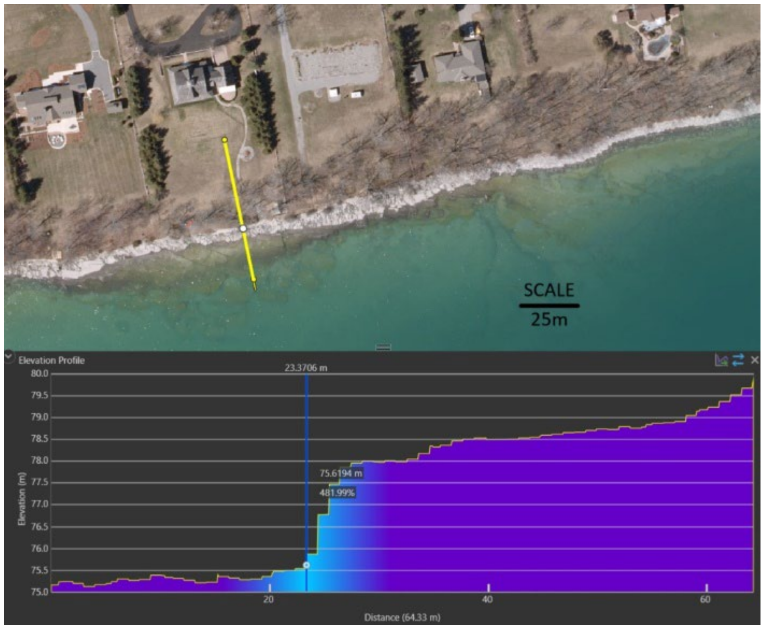


Figure 5.1 Erosion hazard setback approach

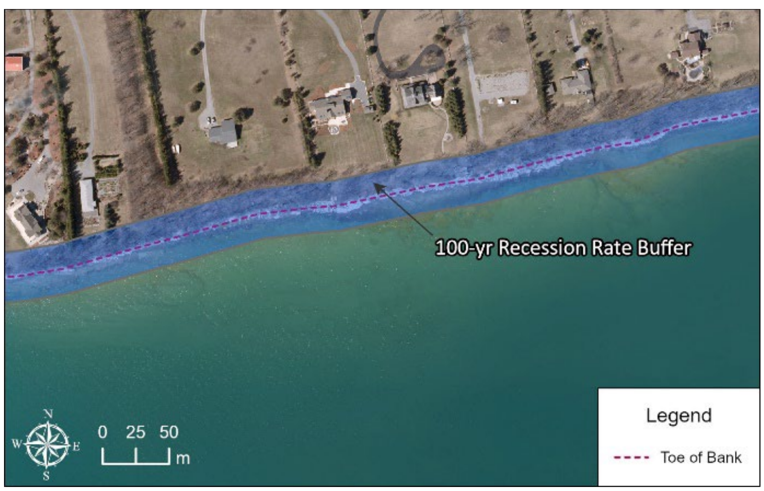
5.1.1 Mapping Approach

For this study, the erosion hazard limit was mapped for eroding bank, bluff and beach shorelines, on Lake Ontario and the Bay of Quinte. The stable slope assessment was summarized in Section 3.5 and the reach recession rates were presented in Section 4.2.2. Within the GIS mapping environment, the steps followed to map the erosion hazard limit are summarized as follows:

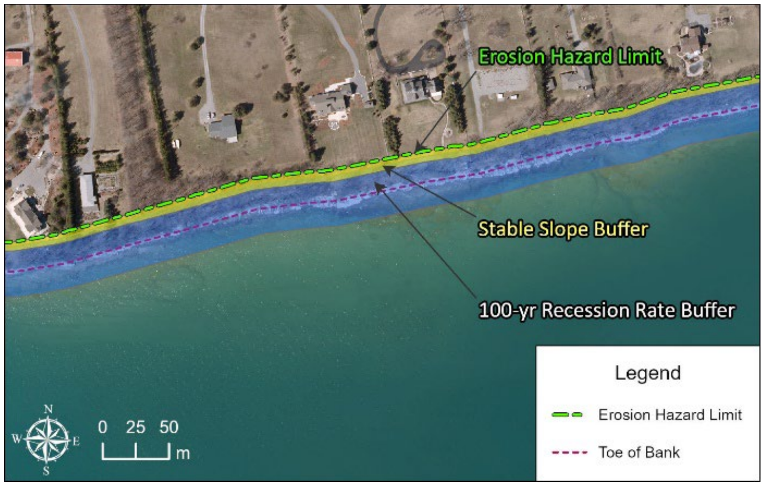
- **Eroding bank or bluff:** the following steps were followed to map the erosion hazard for typical bank and bluff shorelines:
    - Toe of Slope Location: The digital elevation model (DEM) for the 2009 LiDAR was used to evaluate the toe of slope contour. In the image below, GIS tools are used to extract profiles in Reach 3 and record the toe elevation (75.7 m) at the major break in slope from the shelving limestone to the steep bank face. The maximum elevation for the toe of slope was 75.7 m (1.5 m above chart datum). Once the appropriate toe of slope contour was established for a reach or sub-reach, that contour was extracted from the DEM to represent a continuous polyline. Any abnormalities with the contour were visually corrected.



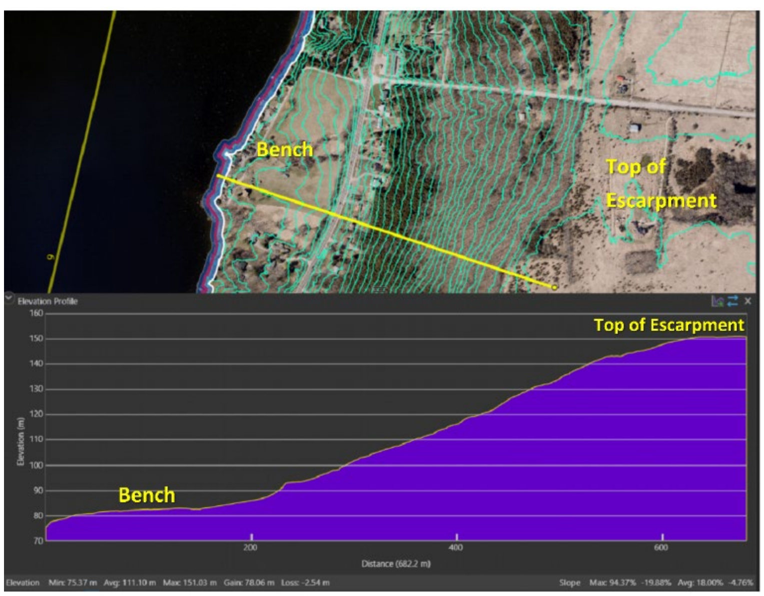
- Map 100-years of Future Recession: The 100-year recession rate was mapped by buffering the toe of slope line by a distance equal to 100 times the average annual recession rate outlined in Section 4.2.2.



- Calculate the Stable Slope Setback: The recession rate buffer line was converted to a series of points spaced at 1 m increments. At each point, the toe elevation was compared to the land elevation from the DEM. When the height of the bank or bluff was greater than or equal to 2.0 m, the standard stable slope allowance of 1.75(H):1.0(V) (refer to Section 3.5) was calculated at each 1 m interval. The points were then joined to create a continuous polygon representing the Erosion Hazard Limit. See the graphic below (dashed green polyline).

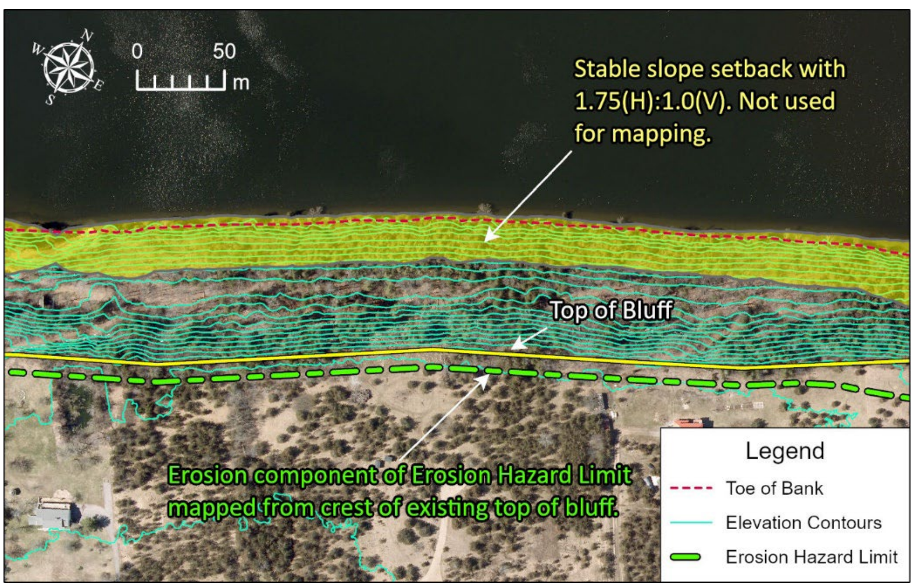


- **Bench at Base of Escarpment:** There were locations in the Bay of Quinte, specifically Reaches 8 to 10, where the bedrock escarpment was located inland from the shoreline and a bench was present at the waters edge. Refer to the plan and profile section below, where the bench is roughly 200 m wide.
    - The erosion hazard limit was mapped from the toe of slope for the bench, not the inland escarpment. The standard method of accounting for 100-years of recession from the toe of slope plus the local stable slope allowance was applied. If future development is proposed on the bench at the base of the inland escarpment, appropriate setbacks would be required for the proposed development.



    - In the transition areas from the bench to a steep bank, the erosion hazard limit line was purposely not connected, as seen below in Glenora. If future development is proposed in these transition areas, a site-specific geotechnical assessment may be requested by the QC.

- **Existing Bluff Slope is Flatter than 1.75(H):1.0(V):** In a few isolated locations, the existing bluff slope in Reaches 8 to 10 was flatter (gentler) than the standard 1.75(H):1.0(V) established for the hazard mapping.
    - If the existing bluff slope was gentler than 1.75(H):1.0(V), the crest of the existing bluff was digitized based on the available LiDAR contour data.
    - The 100-year recession rate (10 m) from Section 4.2.2 was added to the existing top of bluff.



- **Banks and Bluffs comprised of Soil:** If a soil bank or bluff is identified based on local observations (as opposed to bedrock), then a 3:0(H) to 1.0(V) stable slope should be applied.

- **Eroding Barrier Beaches:** Some of the study area barrier beaches were too narrow or did not feature sufficient amounts of sand and gravel material to be mapped as dynamic beaches. See example below, where the 100-year recession rate (green line below) was mapped from the back (toe) of the barrier beach system.

5.2 Flood Hazard Limit

The flooding hazard is defined in the Guidelines for Developing Schedules of Regulated Areas (Conservation Ontario and MNR, 2005) as the 100-year flood level plus a standard 15 m allowance for wave uprush and other water related hazards. When the CAs map their regulated area, an optional additional allowance of up to 15 metres also can be added forming the entire regulated shoreline area. A definition schematic of the flooding hazard is provided in Figure 5.2.

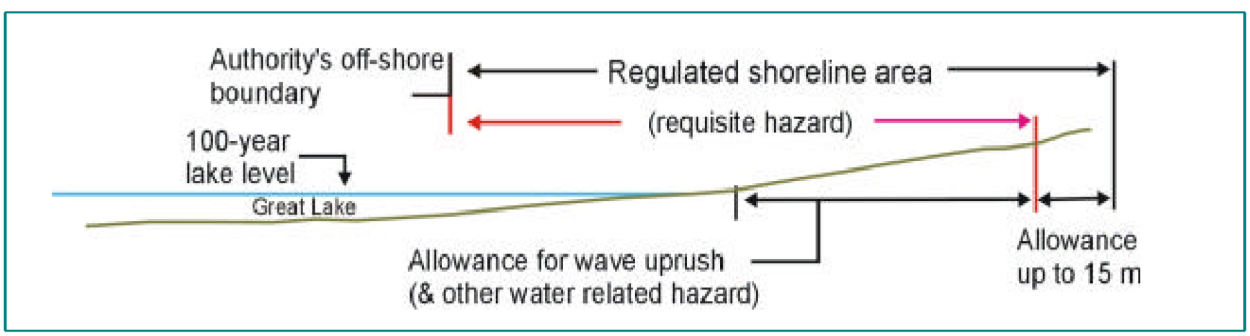


Figure 5.2 Flooding hazard definition

The MNR Technical Guide (MNR, 2001a) provides additional information on the 15 m wave uprush component, including the ability to apply wave uprush calculations to define the setback based on site specific nearshore and beach slope, substrate, and local wave conditions. As was discussed in Section 4.4.4, wave uprush was evaluated at 77 locations around the project geography to determine whether or not the standard 15 m setback was appropriate. These calculations validated the use of the 15 m standard setback for all project shorelines, with the following exceptions:

1. Gentle sloping, sandy beaches. For these shorelines the horizontal extent of wave uprush often exceeds the standard 15 m setback, and is evaluated on a site-specific basis.

2. Steep bank/cliff shorelines where the estimated wave uprush does not exceed the height of the bank. In these situations, the standard 15 m setback has been mapped but may be reduced at the discretion of the CA pending site specific studies to confirm the elevation of the top of bank/cliff.

3. Sheltered locations with substantial emergent vegetation buffers. In these locations a site specific study is recommended to confirm the presence and persistence of emergent vegetation and whether a reduction to the wave uprush component of the flood hazard limit is appropriate.

5.2.1 Mapping Approach

To map the shoreline flooding hazard, the 100-year flood level is first mapped on the appropriate topographic contour. 100-year flood levels for all project reaches are shown in Figure 4.21 and were discussed in Section 4.3.5. The wave uprush setback is subsequently mapped as an offset from the 100-year flood level. The offset is generally 15 m, except for shorelines where gentle sloping, sandy beaches are encountered, as noted above. In these areas the flooding hazard is mapped to a topographic contour corresponding to the wave uprush elevation determined specifically for that beach. Figure 5.3 provides a sample of the flooding hazard mapping for a section of high-risk shoreline near the south end of the Belleville Bridge within Reach 13. The 100-year flood level is shown as a white line, while the flooding hazard limit including wave uprush is shown as a blue line.

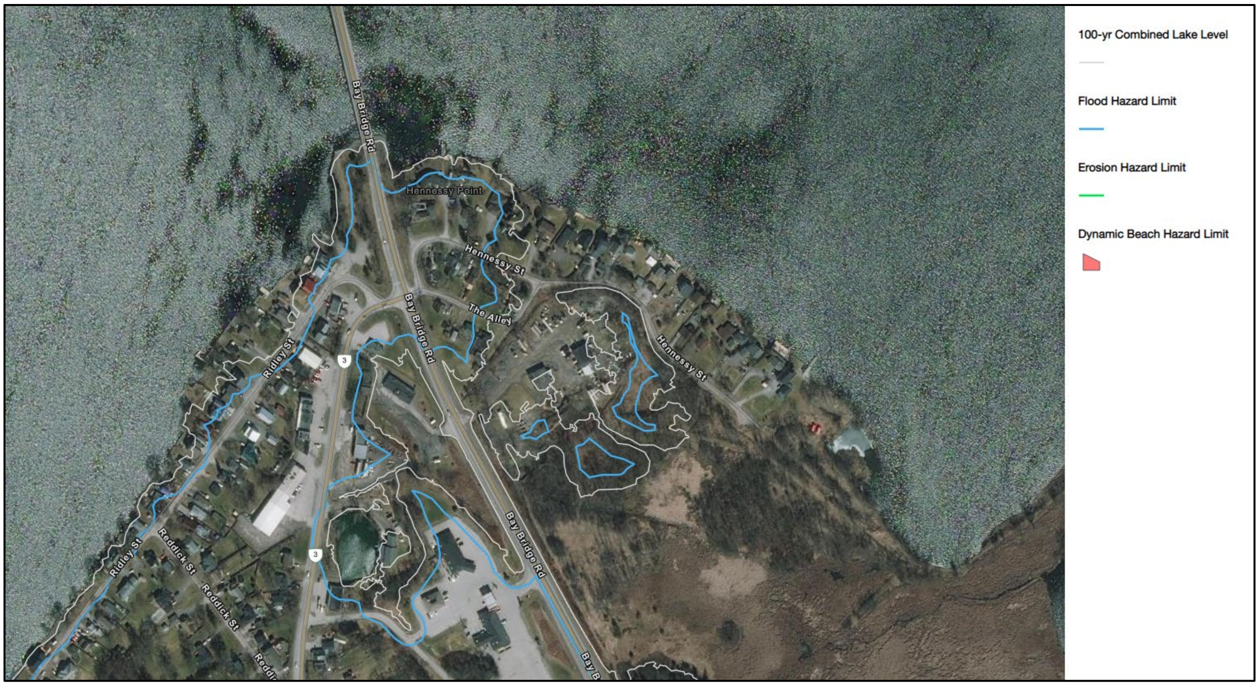


Figure 5.3 Sample of flood hazard mapping for a low-lying area at the southern end of the Belleville Bridge (white line is the 100-year flood level and blue line is the flooding hazard including wave uprush)

5.2.2 Flooding Implications

Several locations have been identified through the flood hazard mapping where existing developments may be impacted by the flooding hazard. These locations are identified and discussed specifically by project reach in Appendix A. In general, where development is impacted by the flooding hazard, the implications can be described as one or more of the following:

- **Lack of safe emergency ingress/egress:** many shoreline properties and broader communities are impacted by a lack of safe access during the 100-year flooding event. Figure 5.4 presents one such example for Hiscock Shores Rd., located on Wellers Bay within Reach 1. Nearly 700 m of Hiscock Shores Rd. is lower than the 100-year flood level (not including the impacts of wave uprush), limiting the ingress/egress to the entire community during the regulatory flood event. In general, emergency vehicles and most personal vehicles cannot travel through flood depths of greater than 0.3 m, as they are limited by the height of their exhaust. The requirement for safe ingress/egress is a critical prerequisite for development, as is clearly outlined in the Provincial Policy Statement (MMAH, 2020) and reiterated in regulations under the *Conservation Authorities Act* (e.g., Ontario Regulation 319-09 for Quinte Conservation).

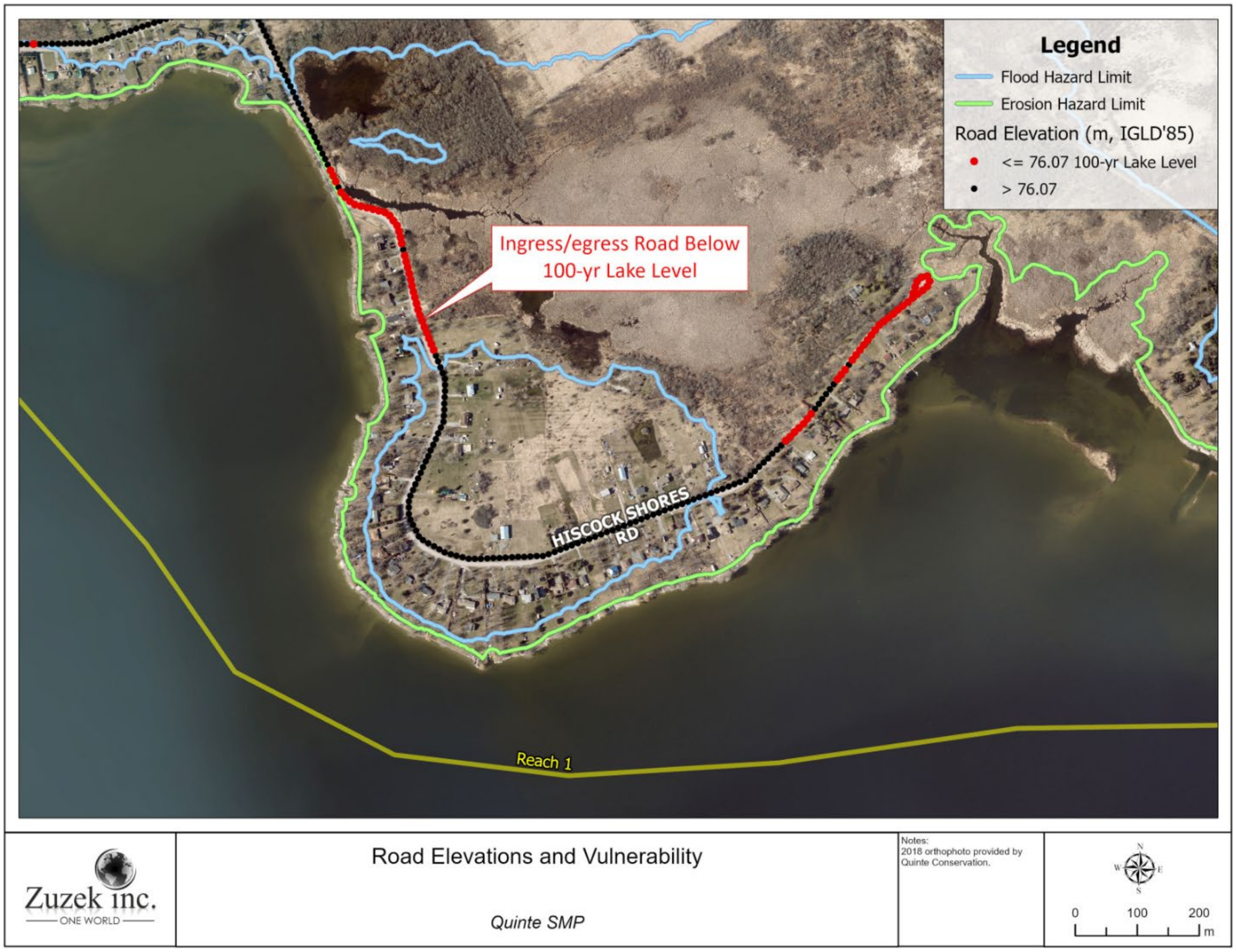


Figure 5.4 Example of a community without safe ingress/egress (emergency access) during the 100-year flooding event, at Hiscock Shores Road, Wellers Bay (Reach 1)

- **Flooded homes/communities:** there are numerous examples throughout Quinte Conservation's jurisdiction where residential and in some cases commercial buildings are located within the flooding hazard. If these homes feature basements or low level openings, they will be prone to damage during a major flooding event. Moreover, where floodwaters surround a home, safe ingress/egress from the home itself may be compromised. Figure 5.5 below shows one such example where nearly every home on Hennessey St. (adjacent to the south end of the Belleville Bridge) is well within the flooding hazard for the Bay of Quinte. Other locations in which homes are impacted by the flooding hazard are identified by project reach in Appendix A.

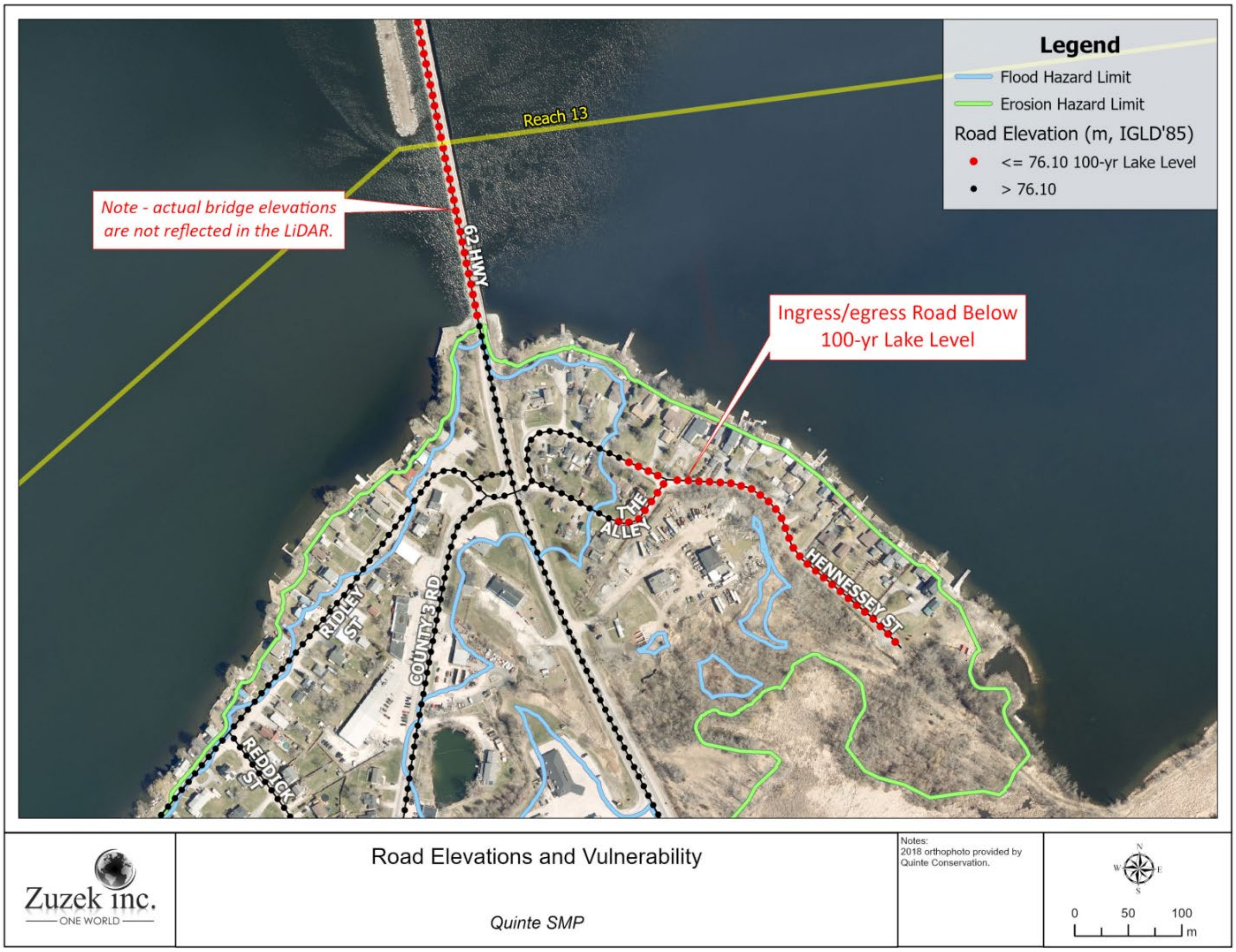


Figure 5.5 Example of a community where multiple homes are well within the flooding hazard and may be subjected to flood damage and access issues during major flooding events

- **Inundated septic systems:** septic systems are generally not functional when inundated and may fail outright resulting in significant environmental implications. Refer to Figure 5.6 below which shows a low-lying community on Lake Erie during the 2019 high water period where several septic systems failed contributing to multiple properties being flooded with contaminated sewage.

Figure 5.6 Sewage ponding from failed septic systems caused by flooding in 2019 in the Marentette community, Southeast Leamington, Lake Erie

5.3 Dynamic Beach Hazard Limit

The dynamic beach hazard is defined in the Guidelines for Developing Schedules of Regulated Areas (Conservation Ontario and MNR, 2005) as the flooding hazard (100-year flood level plus an allowance for wave uprush and other water related hazards), plus a 30 m allowance to account for the dynamic nature of the beach and dune system, including periods of erosion and accretion. When the CAs map their regulated area, an additional allowance of up to 15 metres is added (refer to Figure 5.7).

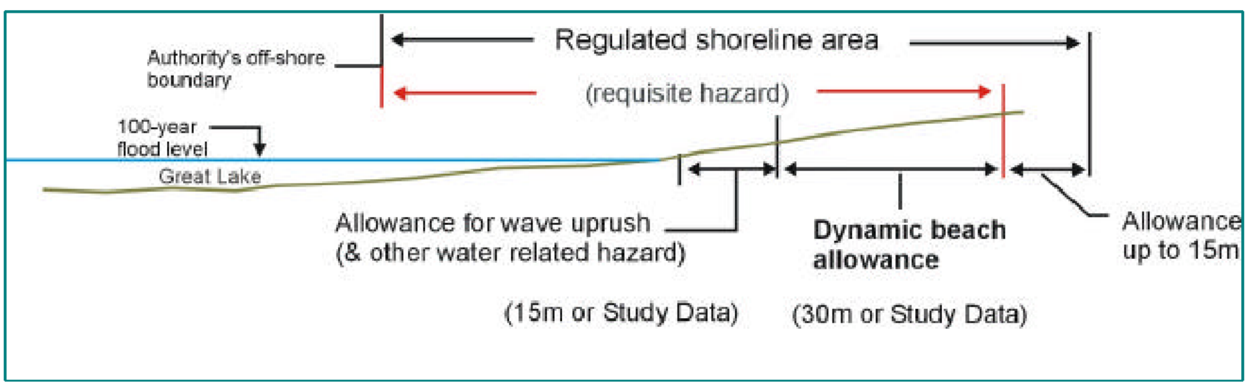


Figure 5.7 Dynamic beach hazard limit

The purpose of the dynamic beach hazard is to restrict development in areas where dynamic beach materials (generally sand, gravel, pebbles, and cobbles) may evolve or erode under certain combinations of wind, wave, and water level conditions. Due to the inherent risks and the environmental and ecological importance of dynamic beach systems, the dynamic beach hazard is generally the most restrictive of the three shoreline hazards from a regulatory perspective. For a shoreline to be classified as a dynamic beach the following criteria must be met (as per MNR, 2001a):

- Beach or dune deposits exist landward of the water line, AND
- Beach or dune deposits overlying bedrock of cohesive material are equal to or greater than 0.3 metres in thickness, 10 metres in width, and 100 metres in length, AND
- The maximum fetch distance measured over an arc extending 60 degrees on either side of a line perpendicular to the shoreline is greater than 5 km.

5.3.1 Mapping Approach

As stipulated by the province, the dynamic beach hazard is typically mapped as a standard 30 metre setback from the previously determined flooding hazard (MNR, 2001a & 2001b). This was the general approach followed for the Quinte Conservation shoreline. The provincial guidance does, however, provide the flexibility to reduce or increase the standard 30 meter setback through a site-specific study using accepted engineering principles, or where specific situations are encountered, including:

1. Where a cliff or bluff, consisting of cohesive sediments or bedrock, exists landward of the beach. In this case the dynamic beach hazard should be terminated at the toe of the cliff or bluff.
2. Where the dynamic beach exists on a narrow barrier beach system and the landward limit of the dynamic beach hazard may fall within the marsh or bay that exists landward of the barrier. In these areas the dynamic beach hazard limit should be defined by the toe of the slope on the back (i.e. landward) side of the barrier system.
3. Where the beach features a long-term erosion trend. In this case the dynamic beach hazard should include an allowance for 100-years of erosion, based on the long-term average annual recession rate for the shoreline, in addition to the standard dynamic beach allowance of 30 metres (or another value as determined by a site specific study).

As stipulated in the Technical Guide, the dynamic beach hazard should not only extend onshore as per the above guidelines, but should also extend offshore to approximately the limit of wave action on the lakebed (MNR, 2001a). This is in recognition of the fact that the nearshore area, beach, and dunes, are part of an inter-connected physical system and should be managed as such. The dynamic beach hazard was therefore mapped as a shaded polygon, with the offshore limit extending approximately 200 m from the shoreline.

Figure 5.8 provides an example of a mapped dynamic beach hazards for the portion of shoreline between North Beach Provincial Park and Huyck's Point on the southwest Prince Edward County shoreline (Reach 2).

Figure 5.8 Sample of dynamic beach hazard mapping for the southwest Prince Edward County shoreline from North Beach Provincial Park to Huyck's Point (red polygon is the dynamic beach hazard, white line is the 100-year flood level and blue line is the flooding hazard including wave uprush)

5.3.2 Importance of Dynamic Beaches

Due to the exposed bedrock present along most of the Quinte Conservation shoreline, the presence of dynamic beaches is limited along the exposed open coast shorelines. The dynamic beaches that were mapped are often located in headland-bay systems. In these systems a beach has formed within an embayment where it is anchored at either end by bedrock headlands. These headland-bay beaches are also generally barrier beaches, which is a narrow strand of dynamic beach material that separates a sheltered embayment or marsh from Lake Ontario. Examples of sandy headland-bay beaches that have been categorized as dynamic beaches in the shoreline hazard mapping are Pleasant Bay Barrier Beach and Huyck's Bay Barrier Beach (Reach 2), Wellington Beach (Reach 3), and Big Sand Bay Barrier Beach (Reach 5). There are several additional sandy barrier systems that have not been mapped due to the fact that they are within the boundaries of a Provincial Park or National Wildlife Area and are therefore outside of the jurisdiction of Quinte Conservation. These include the majority of Wellers Bay Barrier Beach (Reach 1), North Beach Provincial Park (Reach 2) and Sandbanks Provincial Park (Lakeshore Beach and Outlet Beach, Reach 4).

Dynamic barrier beaches such as those encountered throughout the project provide critical natural protection to coastal embayments and marshes, during periods of storm activity on Lake Ontario. The barrier beaches at Sandbanks Provincial Park for example provide shelter to West

Lake and East Lake. The ability of a barrier beach to provide ongoing protection to inland bodies of water during periods of high lake levels and storm action is dependent in large part on the width and height of the barrier. Barriers such as Outlet Beach within Sandbanks Provincial Park are extremely wide, with well established vegetation and an extensive dune system that has been built up over centuries of coastal and aeolian sand transport. These types of barriers are not only effective at protecting interior bodies of water during storms, but they are also resilient in that they are more likely to recover from major erosion events due to the significant volume of sediment contained within the cross-section. Conversely, low-lying, narrow barrier beaches such as the central portion of Wellers Bay Barrier Beach are more apt to be overtopped during storm events resulting in overwash or breaching of the dune system. Many of the narrow barrier beaches on the southwest shoreline of Prince Edward County feature evidence of past breaches, and are likely to breach again in the future. These narrow barrier systems are less resilient and are therefore less likely to recover from periods of high lake levels and major storms.

In addition to providing protection from wave action and erosion, dynamic beaches and particularly those that feature a dune system provide critical habitat, ecological and environmental benefits. They also serve as coveted recreational destinations. The best way to ensure the protection of these critical coastal regions is to limit their ability to be developed, commensurate with the overall intent of the dynamic beach hazard (MNR, 2001a).

5.4 Hazard Mapping Web Application

The draft hazard limits were posted to a web mapping application to share with QC and other project partners during the internal review process. A view of the full study shoreline is provided in Figure 5.9 and a portion of Reach 2 is shown in Figure 5.10. Users can toggle layers on and off, produce a legend, measure distances and areas, change the background image, and print custom maps.

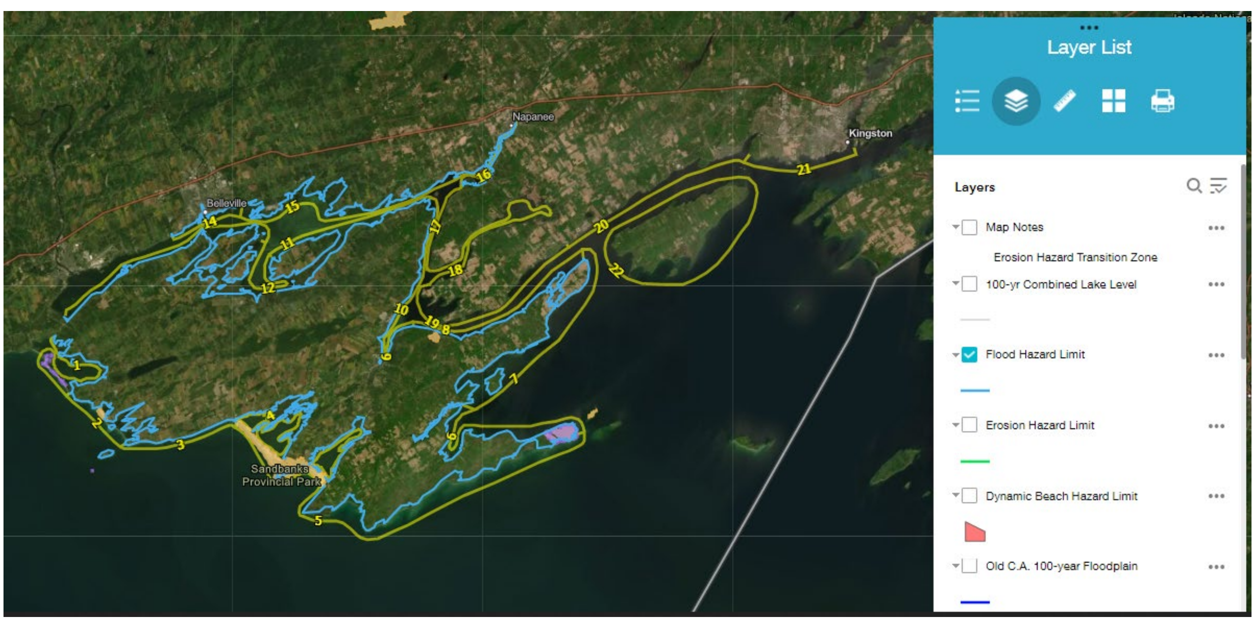


Figure 5.9 Online hazard mapping platform

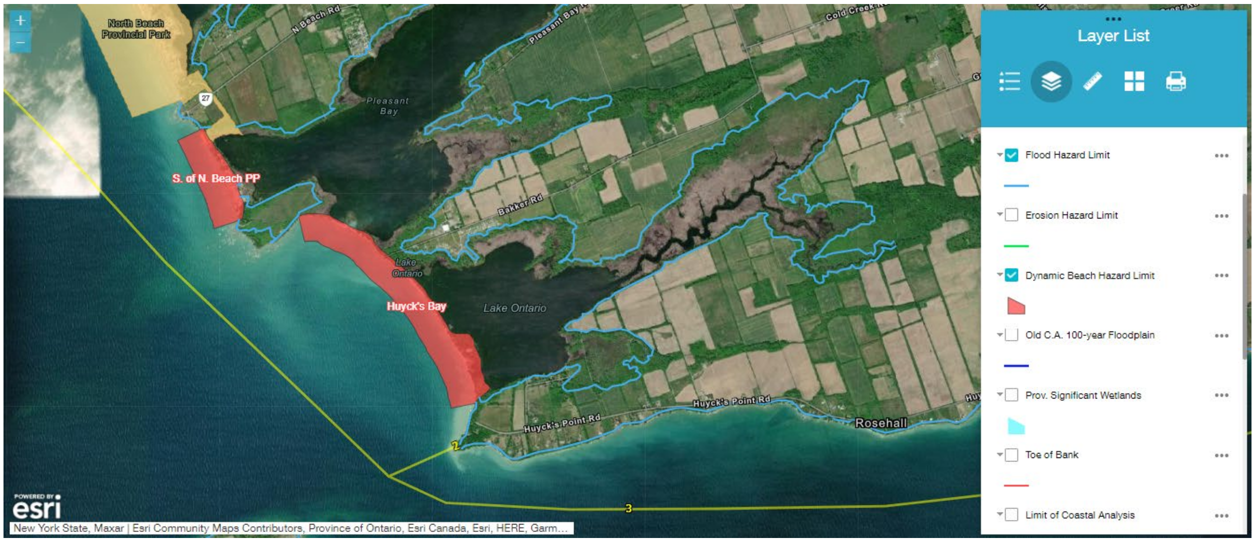


Figure 5.10 Flood hazard limit from North Beach Provincial Park to Huyck's Point

5.5 Future Hazard Mapping Updates

Hazard mapping should be updated on a regular basis, particularly if new elevation data (e.g., topographic LiDAR) becomes available or a new record high lake level is established in the future. This is particularly important for the Erosion Hazard Limit, since an eroding shoreline will make the static maps from 2022 outdated. Higher lake levels in the future may necessitate an update to the 100-year flood level.

Another important consideration is climate change. As outlined in Section 3.1.3 of the PPS (2020), planning authorities are to prepare for the impacts of a changing climate that may increase the risk associated with natural hazards. Section 3.1.3 clearly applies to activities under the *Planning Act*, such as zoning changes or planned developments including new subdivisions.

At present time there is no guidance from the province on how climate change impacts should be incorporated into flooding, erosion, and dynamic beach hazard mapping. However, as noted in Section 2.3.1, the province is currently reviewing and updating the Technical Guide to incorporate climate change and to align the technical guidance upon which regulatory hazard mapping is based with the language in the PPS.

The following climate change impacts and potential policy updates should be monitored, with the appropriate updates to the hazard mapping implemented:

- Updates to the *Conservation Authorities Act* or the Technical Guide that mandate the incorporation of climate change into the flooding, erosion, and dynamic beach hazards.
- New record lake levels are established that would increase the 100-year flood level used for this study.
- Ice cover continues to decrease, and long-term recession rates increase beyond the historical rates calculated for this study.

- Dynamic beach response to fluctuating water levels and erosion occurs beyond the limits of the dynamic beach hazard limit mapped for this study (i.e., more than 30 m inland from the flood hazard limit).

- Changes to the management of discharges at the Moses-Saunders Power Dam in Cornwall, Ontario.

6.0 PUBLIC AND PARTNER ENGAGEMENT

The approach and meetings with public and government partners throughout the study is presented in Section 6.0.

6.1 Municipal Partners and Senior Levels of Government

A committee of municipal partners was assembled at the onset of the study to engage one of the critical end users and funders of the SMP. The municipal participants represented the City of Quinte West, City of Belleville, Hastings County, Mohawks of the Bay of Quinte, Town of Deseronto, Town of Napanee, and Prince Edward County. The partners represented a range of departments from planning, community infrastructure, environmental services, and operations.

Staff from the Ministry of Environment, Conservation and Parks, the Ontario Ministry of Agriculture, Food, and Rural Affairs, Environment and Climate Change Canada, and the International Joint Commission also participated in the government engagement for the study.

6.1.1 October 2021 Progress Meeting

The first engagement with the municipal partners and provincial/federal departments occurred in October 2021 following the completion of the field work. The virtual meeting started with introductions to learn more about anticipated and desired outcomes. Key themes discussed included:

- Better hazard mapping to make land use decisions.
- Long-term information on coastal hazards and risks to help communities build resilience.
- Information and guidance to protect property and infrastructure from high lake levels.
- Strategies to protect existing houses along the lake from coastal hazards.
- Outputs to assist with updates to Municipal Official Plans.
- General information on the SMP development process and outputs.
- Integration of climate change impacts into the SMP.
- Interest in management approaches to reduce climate risk and build community resilience to coastal hazards and periods of high lake levels.

The following presentations were provided by QC staff and members of the study team:

- **Mark Boone, Project Manager for QC**: Mark started the formal presentations with background information on the QC watershed, history and mandate of Conservation Authorities, examples of erosion and flooding in 2017 and 2019, sample hazard mapping, an overview of the scope of work and the planned approach for partner and agency consultation. The timeline for the study was presented and the online survey was introduced.

- **Pete Zuzek, Project Manager for Consulting Team**: Pete provided a background presentation on the unique study area conditions, background on developing SMPs, examples of lessons learned from other studies, and anticipated outputs.

- **Seth Logan, Lead Coastal Engineer for Consulting Team**: The first part of Seth's presentation focused on the field work and ongoing technical studies, including bathymetric survey, collection of oblique photographs, analysis of historical lake level extremes, and analysis of the offshore wave climate. Anticipated study outputs, including shoreline management approaches, strategies for developed areas, and recommendations for shoreline protection structures were presented.

6.1.2 March 2022 Draft Mapping and Recommendations

A second meeting with the municipal partners and representatives from the provincial/federal government was held in March 2022 to present the draft hazard mapping and shoreline management recommendations. Like the first meeting, three presentations were provided:

- **Mark Boone, Project Manager for QC**: Mark provided an overview of the SMP development process and a summary of the public consultation from October 2021.

- **Pete Zuzek, Project Manager for Consulting Team**: Pete reviewed the principles and objectives guiding the study and compared the QC shoreline with other locations in the Great Lakes with higher erosion and flooding risks. Linkages between shoreline erosion and sediment supply to beaches was reviewed. Areas of high biodiversity were identified. Pete concluded by reviewing the role nature plays in coastal resilience, next steps for planning, and identified potential actions that could follow the completion of the SMP.

- **Seth Logan, Lead Coastal Engineer for Consulting Team**: Seth presented the approach to shoreline hazard mapping for erosion, flooding, and dynamic beaches. He showed examples from the online mapping tool and introduced the PARA(P) framework for organizing the shoreline management recommendations. Challenges and recommendations were organized by four regions; the exposed Prince Edward County Shoreline, Long Point to Cressy, Adolphus Reach to Hayward Long Reach including Picton Bay, and the Bay of Quinte.

The municipal partners and government representatives were provided the login and password information for the web mapping application so they could review the draft hazard mapping.

6.2 Public Information Centre #1

Due to the global pandemic, a hybrid format was adopted for the first Public Information Centre (PIC#1), as described below.

6.2.1 Advertising

A comprehensive radio and print advertising campaign was used to spread the word about the SMP study and encourage stakeholders to login and watch a series of pre-recorded presentations.

6.2.2 Online Recorded Presentations

Three online presentations were recorded and saved with embedded video for stakeholders to watch and learn about the SMP study. Presenters were the same as those listed above for the partners meetings.

6.2.3 Online Survey Results

A total of 126 individuals completed the online survey. Each of the sixteen shoreline reaches were represented, with Reach 1 Wellers Bay featuring 20 respondents (refer to Figure 6.1). A total of 22 respondents were not shoreline residents (possibly interior landowners and/or residents).

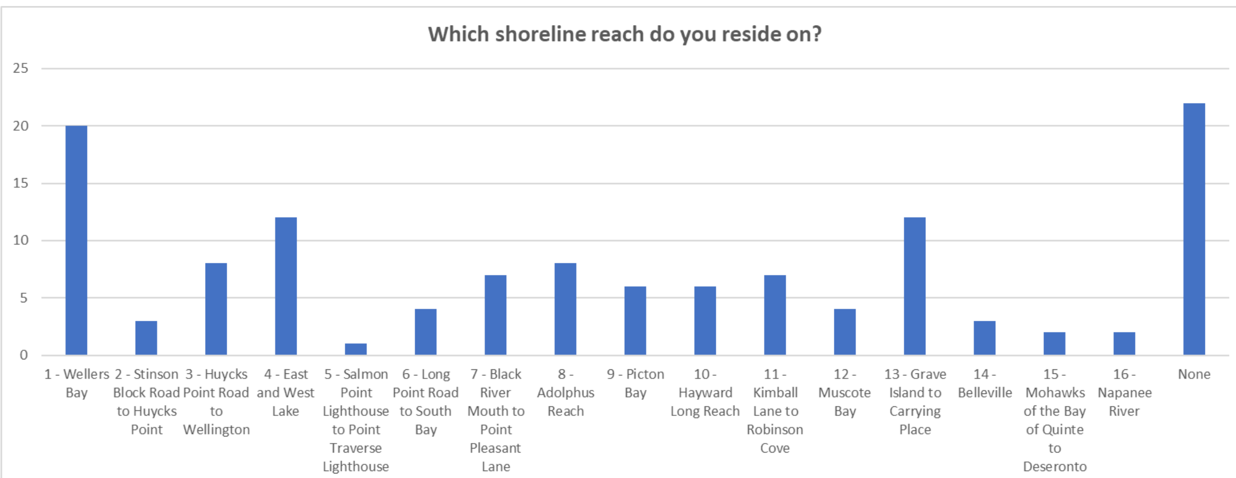


Figure 6.1 Geographic representation of survey respondents

Summary statistics from the questions on erosion, flooding, beaches and shore protection are provided in Figure 6.2 to Figure 6.4. Important findings and themes from the survey include:

- Roughly 70% of respondents experienced erosion problems in 2017 and 2019, while only 12% experienced problems before 2017. Resilience to erosion attributed to high lake levels is very low.
- Approximately 60% experienced flooding problems in 2017 and 2019, while this was only a problem for 8% of respondents prior to 2017. Resilience to high lake level flooding is low. Concern for flooding risks has increased for 80% of the survey participants.
- Roughly 80% of people are concerned about beaches and wetlands, and 40% are also concerned about shoreline development and armouring. Conversely, 29% of respondents have recently armoured their shoreline and 48% think more shoreline armouring is needed to protect infrastructure and development.

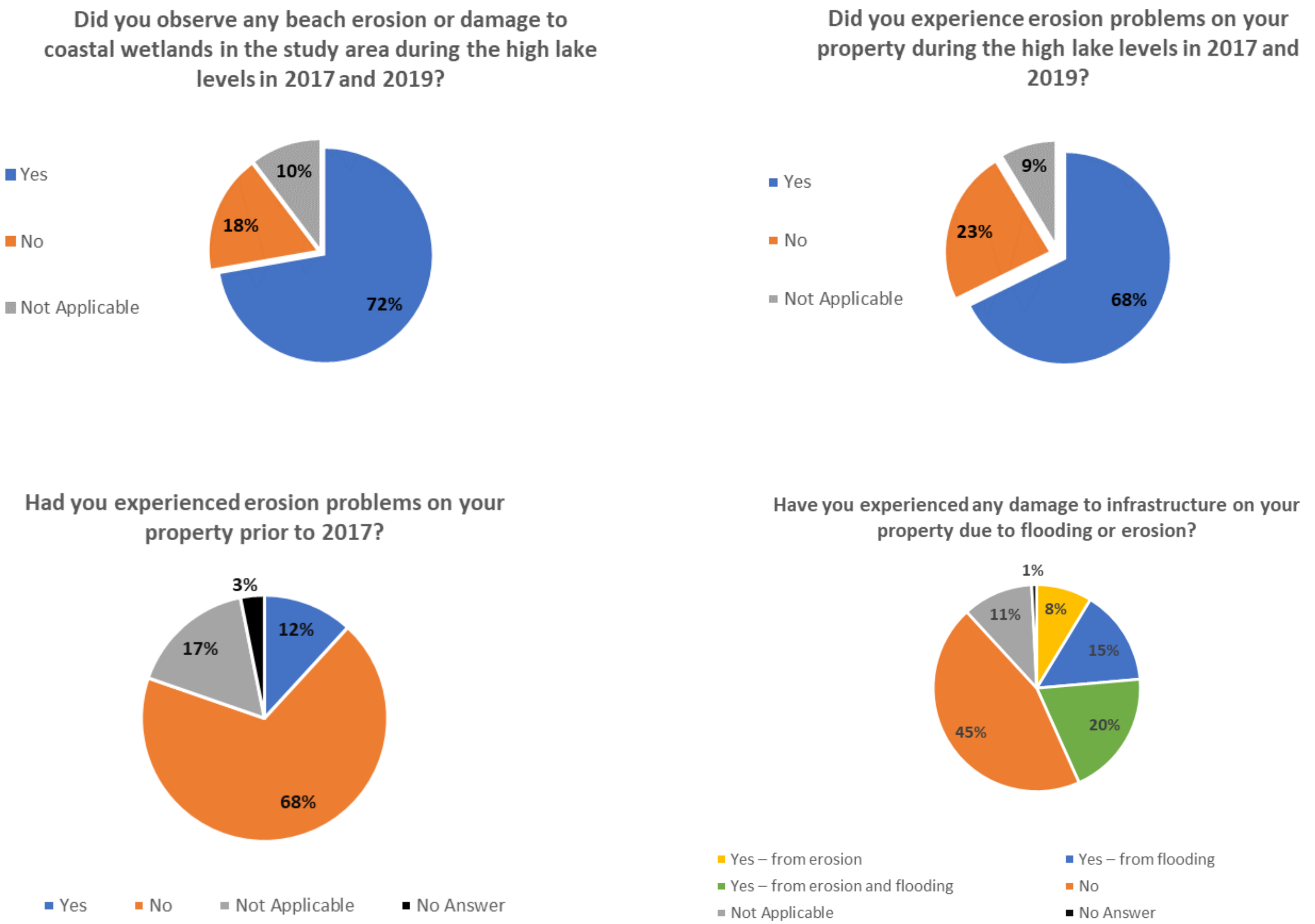


Figure 6.2 Responses to erosion questions

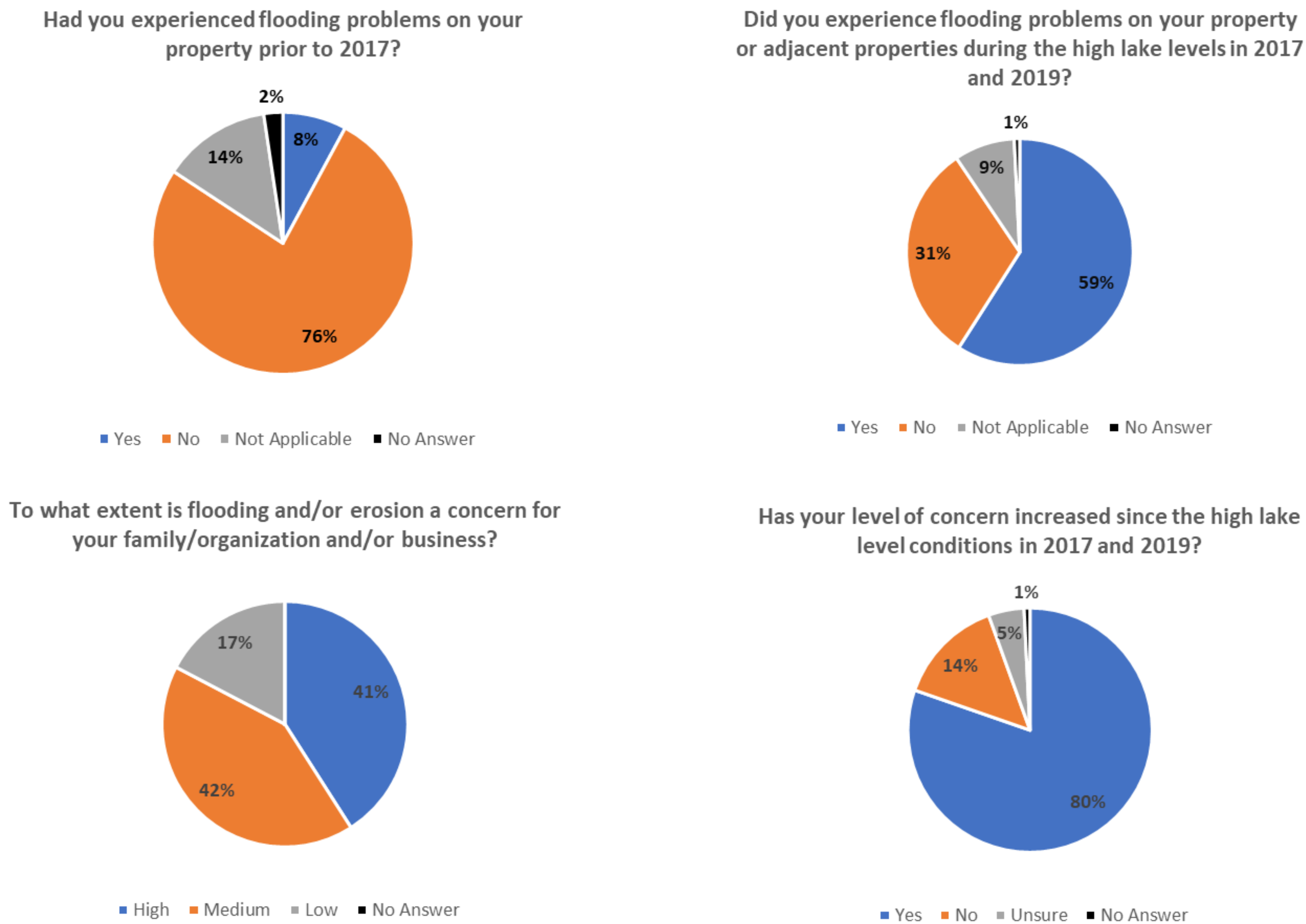


Figure 6.3 Responses to flooding questions

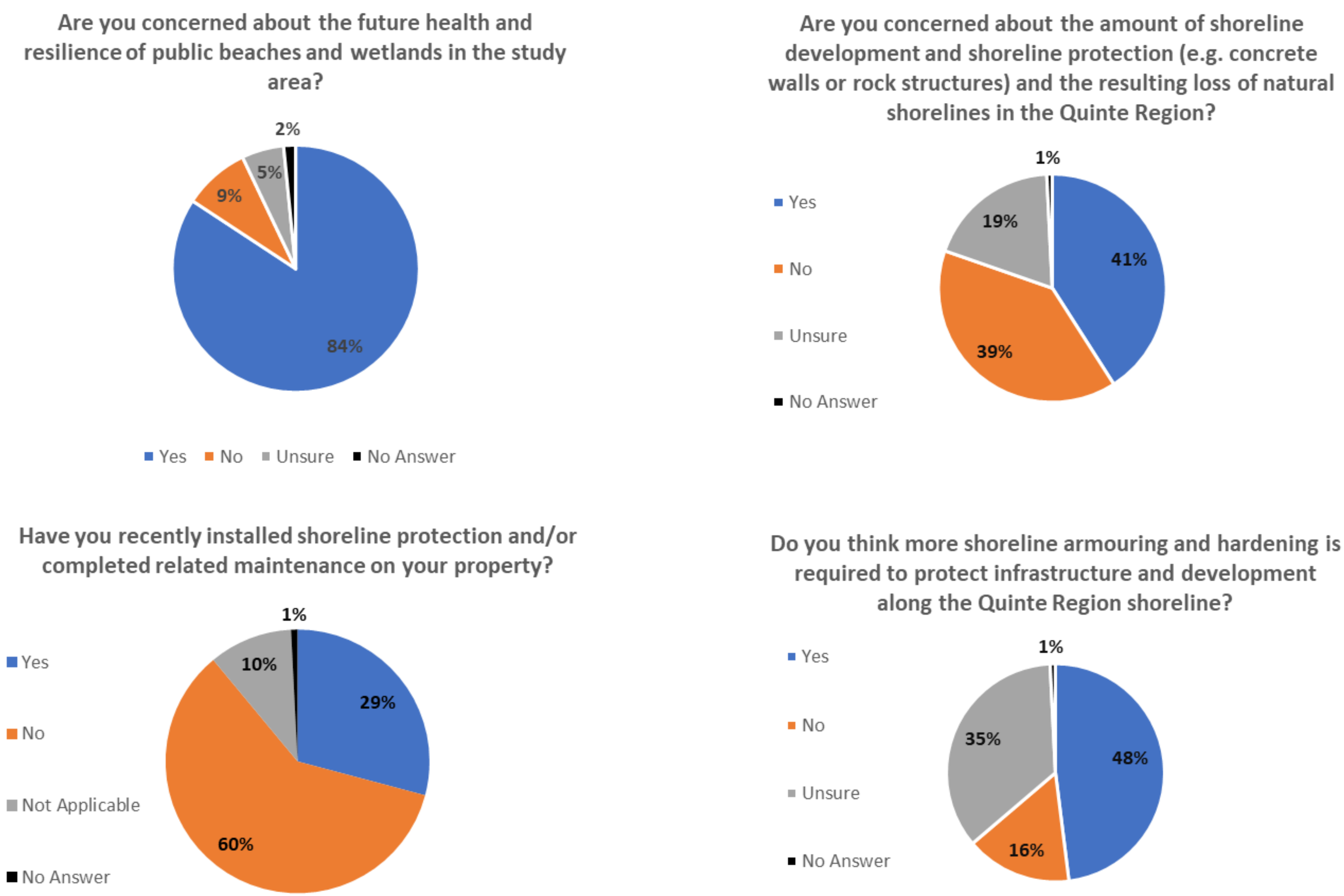


Figure 6.4 Responses to beach and shore protection questions

6.3 Public Information Centre #2

The second Public Information Centre occurred on April 12, 2022, after the release of the first draft of the SMP and associated draft hazard mapping for public feedback.

6.3.1 Advertising

The advertising for the second public meeting is provided below in Figure 6.5. The meeting was a live virtual event on the Zoom platform. A total of 30 individuals participated in the live session.

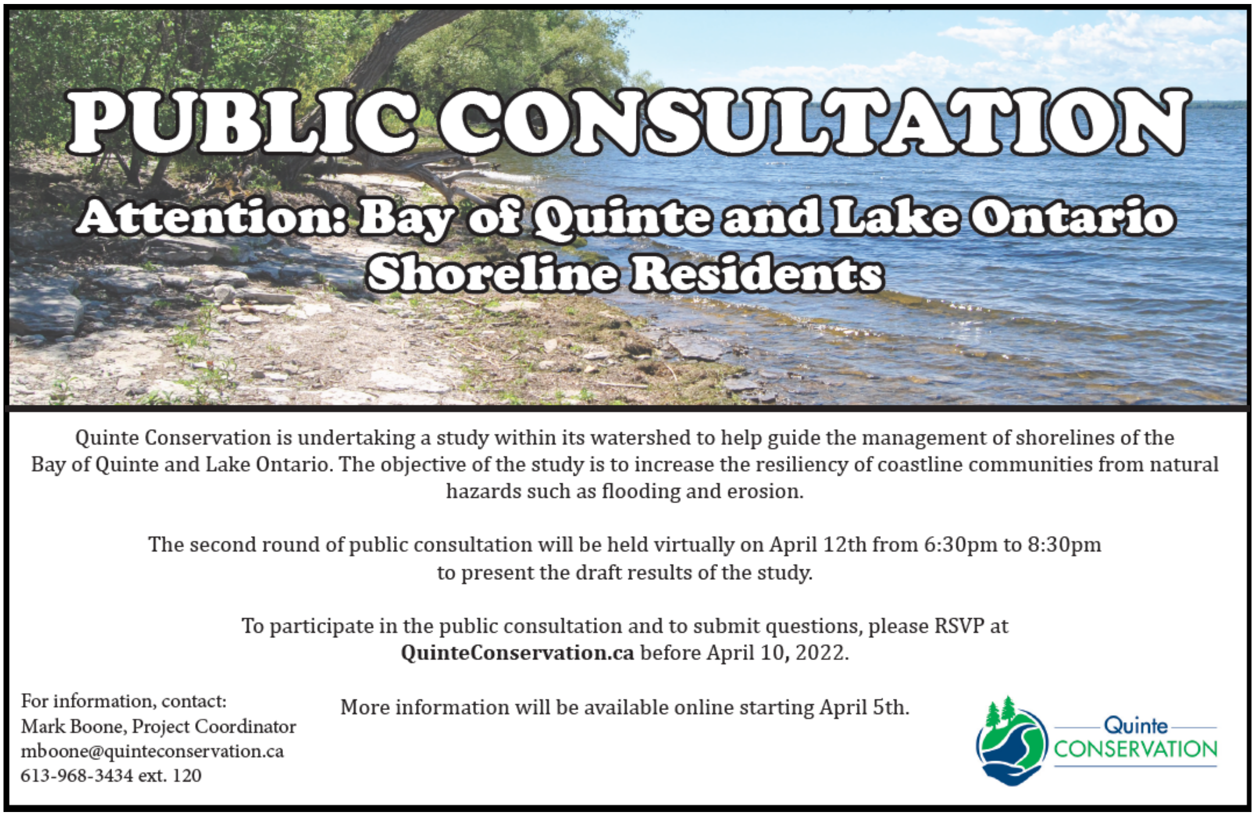


Figure 6.5 Advertising for second public meeting

6.3.2 Live Virtual Presentation and Discussion

Presentations were given by the same individuals who presented at the project partners meetings and PIC#1, with the presentations being held in a live, virtual format using the Zoom platform. An overview of the presentations is provided as follows:

- **Mark Boone, Project Manager for QC**: Mark provided an overview of the SMP development process, a summary of the public consultation from October 2021, and reminded participants that the draft SMP and draft hazard mapping was available online for review, with a link provided on the QC website.

- **Pete Zuzek, Project Manager for Consulting Team**: Pete reviewed the principles and objectives guiding the study, discussed the SMP development process, and provided background on the QC shoreline including classification of the shoreline into project reaches based on physical features, geology, and wave exposure. Pete compared the QC shoreline to other locations around the great lakes, discussed the importance of preserving natural shoreline ecosystems and sediment transport sources and pathways that provide critical sediment to beach systems throughout Prince Edward County. Finally, next steps were presented to follow the SMP including the need for collaboration in order to ensure the information in the SMP is adopted and used in a meaningful way.

- **Seth Logan, Lead Coastal Engineer for Consulting Team**: Seth presented the approach to shoreline hazard mapping for erosion, flooding, and dynamic beaches. He showed examples from the online mapping tool and introduced the PARA(P) framework for organizing the shoreline management recommendations. Challenges and recommendations related to shoreline hazards and risk mitigation were presented to the public, organized into three regions; the exposed Prince Edward County Shoreline, Adolphus Reach to Hayward Long Reach (including Picton Bay), and the Bay of Quinte and other sheltered embayments (Wellers Bay, West Lake, East Lake, etc.).

At the conclusion of the formal presentation, the floor was opened for questions from the public. Several questions were posed through the Zoom platform and responded to by the appropriate members of the study team.

6.3.3 Survey Results

The public was engaged in several ways leading up to, during, and after PIC#2 including: an invitation to submit formal questions to the study team prior to the PIC, a live poll conducted throughout the live presentations using the Zoom platform, and question period at the conclusion of the formal presentation. The results are summarized in the following bullets:

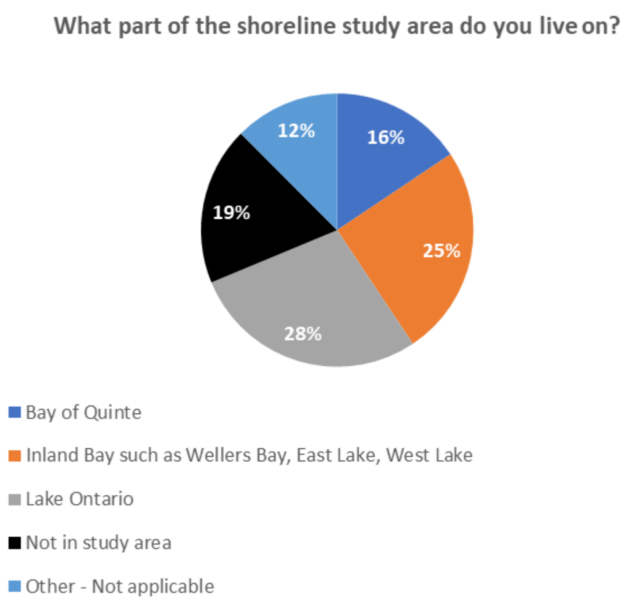
- Of the PIC#2 participants from the study area, 28% live on the Lake Ontario shoreline, 25% are from the inland lakes, and 16% from the Bay of Quinte.

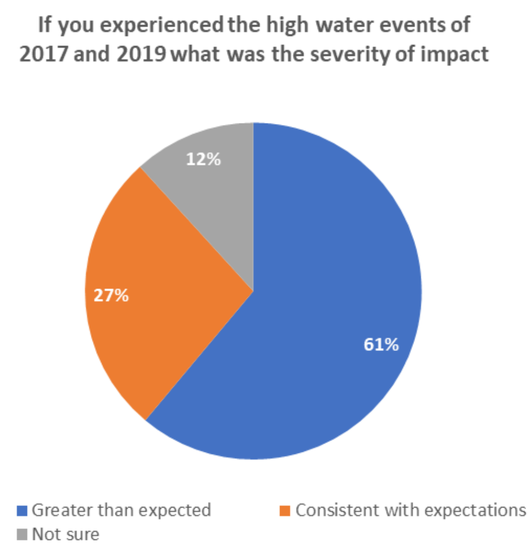
- The high water impacts from 2017 and 2019 were more severe than expected for 61% of respondents.

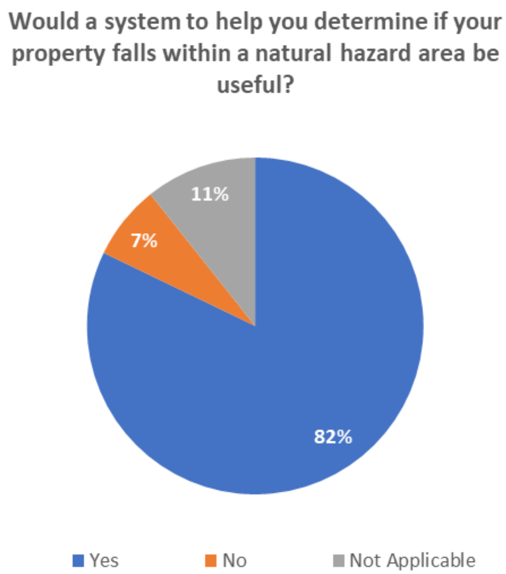
- An information system to help property owners know if their lands fall within a natural hazard would be useful for 82% of respondents. All of the hazard mapping is now available of the QC website.

- 90% would be willing to work collaboratively with Conservation Authorities to develop options to reduce the impacts of natural hazards.

While the poll was not extensive, it was completed by a representative cross-section of landowners across the study area. The high water impacts of 2017 and 2019 had a severe impact on the majority of the respondents and they were interesting in working with Conservation Authority to co-develop solutions to reduce exposure to natural hazards.







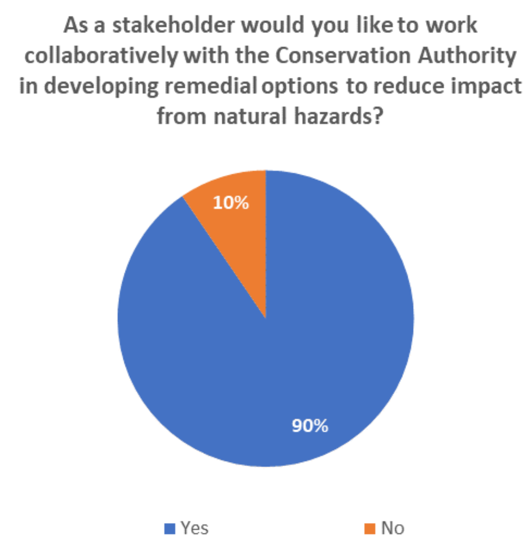


Figure 6.6 Response to PIC#2 Survey

7.0 SHORELINE MANAGEMENT RECOMMNEDATIONS

Section 7.0 provides background on a wide range of coastal hazard mitigation strategies, including specific recommendations to address challenges for the Quinte Conservation shoreline. Guidance is also provided on shoreline protection options.

7.1 Framing Management Options

When evaluating coastal hazard mitigation strategies for Great Lakes shorelines, the PARA(P) framework provides a logical way of grouping concepts. The framework is based on the PARA approach to shoreline risk mitigation (Doberstein et al, 2018), with the addition of a new option 'preserve'. The five broad categories now include **P**reserve, **A**void, **A**ccommodate, **R**etreat/Re-Align, and **P**rotect. Each category is described in the sections that follow, with some of the concepts in the PARA(P) framework requiring engineering support and approvals/permits from regulatory agencies prior to implementation.

7.1.1 Preserve

The principal objective of *Preserve* is to maintain natural shorelines and geodiversity since they are resilient to hazards, protect infrastructure and development, and deliver ecological benefits. This category recognizes that in addition to the critical ecological and environmental benefits of maintaining natural shorelines, in many cases such as where bedrock shorelines are shown to have very low erosion rates, preserving the natural, unarmoured, and unaltered shoreline is often the most effective means to mitigate long-term coastal risk and protect the ecosystem.

Figure 7.1 Preserving natural shorelines should be a priority, particularly where well established vegetation, barrier beach systems and/or bedrock headlands are providing stability and ecological benefits to the shorelines, such as the shoreline from North Beach to Huyck's Point

7.1.2 Avoid

The goal of the avoid strategy is to reduce future exposure of people and property to shoreline hazards and coastal risk by locating new development and redevelopment away from hazardous lands. This concept is also the cornerstone of Ontario's hazard policies as outlined in the PPS (MMAH, 2020) and in the Technical Guide (MNR, 2001a). This planning strategy is best applied when locating development on greenfield sites, but is also applicable for infill development or construction on lots of record. In general, avoid is the most cost effective hazard mitigation strategy. Figure 7.2 presents an example of the avoid strategy where a large natural buffer was incorporated into the planning of residential subdivisions on Lake Ontario.

Figure 7.2 Example the Avoid strategy where a large natural shoreline buffer was included in the planning of residential subdivisions on Lake Ontario

7.1.3 Accommodate

The accommodate strategy leverages a wide range of adaptive approaches to reduce coastal risk and permit continued occupation of communities on hazardous lands. Examples of the Accommodate strategy include floodproofing existing buildings (e.g., flood gates, opening shields, backflow valves, and sump pumps), raising building foundations, raising road elevations to provide safe access during flooding events, relocating high-value assets to areas of highest elevation or furthest from the shoreline hazards within homes or properties, upgrading components of an urban stormwater management system, upgrading emergency plans and emergency vehicle fleets for first responders, and completing emergency preparedness planning. Figure 7.3 presents examples of how existing buildings can be floodproofed (left) and a specialized emergency access vehicle capable of accessing roads inundated by floodwaters (right).

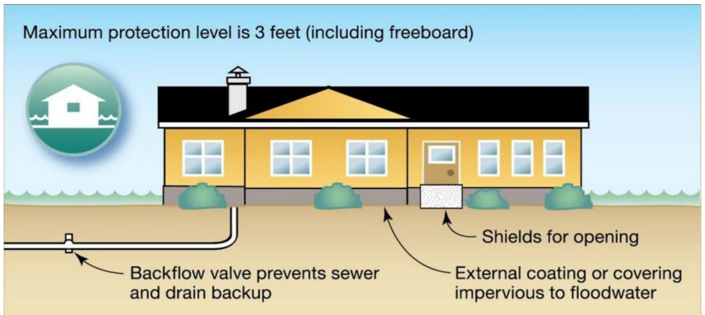


Figure 7.3 Examples of measures for floodproofing an existing building (left) and a specialized emergency vehicle with enhanced abilities to navigate through floodwaters (right)

7.1.4 Retreat / Re-align

Retreat/ Re-align is a coastal risk mitigation category that encompasses strategic decisions to change land use and relocate public or private assets that are exposed to significant risk. Retreat / Re-align strategies are typically considered only when strategies under other PARA(P) categories are either not sufficient to mitigate the risk or cannot be reasonably implemented due to constructability, permitting constraints, negative environmental impacts or where the cost to mitigate the risk is greater than the assets under threat. Strategies within this category include relocating buildings away from the hazards on existing lots or to new lots further inland, re-aligning roads, or removing buildings, typically through a voluntary property disposition program implemented by municipalities on a willing seller/willing buyer basis. For this scenario, funding and fair compensation for landowners is also required. Once the at-risk infrastructure has been relocated or removed, the land use can be transformed to more resilient options, such as reinstating natural shoreline buffers or riparian vegetation and coastal wetlands that also create habitat and ecosystem benefits. Figure 7.4 presents a hypothetical example of flood prone diked agricultural lands converted to a natural coastal wetland and barrier beach system. Figure 7.5 presents an example of a proposed road and building realignment where the risk to homes, homeowners and implications to vehicular access were significant due to the likelihood of a large-scale bluff failure triggered by coastal erosion.

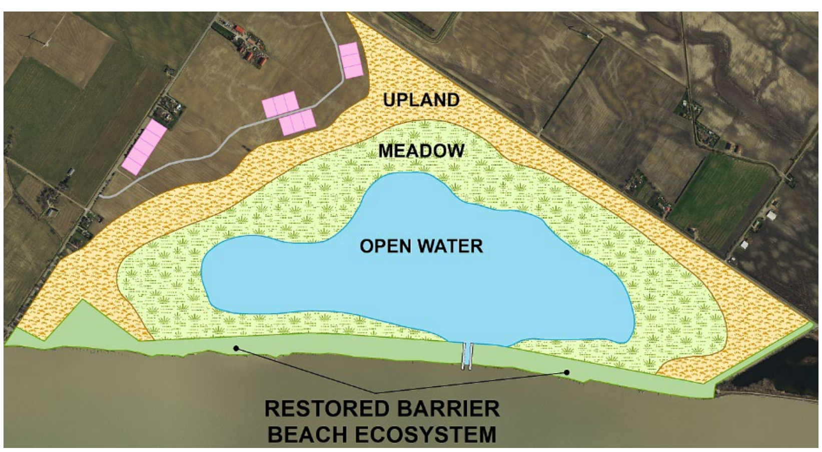


Figure 7.4 Diked agricultural land located below the lake level converted to a coastal wetland with a restored barrier beach

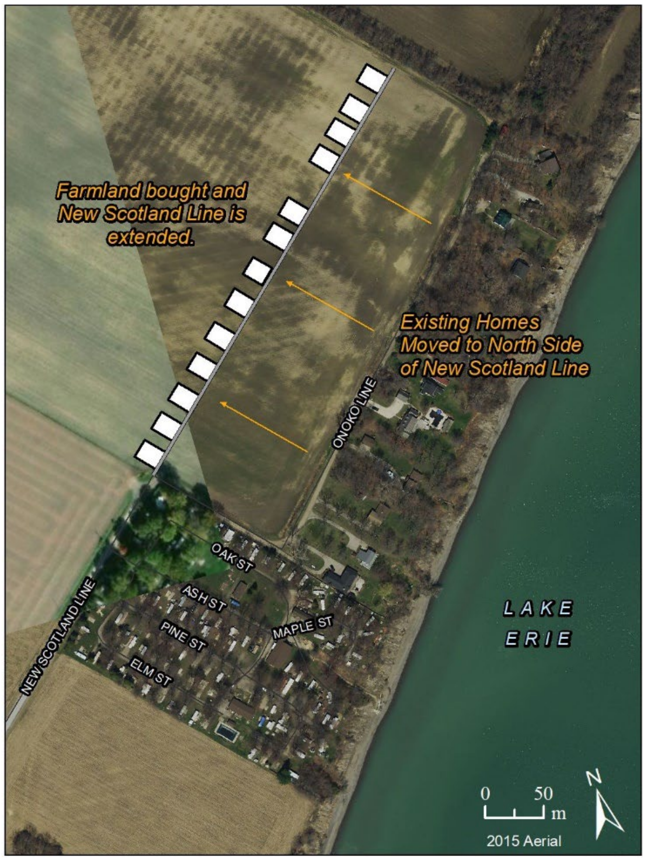


Figure 7.5 Road and home re-alignment further inland to reduce erosion vulnerability

7.1.5 Protect

The protect category is focused on safeguarding people, property, and infrastructure from exposure to shoreline hazards, either through traditional engineering or nature-based solutions. Historically, protect has been the most common approach deployed to address coastal hazards in Ontario for existing shoreline development and at-risk infrastructure. There are many types of shoreline protection structures that can reduce flood or erosion risk, including conventional, shore-parallel shoreline protection structures such revetments, seawalls, and breakwaters (refer to Figure 7.6). Beach nourishment and dune restoration strategies are examples of nature-based protection options (refer to Figure 7.7). For shorelines with relatively low wave exposure, hybrid grey-green protection structures can also be implemented, such as stone revetments fronted by vegetated buffers (refer to Figure 7.8). These hybrid approaches are most applicable in the Bay of Quinte and sheltered embayments throughout the study area. Specific guidance on shoreline protection structures that can be designed to mitigate coastal risk for shorelines within the Quinte Conservation geography is provided in Section 7.3.

Figure 7.6 Example of conventional shoreline protection structures on bedrock shorelines; stacked armour stone seawall (left) and "keyed-in" armour stone revetment (right)

Figure 7.7 Dune restoration program at Darlington Provincial Park, Lake Ontario

Figure 7.8 Hybrid grey-green shoreline protection structures featuring stone and/or concrete infrastructure fronted by vegetated natural buffers and natural riparian conditions

7.2 Technical Summaries and Reach Recommendations

Shoreline management recommendations are provided under the PARA(P) framework in Appendix A for each project reach. Recommendations are provided in a standardized reach summary template. Each template includes a map with the reach boundaries, a description of local conditions, sample photographs from the oblique aerial photo database, shoreline characterization including information from the shoreline protection database, specific challenges related to the mapped shoreline hazards, the technical basis for shoreline hazard mapping including flood levels and erosion rates, and finally reach-specific management recommendations to address the shoreline hazards. Each reach summary also includes a disclaimer for unauthorized use. Refer to Table 7.1 for a copy of the blank reach summary template. Completed reach summaries for each project reach are provided in Appendix A.

Table 7.1 Reach template with field descriptions

<table>
<tr><th colspan="2">Reach # – Name</th></tr>
<tr><td colspan="2">Map of Reach Boundaries</td></tr>
<tr><td colspan="2">Local Conditions</td></tr>
<tr><td colspan="2">• Physical description of reach.</td></tr>
<tr><td>Typical Photo</td><td>Location of Interest Photo</td></tr>
<tr><td colspan="2">Shoreline Characterization</td></tr>
<tr><td colspan="2">• Characterization of natural vs. hardened shoreline
• Identification of significant natural features
• Information on shoreline protection structures (from shore protection database)</td></tr>
<tr><td colspan="2">Challenges associated with Natural Hazards</td></tr>
<tr><td colspan="2">• Specific challenges within reach related to shoreline hazards</td></tr>
<tr><td colspan="2">Technical Basis for Natural Hazard Mapping</td></tr>
<tr><td colspan="2">• Information on erosion rates, flood levels, dynamic beaches and waves</td></tr>
<tr><td colspan="2">Shoreline Management Recommendations</td></tr>
<tr><td colspan="2">• Recommendations for reach specific management actions under the PARA(P) framework</td></tr>
<tr><td colspan="2">Use Disclaimer</td></tr>
<tr><td colspan="2">The information in this reach summary was prepared for Quinte Conservation. If used by a third party, they agree that the information is subject to change without notice. The Consultants assume no responsibility for the consequences of such use or changes in the information. Under no circumstance will the Consultants be liable for direct, indirect, special, or incidental damages resulting from, arising out of, or in connection with the use of the information in this summary by a third party.</td></tr>
</table>

7.3 Shoreline Protection Guidance

Guidance for shoreline protection structures is provided in this section for the Quinte Conservation shoreline. The primary objective of shoreline protection structures is to mitigate erosion. Properly designed structures may also mitigate some flooding impacts related to wave overtopping. The guidance provided in this section is generally based on regional coastal conditions commensurate with a 100-year planning horizon and covering the typical shoreline types encountered within the project region. However, the design of shoreline protection is site-specific, as local shoreline conditions and wave exposure can vary significantly over short distances. Information provided herein including opinions of probable cost should be taken as a general guide only. Site specific advice and engineering should always be sought from a professional engineer before implementing shore protection works.

Protection structures should generally be shore-parallel and placed against the existing bank or bluff (i.e., minimal lakeward projection) to mitigate potential impacts to longshore sediment transport and other nearshore coastal processes. Shore protection structures should be comprised of natural stone materials, such as sound, durable, angular, or blocky quarry stone, or large rounded field stone (i.e., boulders). Natural stone materials are preferred over alternative construction materials such as concrete due to their density, durability, and the fact that they are better for the aquatic environment and more closely replicate natural shoreline conditions and habitat.

7.3.1 Exposed, High-Energy Shorelines

In general, for exposed, high-wave energy shorelines on the Great Lakes where erosion rates may be high, sloping shore protection structures such as revetments are preferred over vertical structures due to their superior ability to dissipate wave energy. Vertical structures tend to reflect more wave energy causing increased lakebed erosion directly in front of the structure. This can lead to failures if the structure toe is not designed properly. Sloping structures are also less likely to fail due to ground or hydrostatic pressures compared to their vertical counterparts. The adjacent image captured a vertical concrete block seawall failure on Lake Ontario during the high water period in 2017 and 2019.

A significant advantage to sloping structures is that they tend to have gradual failure mechanisms such as displacement of structure elements (typically stones) or settlement over relatively long periods of time. By contrast, vertical structures tend to fail abruptly and catastrophically during a major storm event. Sloping structures can be monitored and maintained more readily throughout their design life relative to their vertical protection.

A typical design for a sloping stone revetment would include an outer ‘primary’ stone course, with underlaying courses of smaller ‘filter’ stone. The primary stone layer can be comprised of a single layer of very large, tightly packed, blocky armour stone (quarried stone), or multiple layers of randomly placed irregular armour stone or field stone (natural boulders). Single-layer armour stone structures require a smaller volume of material; however, the cost of blocky armour stone is typically much higher per tonne than irregular armour stone or field stone. Ultimately the selection between the two types of revetments is based on the availability of materials and cost, as both structure types can be designed to effectively resist wave loading and mitigate erosion for Lake Ontario shorelines. Figure 7.9 presents examples of single-layer block armour stone revetments, while Figure 7.10 presents examples of randomly placed armour and field stone revetments.

Figure 7.9 Examples of single-layer, blocky armour stone revetments on Lake Ontario

Figure 7.10 Examples of conventional, randomly placed armour stone (left) and field stone (right) revetments on Lake Ontario

When designing a sloping structure, special attention must be given to the toe detail (i.e., the lowest elevation and lakeward-most portion of the structure). For cohesive or glacial till shorelines where the structure is founded on cobble, sand, silt or clay, the toe stones would typically be fully or partially trenched into the substrate to provide stability. For bedrock shorelines such as those present around much of the Quinte Conservation region, anchoring the toe stones can present a design challenge. Options to address this include keying the toe stones into the bedrock, pinning the toe stones with steel rods anchored into the bedrock, or significantly oversizing the toe stones to ensure sufficient weight and friction between the stones and underlaying bedrock for stability. In general, rounded field stone (boulders) should not be used as toe stones where they are to be founded on a bare or seasonally bare bedrock shelf as they are more likely to slide or roll than angular or blocky armour stone. An example of an armour stone revetment being "keyed" into a bedrock shelf in Prince Edward County is provided in Figure 7.11 below. Typical, concept-level cross-sections for single-layer, blocky armour stone revetments on cohesive shorelines are provided in Figure 7.17 and Figure 7.18. A similar cross-section founded on a flat bedrock shelf is provided in Figure 7.19. Elements of the design including the necessary toe details to resist sliding or settlement, the necessary crest elevation to mitigate wave overtopping, and the required size of individual stones for stability under wave loading, are all examples of detailed design elements that need to be evaluated on a site-specific basis by a professional engineer.

Figure 7.11 Single-layer blocky armour stone revetment with toe stones "keyed" into underlying bedrock shelf

In some cases, due to space limitations or specific shoreline characteristics such as the presence of a flat bedrock shelf backed by a vertical eroding bedrock cliff, not-withstanding the above, vertical, or near-vertical structures may be warranted. In these cases, the preferred structure is a stacked, or stepped armour stone seawall. Armour stone seawalls are particularly well suited for shorelines with flat, shallow bedrock, such as those present along much of the exposed Prince Edward County shoreline. They are also preferred where erosion has compromised a small section of bedrock cliff, as they can be "plugged" into surrounding bedrock more readily than a sloping structure (refer to left portion of Figure 7.12). Finally, armour stone seawalls can be an effective shoreline treatment when placed at the back of a cobble or shingle beach or behind (landward) of emergent vegetation on a low-wave energy shoreline such as those encountered within many sheltered embayments (discussed further in Section 7.3.2 below).


Figure 7.12 Stacked armour stone seawalls on Lake Ontario, "plugged" into an eroded section of bedrock cliff (left) and at the back of a cobble beach (right).

Stacked armour stone seawalls are typically comprised of multiple rows of large, blocky armour stone, stacked vertically or near-vertically (i.e. each row setback back slightly from the previous row). These structures typically feature a coarse filter layer of rip rap or large gabion stone behind the outer armour stone, and require extremely tight packing of the outer stone layer to ensure that no filter stone is lost through voids in the structure. Where the structure is located on a cohesive or glacial till shoreline, the bottom row of stones should be fully or partially buried in the substrate. Where the structure is to be founded directly on bedrock, providing sufficient anchorage or friction with the underlaying bedrock is critical to stability and longevity of the structure. The bedrock shelf should first be flattened through chipping away loose layers of shale and limestone, or conversely levelled through the use of a thin layer of concrete. An example of this technique is shown in Figure 7.13. Toe stones founded directly on the bedrock shelf should be oversized and may be pinned to the bedrock with steel rods. Typical, concept-level cross-sections of stacked armour stone seawalls for bedrock shorelines and cohesive or till shorelines are provided as Figure 7.20 and Figure 7.21. Design details including stone sizes, toe and crest elevations and anchorage should be evaluated by a professional engineer on a site-specific basis.

Figure 7.13 Stacked armour stone seawall founded on a thin concrete foundation over an irregular bedrock shelf

For shoreline protections such as those described above located on exposed, high-energy shorelines, flanking of the structures must be carefully mitigated through detailed engineering design. Flanking refers to the ongoing erosion of the adjacent shoreline at the termination of a structure that may compromise the integrity of the structure if not mitigated. Near-term flanking can generally be mitigated through carefully designing structural transitions at either end of a coastal structure such that the structure abuts or is embedded into the native material (bank, cliff, bluff) at each end. For addition flanking protection on cohesive shorelines, stone can be buried beneath the ground level at the property line, such that they will settle to the base of the eroding bank at the termination of the structure as the neighbouring shoreline continues to erode. This technique is not feasible for bedrock shorelines. To mitigate long-term flanking where a neighbouring shoreline continues to erode over long periods of time, the structure terminations should be monitored at regular intervals and additional stone added as required.

7.3.2 Sheltered, Low-Energy Shorelines

For low-wave exposure shorelines such as those encountered within sheltered embayments and throughout the Bay of Quinte, preserving natural shoreline buffers and maintaining sloped, vegetated banks should generally be prioritized where erosion risks are low. Where shoreline protection is warranted, nature-based and hybrid grey(traditional)/green(nature-based) shoreline protection structures are preferred over traditional revetments and seawalls. Nature-based and hybrid grey/green infrastructure should be prioritized over traditional shoreline engineering wherever possible. Nature-based solutions may include such approaches as the establishment or preservation of shoreline vegetation with erosion-resistant root-structures, the placement of woody debris at the base of an eroding bank or bluff, vegetated flood berms, beach nourishment through the placement of dredged sediment, or supplementing a cobble or shingle beach shoreline with additional, oversized cobbles to improve stability and wave dissipation. Dune restoration is also an important form of nature-based shoreline protection for dynamic beach environments, whereby the beach-dune system is restored with native vegetation that traps sand and helps re-build eroded foredunes. Figure 7.14 presents an example of an artificial dune constructed on West Beach in Port Stanley on Lake Erie to reduce sand loss inland. For more information on Nature-based Solutions to shoreline erosion and flooding, please consult Bridges et al (2021) and CSA (2021).

Figure 7.14 Example of successful dune restoration at Port Stanley, Lake Erie

Hybrid grey/green shoreline protection structures are a suitable option for most shorelines within sheltered embayments (Wellers Bay, West Lake, East Lake, etc.) or throughout the Bay of Quinte where erosion or flooding may occur during periods of high lake levels, but the wave exposure is low. Hybrid solutions generally involve the placement of stone materials to mitigate erosion or flooding such as a rip rap or cobble berm, revetment, or stacked armour stone wall, with the structure itself being vegetated or a natural vegetated buffer being included in front of the structure to better replicate natural riparian conditions. Many existing shoreline structures can be supplemented with nature-based elements to improve their overall stability, performance and longevity while restoring a more natural shoreline. For example, aging concrete seawalls on the Bay of Quinte can be supplemented with a vegetated cobble berm on their lakeside to provide stability and reduce erosion and flooding risks through improved wave dissipation. This concept and several other examples of hybrid grey-green shoreline protection schemes are provided in Figure 7.15 below. Concept level cross sections for two such approaches are provided in Figure 7.22 and Figure 7.23.

Figure 7.15 Examples of hybrid grey/green shoreline protection schemes suitable for low exposure, low-energy shoreline environments such as those present in sheltered embayments and the Bay of Quinte

Shoreline protection is generally not appropriate for dynamic beach environments. However, there may be some select circumstances where protection and stabilization at the back of a beach is appropriate where a legacy development such as a waterfront park is present. In this case, an armour stone beach curb is an appropriate form of shoreline protection. A beach curb is a low-crested wall placed at the back of the beach, behind the beach crest, and founded (the toe) at least 1 to 2 m below the typical beach crest elevation to account for potential variability in the beach profile. Figure 7.16 presents examples of armour stone beach curbs on Lake Ontario.

Figure 7.16 Examples of stacked armour stone beach curbs

In general, structures comprised of items such as pre-cast concrete blocks, gabion baskets, timber and scrap concrete should be avoided on Great Lakes shorelines. These forms of shoreline protection are inadequate to resist the significant loads and erosive forces on Lake Ontario over the long term and are generally poor for the aquatic and shorelands environment.

Construction cost estimates are provided in Table 7.2 for armour stone revetments and armour stone seawalls on Great Lakes shorelines. Costs are provided per metre of shoreline to be armoured (measured in a shore-parallel direction). In general, structures designed and constructed for high-energy, exposed shorelines are much more expensive than costs associated with hybrid grey/green, nature-based, or traditional solutions in low-energy environments. Cost estimates are based on unit rates and construction quotations for projects throughout Ontario and are indexed to 2021 dollars. Costs may vary from the provided ranges depending on material availability, location, contractor availability and site access, among other things. Prices listed in Table 7.2 do not include contingencies, engineering design fees or other professional costs associated with the implementation of shoreline protection. A minimum contingency of 20% should be added to the costs provided when considering the affordability of implementing shoreline protection.

Table 7.2 Estimated ranges of probable construction costs for recommended shoreline protection concepts

Shoreline Exposure to Waves	Shoreline Protection Concept	Typical Construction Costs, per metre (in 2021 CAD)
High	Armour Stone or Field Stone Revetment	\$3,000 - \$4,500 / m
High	Stacked Armour Stone Seawalls	\$3,000 - \$4,700 / m
Low	Stone Revetment (Rip rap or Field Stone)	\$1,100 - \$2,200 / m
Low	Stacked Armour Stone Wall or Beach Curb	\$1,300 - \$2,400 / m

Section 7.3 including the conceptual cross-sections presented below are presented as broad guidance for shoreline protection structures only and do not negate the requirement for site-specific engineering to be carried out by a professional engineer with experience in the design of coastal structures. Moreover, all shoreline protection works will require site-specific work permits from Quinte Conservation, with additional permits or approvals likely required from the Ministry of Northern Development, Mines, Natural Resources and Forestry (NDMNRF) and the Department of Fisheries and Oceans (DFO) should any portion of the structure be situated lakeward of the high water line. For permits and approvals to be issued, the proposed shoreline protection structures must adhere to the specific policies of the regulatory bodies listed above.

7.3.3 Monitoring and Maintenance

To maximize the effective lifespan of new and existing shoreline protection structures, regular monitoring should be carried out by the owner, with less frequent monitoring (every 5 – 10 years or after a major storm event) carried out by a professional engineer. Regular monitoring should include photographs and visual observations documenting any apparent movement or displacement of structural elements such as stones, settlement, or loss of material. A professional engineer should be contacted if any of these processes are observed. Less frequent, detailed monitoring to be carried out by an engineer may include surveying of the structure to look for changes in slope, toe or crest elevation, and underwater inspections where appropriate. Community-scale monitoring should be completed for community-scale shoreline protection projects, where possible.

If required, structure maintenance should be completed in a timely fashion by a contractor with experience in the construction of coastal structures. Appropriate maintenance measures should be determined by a professional engineer. It is recommended that long-term monitoring and maintenance plans be a requirement of regulatory approvals for new shoreline protection structures.

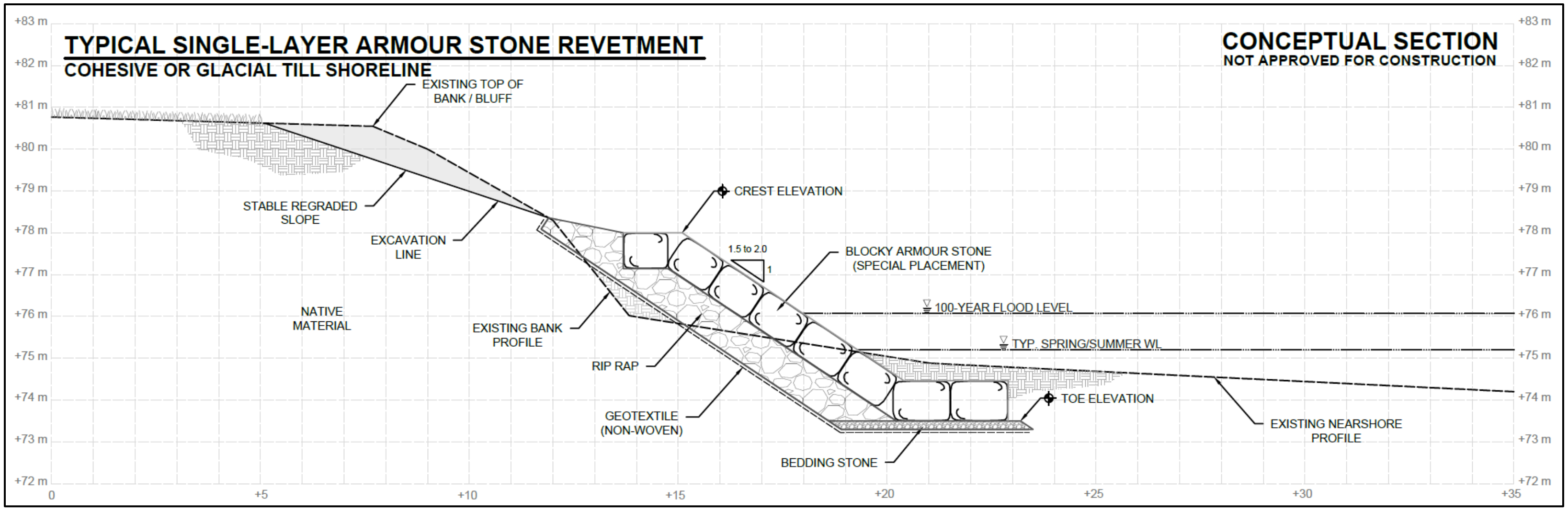


Figure 7.17 Typical single-layer armour stone revetment for a cohesive or glacial till shoreline (concept only)

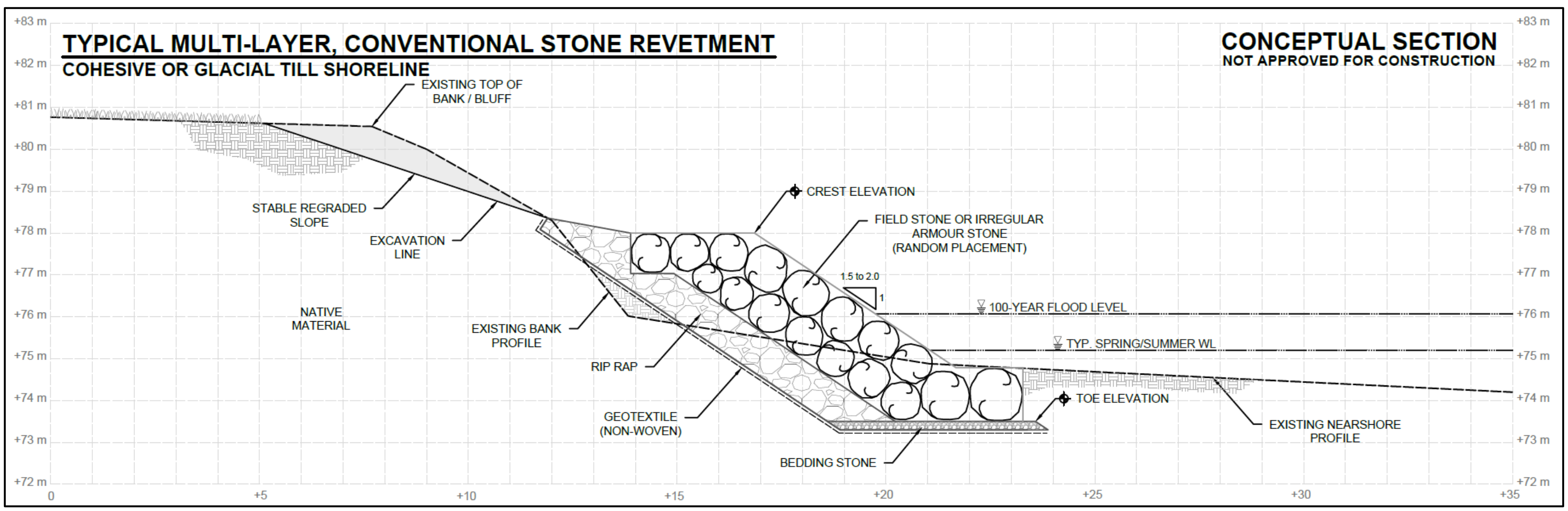


Figure 7.18 Typical multi-layer, randomly placed stone revetment for a cohesive or glacial till shoreline (concept only)

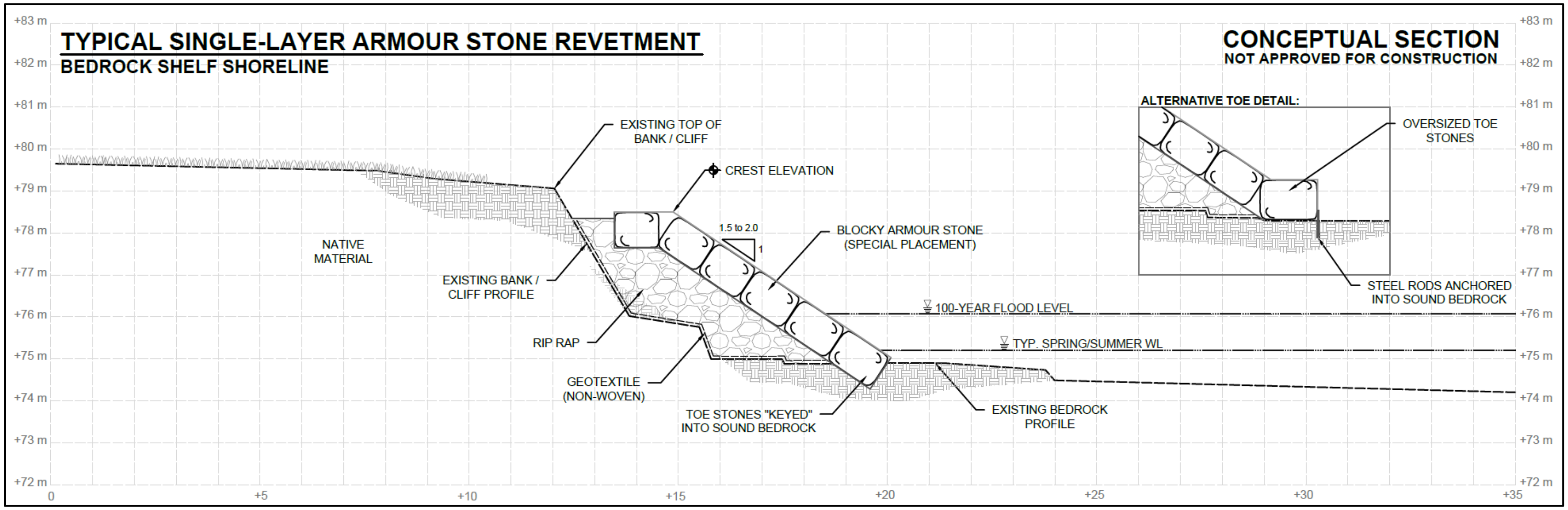


Figure 7.19 Typical single-layer armour stone revetment founded on a bedrock shelf (concept only)

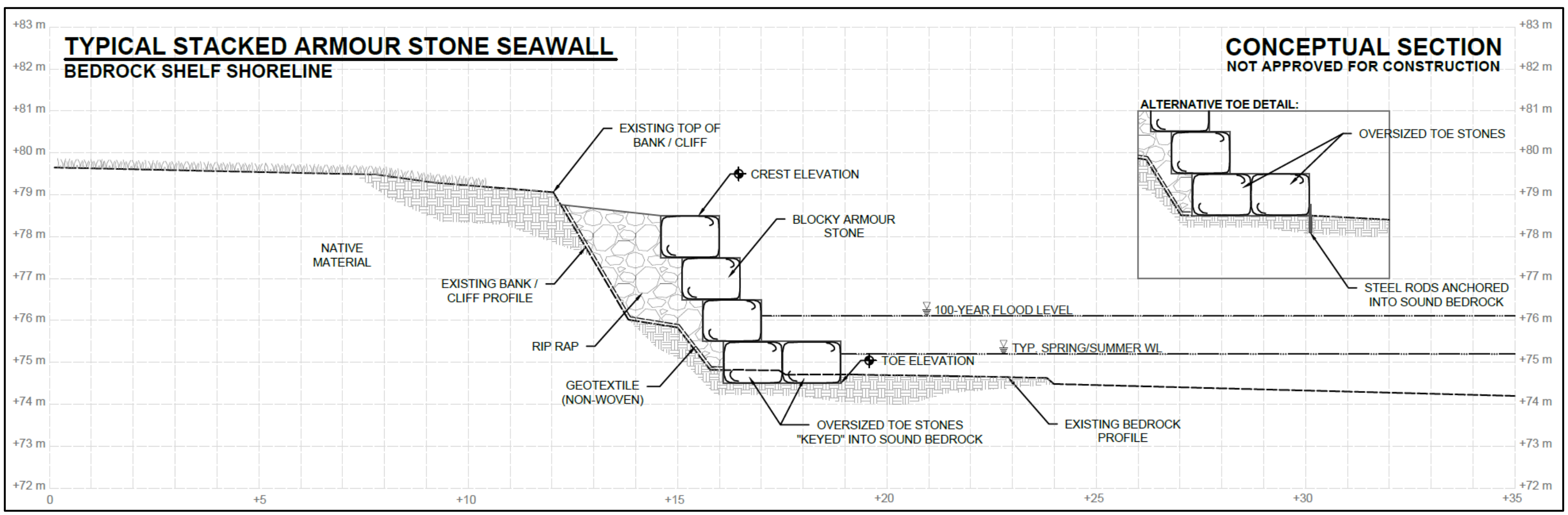


Figure 7.20 Typical stacked armour stone seawall founded on a bedrock shelf (concept only)

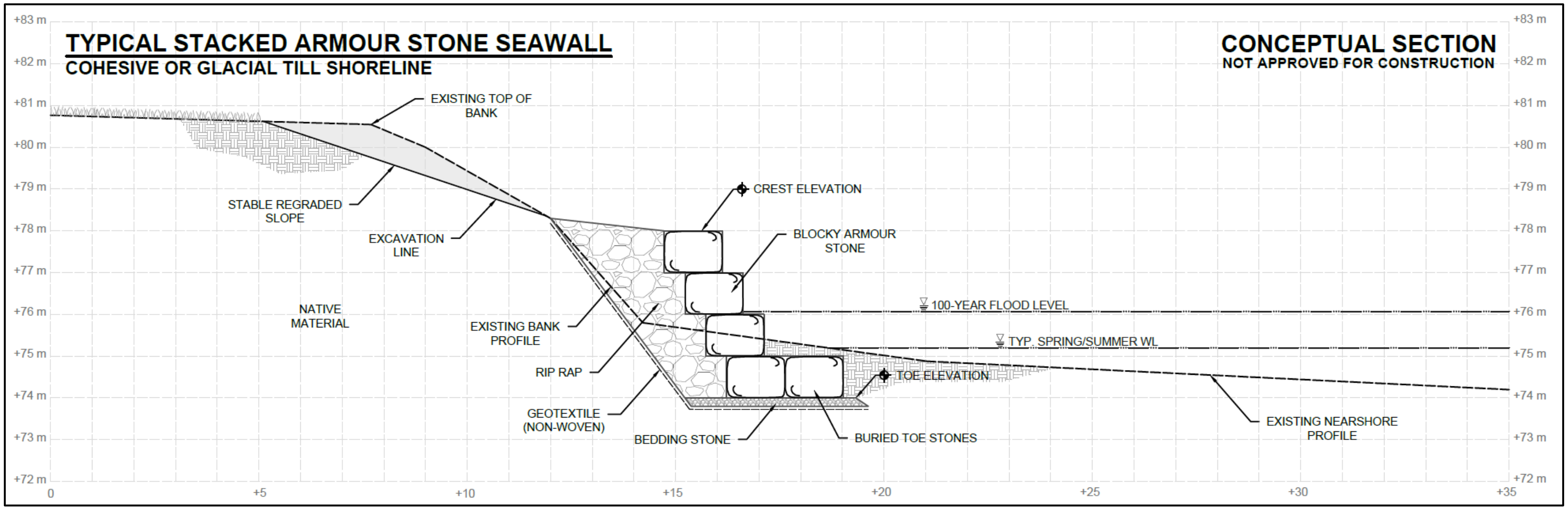


Figure 7.21 Typical stacked armour stone seawall for a cohesive or glacial till shoreline (concept only)

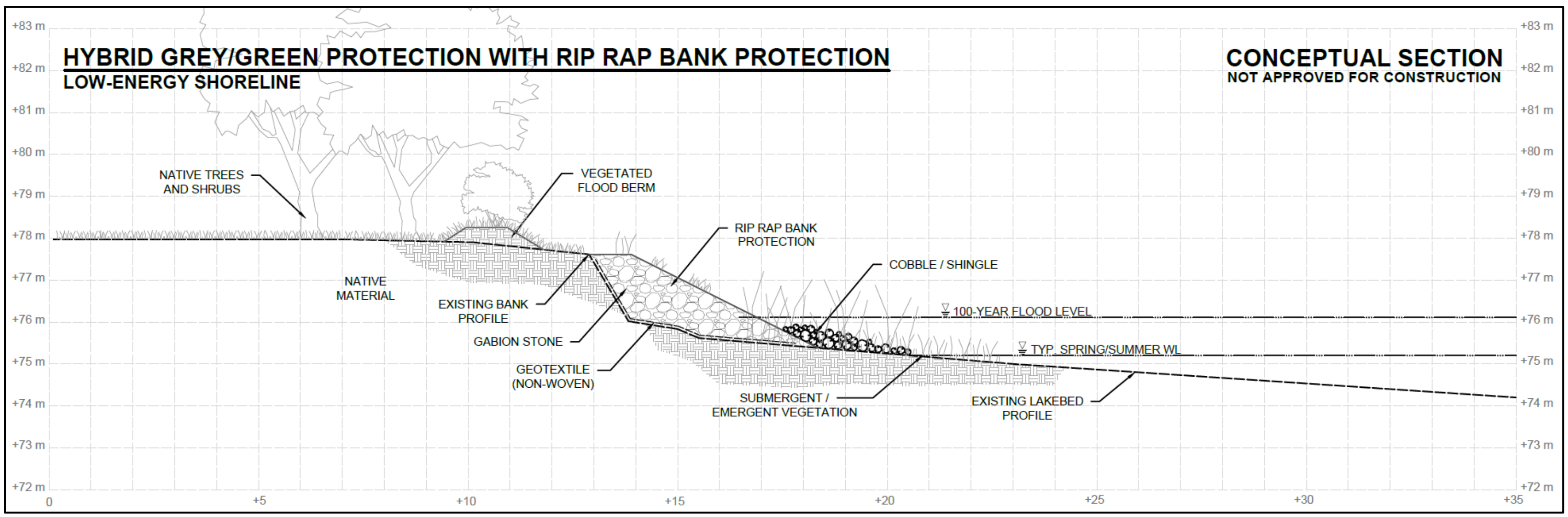


Figure 7.22 Aspects of a hybrid grey-green shoreline protection scheme for sheltered embayments and other low wave energy environments featuring a vegetated rip rap slope (concept only)

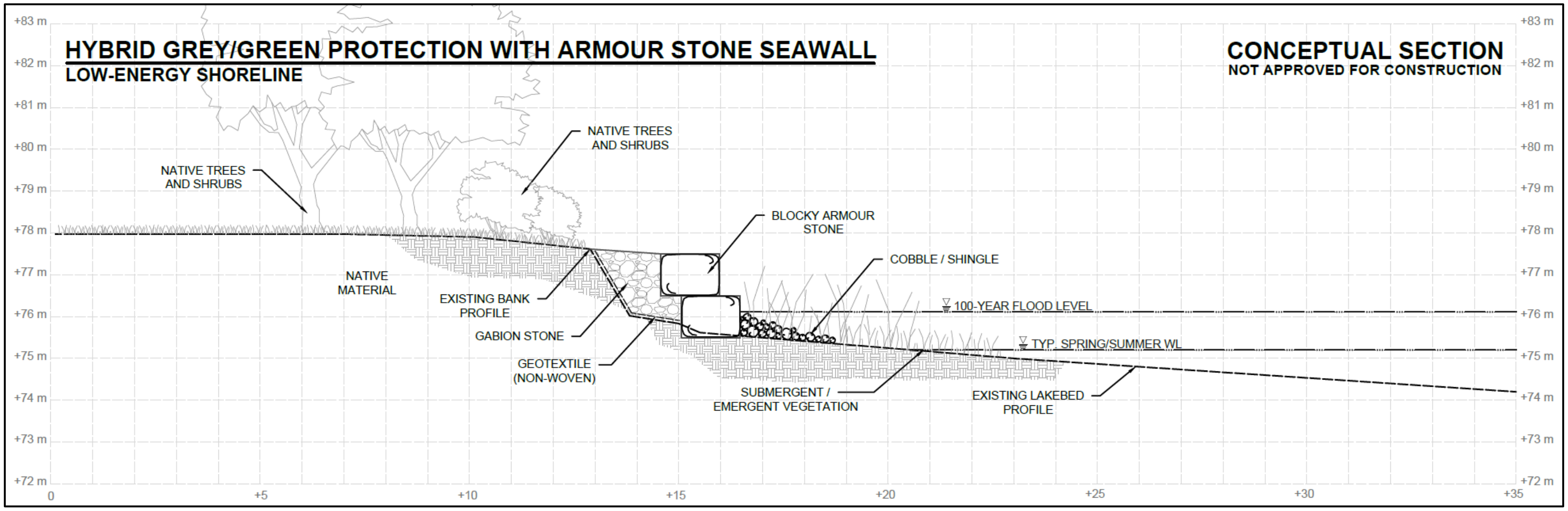


Figure 7.23 Aspects of a hybrid grey-green shoreline protection scheme for sheltered embayments and other low wave energy environments featuring a stacked armour stone seawall (concept only)

8.0 STUDY CONCLUSIONS AND RECOMMENDATIONS

The study conclusions and recommendations are provided in Section 8.0. Detailed descriptions of study findings, conclusions and recommendations are provided separately for each project reach in Appendix A.

8.1 Key Study Findings

The key study findings from the QC SMP include:

- The study area features a bedrock shoreline and consequently the exposure to coastal hazards is not as severe as other communities in the Great Lakes Basin. The sheltered nature of the Bay of Quinte also moderates the wave climate, further reducing exposure to flooding and erosion hazards compared to other open lake shorelines comprised of erodible glacial sediments (e.g., north shore of Lake Erie) or beaches (e.g., north shore of Lake Ontario).

- Bedrock geology is responsible for the headland beach systems that dominate the lake shoreline and the large system of sheltered embayments found throughout the Bay of Quinte. The intrinsic beauty of these natural systems, also referred to as geodiversity, is unparalleled throughout the Great Lakes and should be protected in perpetuity.

- Approximately 16% of the study area shoreline features some form of shoreline protection infrastructure as of the Fall of 2021. Existing shoreline protection structures should be monitored, maintained, and improved as required to extend their design life. Future shoreline development should be located as far back from the lake and associated shoreline hazards as possible to reduce the future need for shoreline protection structures.

- Biodiversity is very high within the limits of the study area and protecting the unique natural resources such as coastal wetlands should remain a high priority in Municipal Official Plans and this SMP.

- Sandy beaches in the study area have been popular recreational destinations for decades and have increased in popularity during the recent pandemic. Usage pressure will continue to increase and requires additional management efforts to preserve and enhance these dynamic beach systems.

- The elevation of the 100-year flood level has increased and consequently the inland extent of the flood hazard limit has increased throughout the study area. "Accommodate" risk mitigation strategies should be implemented where required to reduce flood risks for existing development located inside the flooding hazard limit.

- Numerous developments throughout the bay and lake shoreline can be isolated during the 100-year flood level due to road flooding. Further technical studies are required at a local scale to assess the impacts of road flooding and wave action on emergency ingress and egress. As noted in Section 3.1.2 of the PPS (2020) and Section 7.1 of the Technical Guide (MNR, 2001a), development and site alterations are not permitted within areas rendered inaccessible to people and vehicles during times of flooding, erosion, and dynamic beach hazards.

- Critical road infrastructure is located at the edge of eroding banks and bluffs at several locations throughout the study area. Site-specific technical studies are required, such as an Environmental Assessment, to evaluate alternatives to maintain the roads including re-aligning them further inland or implementing continuous, engineered shoreline armouring.

8.2 Next Steps to Increasing Coastal Resilience

The following suggestions are provided to increase coastal resilience to natural hazards throughout the SMP study area:

- The SMP and hazard mapping should be adopted by the various Official Plans with jurisdiction over the Quinte Conservation shoreline.
- Future municipal planning and zoning should integrate higher flood levels and recession rates than the standards used in this SMP to prepare for the impacts of climate change.
- The regulatory hazard mapping generated for this study is the minimum requirement at this time. However, all proponents of future development and site alterations are encouraged to consider higher flood levels and larger erosion hazard setbacks to increase resilience to a changing climate.
- Further local technical studies are required to assess the impacts of road flooding and wave action on emergency ingress and egress to communities (locations identified in Appendix A).
- Additional technical studies, such as environmental assessments, are required to evaluate alternatives to mitigate erosion threats to road infrastructure (locations identified in Appendix A). Such studies will provide the framework to explore various alternatives, such as managed realignment and protecting the existing road alignments.
- A site-specific study is recommended for Wellington Beach to develop a beach improvement and management plan that includes a new parking strategy, dune restoration, mitigation of sedimentation within the navigation channel, and sediment retention strategies to increase the width of the west portion of the beach.
- Nature-based solutions and hybrid green-grey shore protection solutions should be the first consideration to address coastal hazards, such as erosion and flooding, particularly in areas of low-wave energy and erosion including sheltered embayments on the southwest side of Prince Edward County and throughout the Bay of Quinte.
- Technical studies and restoration actions are required to increase the resilience of local beaches to future periods of high lake levels, ice-free winters, and increased storm exposure.

- The QC regulations and planning policies should be reviewed to identify any inconsistencies with the SMP and updated accordingly.

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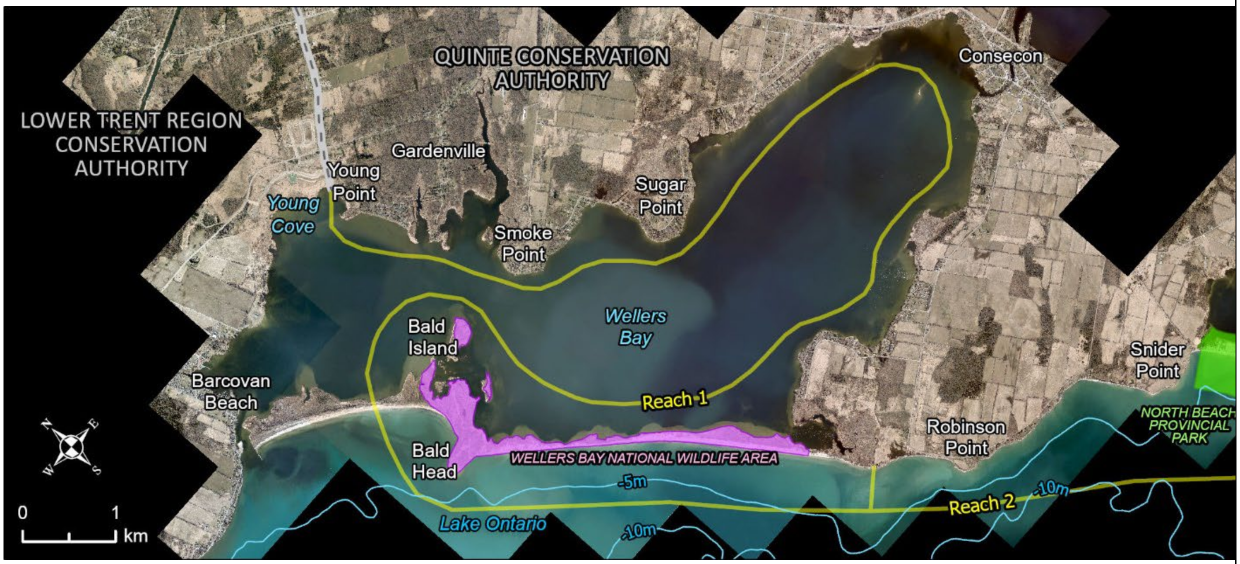
APPENDIX A –Reach Summaries

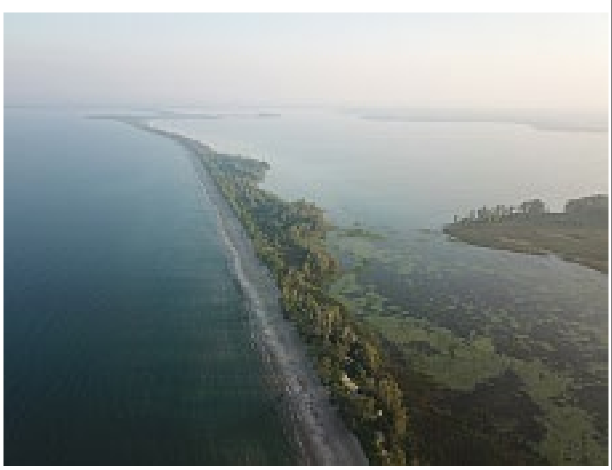
Reach 1 – Wellers Bay



Local Conditions

- Reach Length = approximately 34 km.
- The Wellers Bay National Wildlife Area shelters a significant portion of Wellers Bay from lake waves. The barrier beach is also low and narrow in several locations, which could breach in future storm events.
- Due to the shallow water depths and low-lying lands surrounding the bay, extensive coastal wetlands are found in Wellers Bay.
- The remaining shoreline is densely developed with cottage and permanent homes.
- Flood impact risks are very high in Wellers Bay and many communities do not have safe emergency ingress and egress.

Wellers Bay Barrier Beach

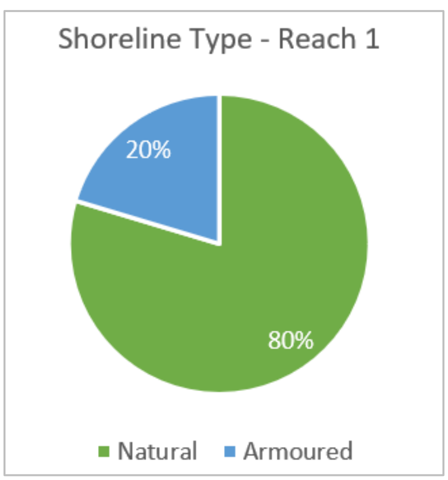


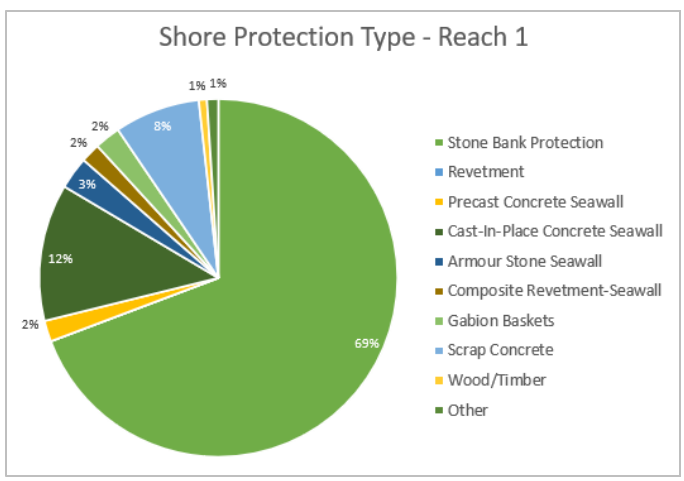
Shoreline Development and Armouring

Shoreline Characterization

- Provincially significant wetlands are extensive throughout Reach 1. See adjacent image.
- Although not recognized as provincially significant, other wetlands are found throughout the Wellers Bay, including shallow submerged wetlands.
- Isolated stands of the invasive phragmites were observed, including the sheltered side of the Wellers Bay barrier beach.

- Isolated exposures of bedrock were observed at the waters edge, but most is covered with various forms of shoreline protection.
- Much of the shoreline is low-lying and flood prone with flat topography.
- The reach terminates on the lake side of the bay with a 700 m long dynamic beach.
- Reach 1 shoreline is 80% natural and 20% armoured, based on the entire shoreline length (including Wellers Bay barrier beach).
- Of the armoured portion of the shoreline, 69% is ad-hoc field stone or quarry stone bank protection, 12% is concrete seawall, and 8% is scrap concrete placed on the shoreline.
- Tolerance for additional shoreline hardening is low.





Challenges Associated with Natural Hazards

- Wellers Bay shoreline is low lying and many of the buildings and underground utilities (septic systems) are located within the Flooding Hazard Limit (see below).

- Several communities feature flooded ingress/egress routes, which may prohibit evacuations during a flood or limit emergency responders from providing services. Affected roads include Harbard Lane, Hiscock Shores Road, and Sunset Lagoon Drive.

- The barrier beach that defines the Wellers Bay National Wildlife Area is very narrow and the northern half has been eroding at least since 1962. The barrier beach has breached in the past, and future breaches of the barrier are likely. This may increase the exposure to natural hazards within Wellers Bay in the future.

Technical Basis for Natural Hazard Mapping

- Recession Rate for Erosion Hazard Limit (Stable Slope not included):

Geographic Area	Recession Rate (m/year)
Wellers Bay (sheltered shoreline in bay)	0.10
Low bank shoreline (lake shoreline)	0.16

- 100-year Flood Level and Wave Uprush Limit:

Reach	100-year Flood Level (m IGLD'85)	Horizontal Uprush Allowance (m)	Calculated Wave Uprush Elevation (m IGLD85')
Inside Wellers Bay (sheltered)	76.07	15 m	76.7
National Wildlife Areas (lake shoreline)	76.07	Varies	78.1
Exposed Low Bank Shoreline on Lake	76.07	15 m	79.0

- Dynamic Beach(es): Coordinates in UTM Zone 18N, NAD 1983

Start	End	Recession Rate (m/year) or Stable	Dynamic Beach Name
293284, 4873312	293646, 4872689	Stable	SE End of Wellers Bay

- Offshore Wave Climate:

WIS Station	ARI (years)	Depth (m)	Hs (m)	Tp (s)	DIR (deg)
91206	25	19	6.4	10.5	230 – 245
	100	19	7.0	11.0	230 – 245
91209	25	24	6.9	10.7	235 – 250
	100	24	7.5	11.1	235 – 250

Shoreline Management Recommendations

- **Preserve:** maintain natural shorelines, geodiversity, and vegetation to preserve resilience, natural protection, and ecological benefits.
- **Avoid:** ensure new development occurs outside of hazardous lands, and prohibit development/re-development in areas that are inaccessible during major floods.
- **Accommodate:** site specific investigations are required for communities with safe access challenges, as identified through the hazard mapping. Floodproof buildings, raise foundations, and upgrade septic systems on flood prone lands. Emergency planning and preparedness for a major flooding event.
- **Retreat and Realign:** re-align driveways, roadways through trailer parks, cottage communities, etc. and relocate homes to highest ground, where possible.
- **Protect:** hybrid grey/green erosion and flood protection schemes are recommended, as discussed in Section 7.3.2 of the SMP. Engage with the Canadian Wildlife Service, which own the majority of the Wellers Bay barrier beach, and discuss potential restoration options.

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Reach 2 – Stinson Block Road to Huyck's Point

Local Conditions

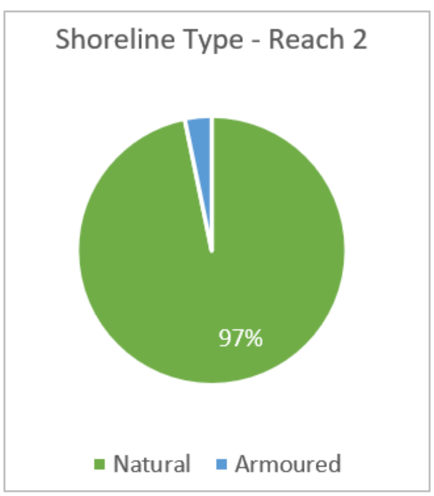
- Reach Length = approximately 49 km.
- Shoreline features bedrock headlands and sandy pocket beaches.
- The barrier beaches protect the sheltered embayments of North, Huyck's and Pleasant Bay.
- Sheltered embayments feature extensive coastal wetlands.
- North Beach Provincial Park provides public access to the Lake Ontario shoreline.

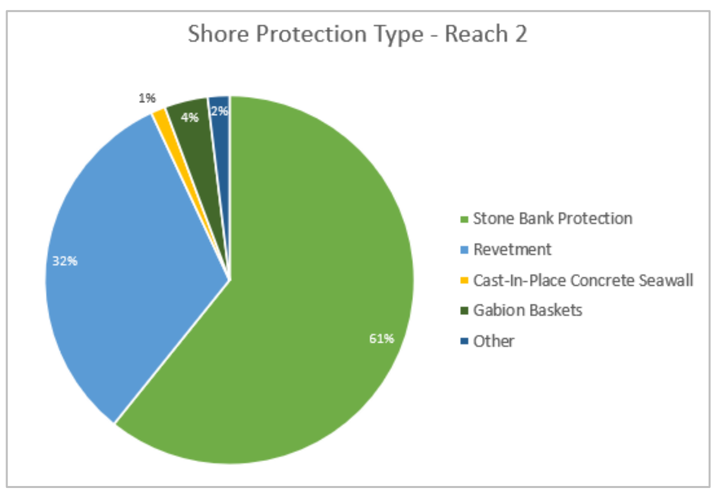
Bedrock Shoreline on Lake Ontario

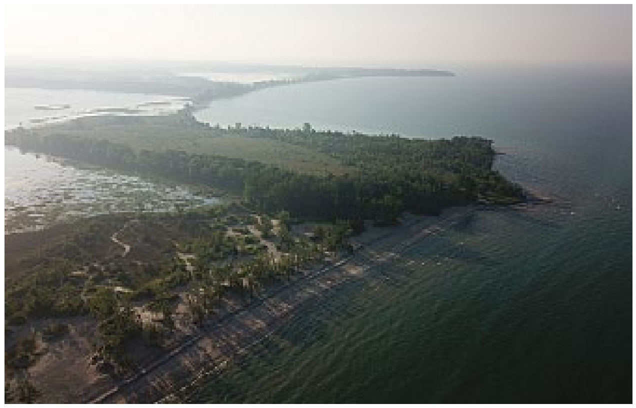
Trailer Park in Pleasant Bay

Shoreline Characterization

- Pleasant Bay and the majority of Huyck's Bay is classified as Provincially Significant Wetland.
- Extensive sandy beaches in Reach 2, including North Beach Provincial Park and three Dynamic Beaches.
- Barrier beaches provide critical protection to interior embayments including North Bay, Pleasant Bay, and Huyck's Bay.
- Bedrock headlands anchor sand beaches and rare dune ecosystems.
- Reach 2 shoreline is 97% natural and only 3% armoured, based on the entire shoreline length (including barrier beaches and coastal wetlands).
- Of the armoured portion of the shoreline, 61% is ad-hoc field stone or quarry stone bank protection, and 32% is engineered revetment.
- Tolerance for additional shoreline hardening is low.





Challenges Associated with Natural Hazards
• Beach and dune ecosystems are vulnerable to erosion during period of high lake levels and development pressure. Development within the Dynamic Beach Hazard limit is prohibited under the Provincial Policy Statement and not recommended in the Great Lakes Technical Guide.  • Existing development located within the erosion hazard may require shoreline protection to save buildings. Permits will be required if shore protection is pursued.  • Sections of Stinson Block Road are within the Flood Hazard Limit. 

Technical Basis for Natural Hazard Mapping

- Recession Rate for Erosion Hazard Limit (Stable Slope not included):

Geographic Area	Recession Rate (m/year)
Lake shoreline	0.16
Embayment shoreline	0.10

- 100-year Flood Level and Wave Uprush Limit:

Reach	100-year Flood Level (m IGLD'85)	Horizontal Uprush Allowance (m)	Calculated Wave Uprush Elevation (m IGLD85')
Low Bank Shorelines on the lake	76.07	15.0	79.0
Embayments	76.07	15.0	76.7
Barrier Beaches	76.06	Varies	77.7

- Dynamic Beach(es): Coordinates in UTM Zone 18N, NAD 1983

Start	End	Recession Rate (m/year) or Stable	Dynamic Beach Name
295812, 4871657	296168, 4871133	Stable	N. or North Beach PP
297661, 4869416	297972, 4868658	Stable	S. of North Beach PP
298465, 4868662	299878, 4867086	Stable	Huyck's Bay

- Offshore Wave Climate:

WIS Station	ARI (years)	Depth (m)	Hs (m)	Tp (s)	DIR (deg)
91209	25	24	6.9	10.7	235 – 250
	100	24	7.5	11.1	235 – 250
91212	25	36	7.6	10.7	240 – 255
	100	36	8.3	11.1	240 – 255

Shoreline Management Recommendations

- **Preserve:** maintain natural shorelines, geodiversity, and vegetation, to preserve resilience, natural protection, and ecological benefits (recession rates are generally low for bedrock shorelines).
- **Avoid:** ensure new development occurs outside of hazardous lands, and prohibit development/re-development in areas that are inaccessible during major floods. Avoid development that will impact dynamic beaches and sensitive marsh ecosystem.
- **Protect:** New shoreline protection structures on bedrock shorelines should be carefully designed by a professional engineer. Existing structures should be monitored and maintained or replaced as necessary.

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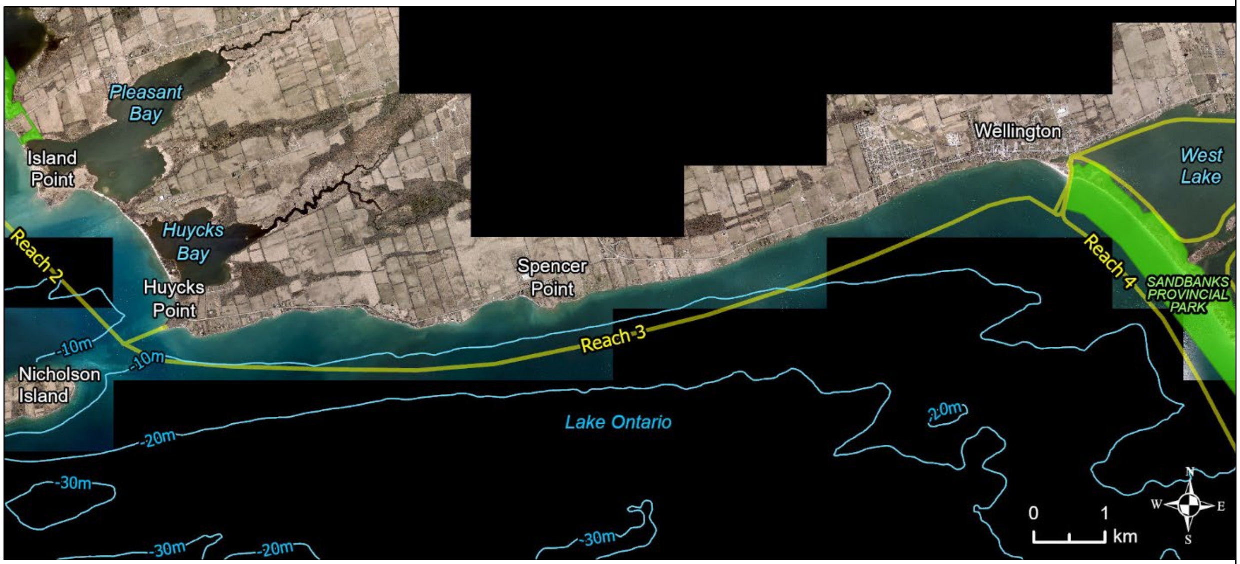
Reach 3 – Huyck's Point to Wellington



Local Conditions

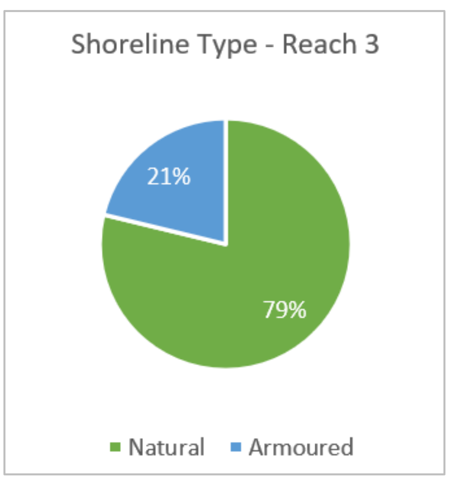
- Reach Length = approximately 14 km.
- Most of Reach 3 features an eroding bedrock bank with a thin layer of glacial till overburden. The nearshore is dominated by flat bedrock shelves.
- The reach terminates at Wellington Beach, a filet beach anchored by armour stone jetties.
- Reach 3 is developed with estate residential lots in the west and denser settlement in Wellington.

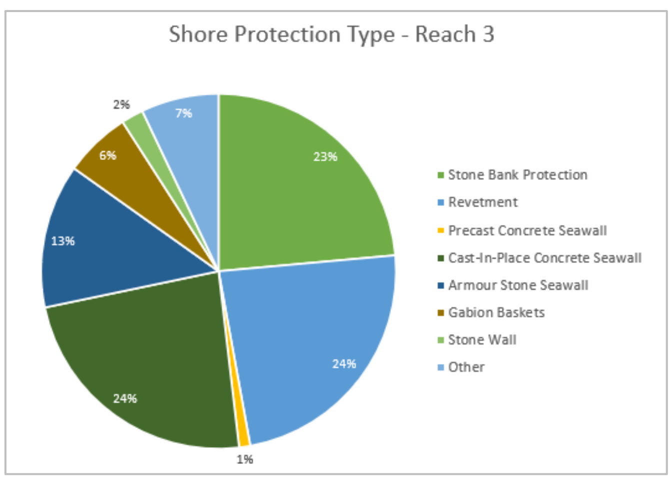
Eroding Bedrock Bank

Jettied Entrance to West Lake

Shoreline Characterization

- Huyck's Point Road is very close to the eroding bedrock bank in places.
- Some of the bedrock banks have been armoured, especially in locations where the buildings are vulnerable to erosion.
- Some historical development in Wellington is very close to the lake and within the flood and erosion hazard limits.
- The beach at Wellington is a popular summer destination creating parking challenges. Vehicles park in the zone that would typically feature a coastal dune providing protection from flooding and erosion.
- The eastern boundary of the reach features a navigation channel into West Lake. The channel is fixed with armour stone jetties and has a sedimentation problem.
- The west side of the navigation channel features a boat launch and parking.
- Reach 3 shoreline is 79% natural and 21% armoured, based on the entire shoreline length.
- Of the armoured portion of the shoreline, 24% is engineered revetment, 24% is cast-in-place concrete seawall, and 23% is ad-hoc stone bank protection.
- Tolerance for additional shoreline hardening is low.





Challenges Associated with Natural Hazards
• Road infrastructure vulnerable to erosion (Huyck's Point Rd.).  • Erosion will threaten new homes if not setback sufficiently from the eroding banks.  • Legacy development on hazardous lands in Wellington with old, failing shore protection.  • Lack of a healthy back beach and dune system at Wellington Beach which would provide erosion and flooding protection and improve the resilience of the beach. • Sedimentation in navigation channel to West Lake requires regular maintenance dredging.

Technical Basis for Natural Hazard Mapping

- Recession Rate for Erosion Hazard Limit (Stable Slope not included):

Geographic Area	Recession Rate (m/year)
Reach 3	0.19

- 100-year Flood Level and Wave Uprush Limit:

Reach	100-year Flood Level (m IGLD'85)	Horizontal Uprush Allowance (m)	Calculated Wave Uprush Elevation (m IGLD85')
Exposed Lake Shoreline	76.07	15.0	79.2

- Dynamic Beach(es): Coordinates in UTM Zone 18N, NAD 1983

Start	End	Recession Rate (m/year) or Stable	Dynamic Beach Name
311834, 4869104	312376, 4868821	Stable	Wellington Beach

- Offshore Wave Climate:

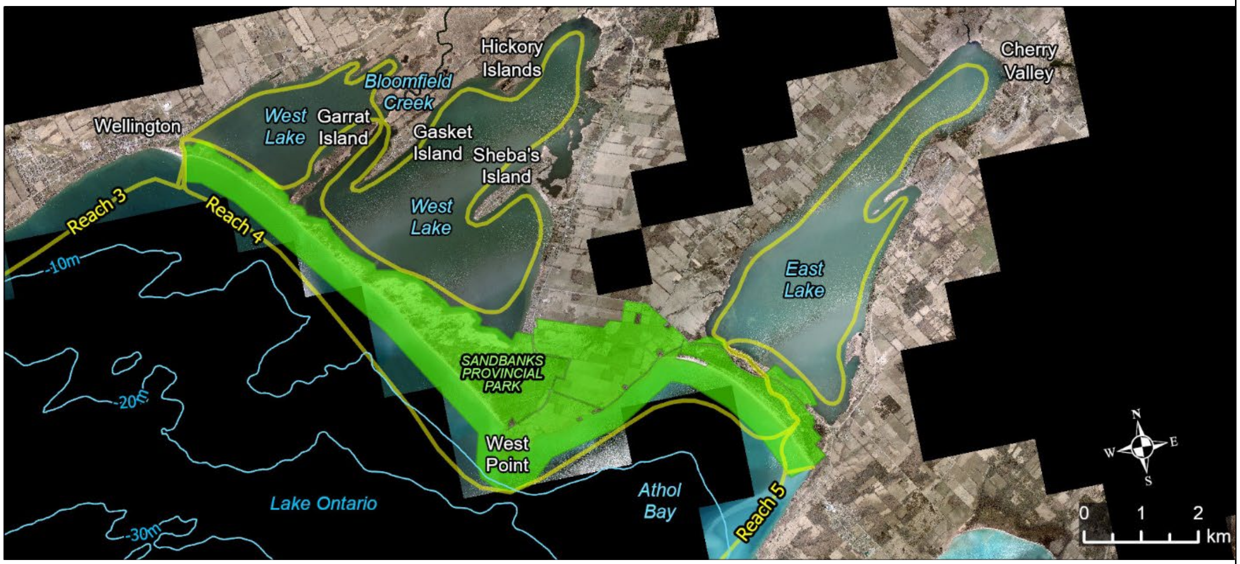
WIS Station	ARI (years)	Depth (m)	Hs (m)	Tp (s)	DIR (deg)
91214	25	29	6.7	10.6	235 – 250
	100	29	7.2	11.1	235 – 250
91217	25	24	7.0	10.8	240 – 250
	100	24	7.5	11.2	240 – 250

Shoreline Management Recommendations

- **Preserve:** maintain natural shorelines, geodiversity, and, vegetation to preserve resilience, natural protection, and ecological benefits (recession rates are generally low for bedrock shorelines).
- **Avoid:** ensure new development occurs outside of hazardous lands, and prohibit development/re-development in areas that are inaccessible during major floods. Avoid development that will impact dynamic beaches and sensitive marsh ecosystem.
- **Accommodate:** site specific study to develop a beach improvement / management plan for Wellington Beach that includes dune restoration, new parking strategy, mitigation of sedimentation within navigation channel, and sediment retention strategies for west half of beach.
- **Retreat and Realign:** Investigate re-alignment of Huyck's Point Road where road is threatened by erosion (compare to protect cost).
- **Protect:** Investigate protection of Huyck's Point Road in key areas through traditional engineered erosion protection structure (compare to re-align cost). Shore protection within Reach 3 should be carefully designed for bedrock shoreline and on a site-specific basis by a professional engineer (refer to Section 7.3). Monitor and maintain existing shoreline protection structures.

Use Disclaimer

Reach 4 – East and West Lake



Local Conditions

- Reach Length = approximately 91 km.
- Reach 4 is centred on Sandbanks Provincial Park which features extensive sandy beaches and dunes. There is no hazard mapping for the park, since QC does not have jurisdiction over development inside the park (except for County Road 12 and one small section of beach along Welsh Lane, opposite East Lake).
- County Road 12 between West Point and Outlet Beach runs along a section of eroding bedrock bank and is threatened by erosion.
- East and West Lake feature extensive coastal wetlands.
- Portions of the shoreline along East and West Lake are extensively developed with homes and seasonal residences.

Extensive Coastal Wetlands, East Lake

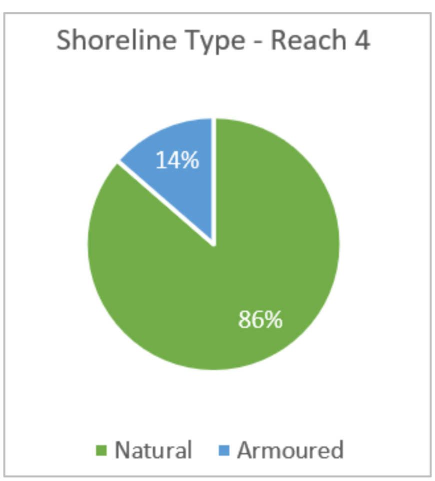
Eroding Bank along Highway 12

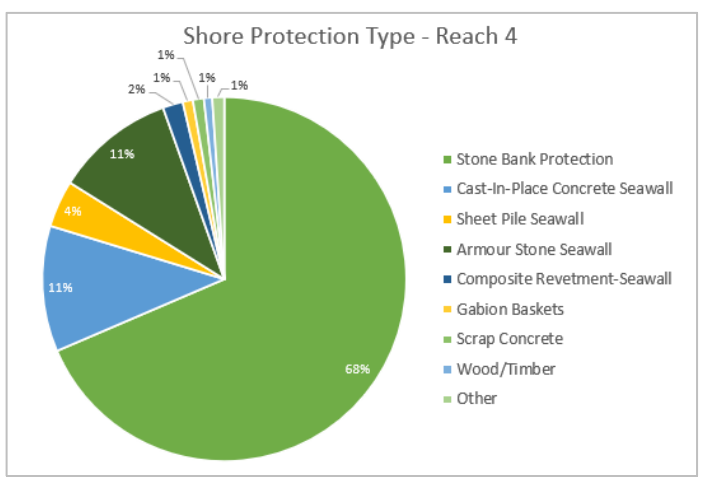
Shoreline Characterization

- The sheltered waters of East and West Lake make floating or removable docks for recreational boats feasible.
- The northeastern shore of West Lake and northwestern shore of East Lake are recognized as provincially significant wetlands.
- West Lake outlets through the navigation channel at Wellington. East Lake outlets through a channel via Outlet Beach which is susceptible to sedimentation.

- West Point is a bedrock headland that anchors significant beaches on either side (part of Sandbanks Provincial Park).
- County Road 12 runs along the bank from West Point to Outlet Beach and was impacted by erosion in 2017 and 2019.
- Reach 4 shoreline is 86% natural and 14% armoured, based on the entire shoreline length including the Provincial Park shorelines.

- Of the armoured portion of the shoreline, 68% is ad-hoc field stone or quarry stone bank protection, 11% is cast-in-place concrete seawall, and 11% is stacked armour stone seawall.
- Tolerance for additional shoreline hardening is low.





Challenges associated with Natural Hazards

- Several of the shoreline developments in West and East Lakes have access challenges during major flooding events. These include Wesley Acres, Hideaway Trailer Park and Sheba's Island (pictured) on West Lake, and Cherry Beach, Copenhagen Lane, and Parr Island on East Lake.

- Many residential buildings are within the flooding hazards of West Lake and East Lake.
- Sedimentation in the mouth of the Outlet River can lead to elevated water levels in East Lake after major rainfall events.
- Approximately 1 km of County Rd. 12 is threatened by erosion, with portions of it being impacted in the high water periods of 2017 and 2019 (refer to images below).

Technical Basis for Natural Hazard Mapping

- Recession Rate for Erosion Hazard Limit (Stable Slope not included):

Geographic Area	Recession Rate (m/year)
Lake shoreline between Lakeshore and Outlet Beaches	0.19
East and West Lake shoreline	0.10

- 100-year Flood Level and Wave Uprush Limit:

Reach	100-year Flood Level (m IGLD'85)	Horizontal Uprush Allowance (m)	Calculated Wave Uprush Elevation (m IGLD85')
Lakeshore Beach	76.07	n/a	77.7
Outlet Beach	76.07	Varies	77.1
East and West Lake (sheltered)	76.07	15.0	76.7
County Rd. 12	76.07	15.0	78.0

- Dynamic Beach(es): Coordinates in UTM Zone 18N, NAD 1983

Start	End	Recession Rate (m/year) or Stable	Dynamic Beach Name
320105, 4863654	320643, 4863393	Stable	Welsh Lane

- Offshore Wave Climate:

WIS Station	ARI (years)	Depth (m)	Hs (m)	Tp (s)	DIR (deg)
91217	25	24	7.0	10.8	240 – 250
	100	24	7.5	11.2	240 – 250
91220	25	26	7.2	10.9	245 – 260
	100	26	7.8	11.4	245 – 260

Shoreline Management Recommendations

- **Preserve:** maintain natural shorelines, geodiversity, and vegetation to preserve resilience, natural protection, and ecological benefits (recession rates are generally low for bedrock shorelines).
- **Avoid:** ensure new development occurs outside of hazardous lands, and prohibit development/re-development in areas that are inaccessible during major floods. Avoid development that will impact dynamic beaches and sensitive marsh ecosystem.
- **Accommodate:** site specific investigations are required for communities with safe access challenges, as identified through the hazard mapping. Floodproof buildings, raise foundations, and upgrade septic systems on flood prone lands in East/West Lake. Emergency planning and preparedness for a major flooding event.
- **Retreat and Realign:** re-align driveways, roadways through trailer parks, cottage communities, etc. and relocate homes to highest ground, where possible. Investigate re-alignment of County Rd. 12 and compare to "protect" cost.
- **Protect:** hybrid grey/green erosion and flood protection schemes are recommended for properties on East/West Lake with erosion/flood risk, as discussed in Section 7.3.2 of the SMP. Investigate traditional shoreline protection structure for County Rd. 12 and compare to "re-align" cost.

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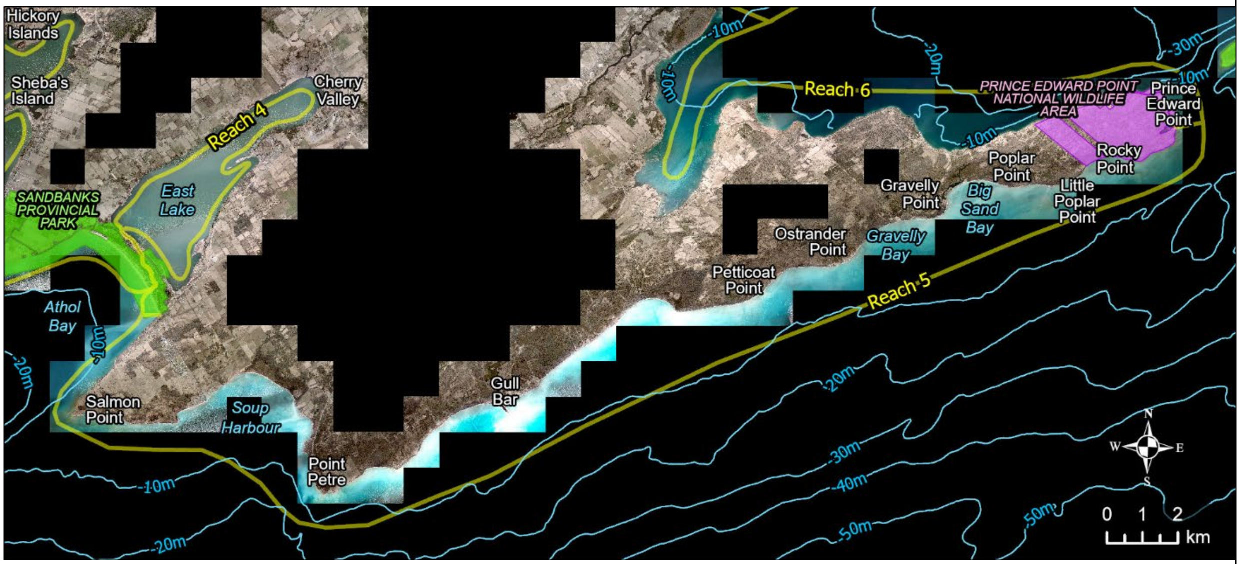
Reach 5 – Salmon Point Lighthouse to Point Traverse Lighthouse



Local Conditions

- Reach Length = approximately 45 km.
- Reach 5 extends from the southeast boundary of Sandbanks Provincial Park to the Point Traverse Lighthouse. It traverses the most rural part of the study area.
- Prominent bedrock headlands and Salmon Point and Point Petre define the Soup Harbour embayment.
- Point Petre to Prince Edward Point features a series of smaller headlands that separate mostly cobble barrier beaches and low-lying coastal wetlands. The nearshore is generally flat bedrock shelves.

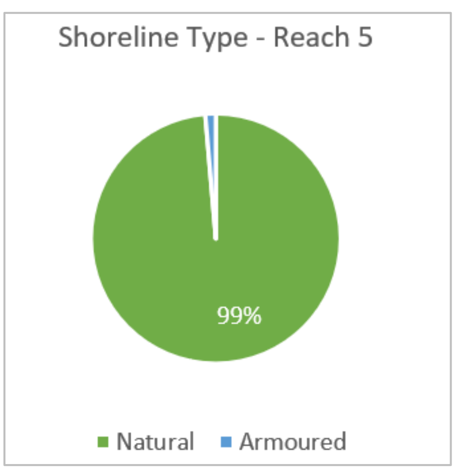
Salmon Point Lighthouse with Bedrock Nearshore

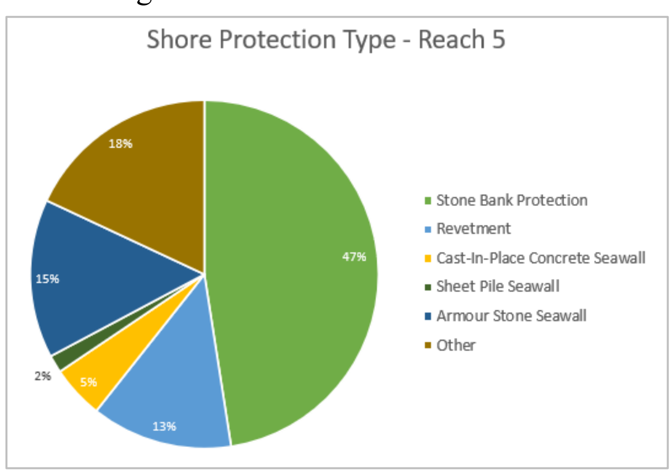
Big Sandy Bay Barrier Beach Protecting Coastal Wetlands

Shoreline Characterization

- Reach 5 features numerous provincially significant coastal wetlands and the Prince Edward Point National Wildlife Area.

- Access to the shoreline via road infrastructure is limited in Reach 5 and consequently residential development along the shoreline is sparse.
- Although there are several narrow gravel beaches in Reach 5, Gull Point is the only beach that meets the requirements to be mapped as a Dynamic Beach (pictured).
- Reach 5 shoreline is 99% natural and 1% armoured.
- Of the armoured portion of the shoreline, 47% is ad-hoc field stone or quarry stone bank protection, 15% is stacked armour stone seawall, and 13% is engineered revetment.
- Tolerance for additional shoreline hardening is low.

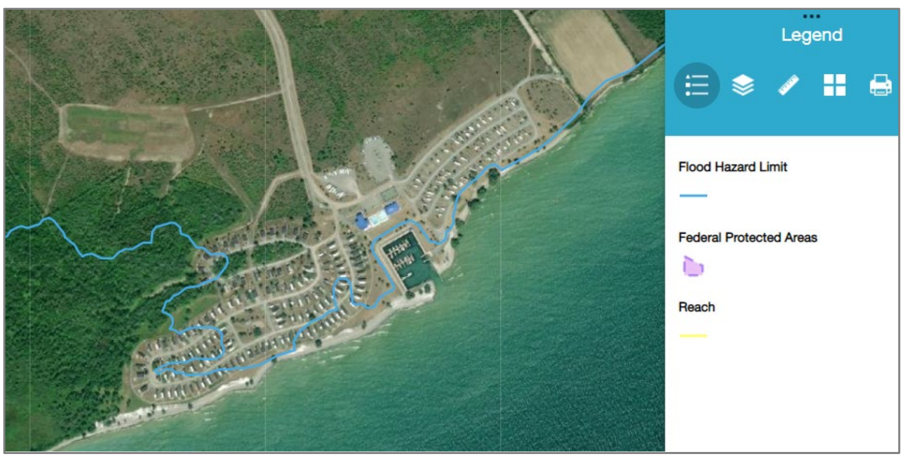




Challenges Associated with Natural Hazards

- Salmon Point Road is located at the edge of a low bank shoreline and has been damaged by erosion. Localized repairs have been completed but vulnerable sections remain.

- Large areas within the Quinte's Isle trailer park were constructed on hazardous lands based on the new flood hazard mapping (see below).



- Erosion of the bedrock banks threatens residential developments on Salmon Point Road where buildings are located too close to the top of bank. Shore protection must be well engineered to remain stable on the bedrock shoreline and withstand potential damage during severe storms.

Technical Basis for Natural Hazard Mapping

- Recession Rate for Erosion Hazard Limit (Stable Slope not included):

Geographic Area	Recession Rate (m/year)
Reach 4 to Salmon Point	0.21
Salmon Point to Point Petre	0.42
Point Petre to Point Edward	0.21

- 100-year Flood Level and Wave Uprush Limit:

Reach	100-year Flood Level (m IGLD'85)	Horizontal Uprush Allowance (m)	Calculated Wave Uprush Elevation (m IGLD85')
Reach 4/5 Boundary to Point Petre	76.07	15.0	77.8
Point Petre to Point Edward	76.07	15.0	77.5

- Dynamic Beach(es): Coordinates in UTM Zone 18N, NAD 1983

Start	End	Recession Rate (m/year) or Stable	Dynamic Beach Name
331088, 4858770	332397, 4859068	Stable	Gull Point
344349, 4864370	346116, 4864903	0.21	Big Sandy Bay

- Offshore Wave Climate:

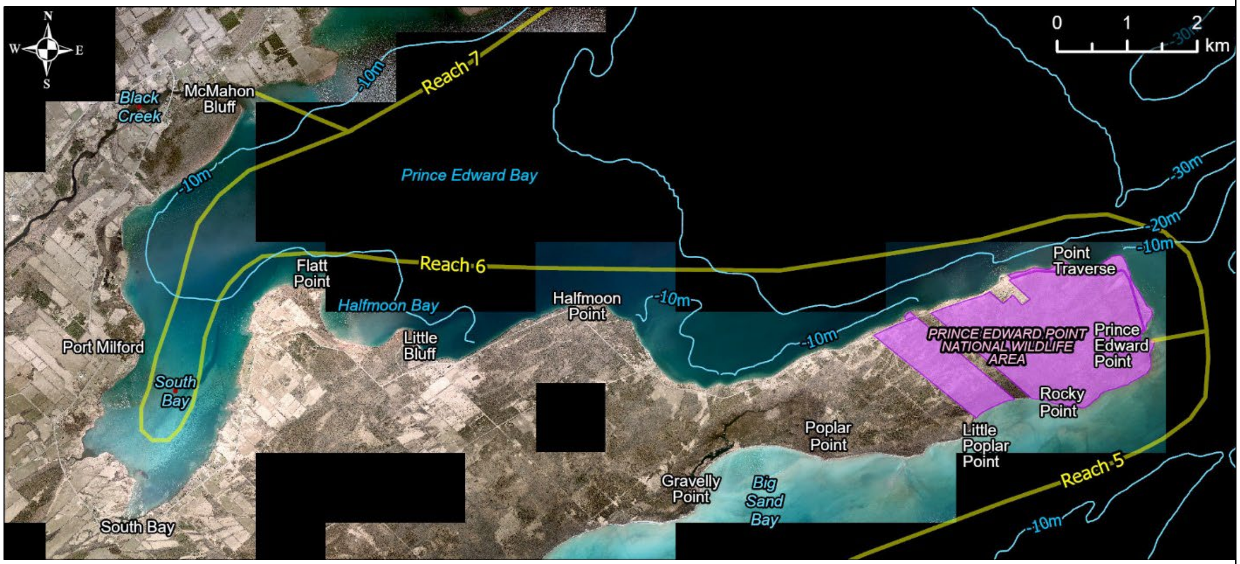
WIS Station	ARI (years)	Depth (m)	Hs (m)	Tp (s)	DIR (deg)
91220	25	26	7.2	10.9	245 – 260
	100	26	7.8	11.4	245 – 260
91224	25	38	7.8	11.1	250 – 260
	100	38	8.2	11.4	250 – 260
91228	25	27	5.9	10.6	235 – 245
	100	27	6.3	11.0	235 – 245
91234	25	33	6.9	10.8	235 – 245
	100	33	7.6	11.3	235 – 245

Shoreline Management Recommendations

- **Preserve:** maintain natural shorelines, geodiversity, and vegetation to preserve resilience, natural protection, and ecological benefits (recession rates are generally low for bedrock shorelines).
- **Avoid:** ensure new development occurs outside of hazardous lands. Avoid development that will impact dynamic beaches and sensitive marsh ecosystem.
- **Accommodate:** Floodproof buildings, raise foundations, and upgrade septic systems in flood prone areas as per mapping. Emergency planning and preparedness for a major flooding event.
- **Retreat and Realign:** Investigate re-alignment of Salmon Point Rd, compare to "protect" cost.
- **Protect:** Investigate traditional shoreline protection structure for Salmon Point Rd., and compare to "re-align" cost. Shore protection within Reach 5 should be carefully designed on a site-specific basis for bedrock shoreline by a professional engineer (refer to Section 7.3). Monitor and maintain existing shoreline protection structures.

Use Disclaimer

Reach 6 – Long Point Road to South Bay



Local Conditions

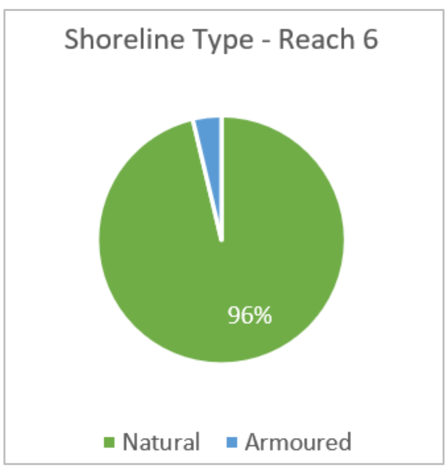
- Reach Length = approximately 33 km.
- Prominent bedrock headlands are found at Flatt Point, Little Bluff, Halfmoon Point, and Point Traverse.
- The nearshore is steep and deep between Flatt Point and Point Traverse, allowing large waves to propagate close to shore and erode the bluff toe.
- South Bay is partially sheltered from the wave climate on Kingston Basin which makes floating or removable boat docks possible (pending approval from QC).
- The head of South Bay features extensive coastal wetlands with emergent/submergent vegetation.
- Dynamic Beaches were mapped at Little Bluff and north of Port Milford.

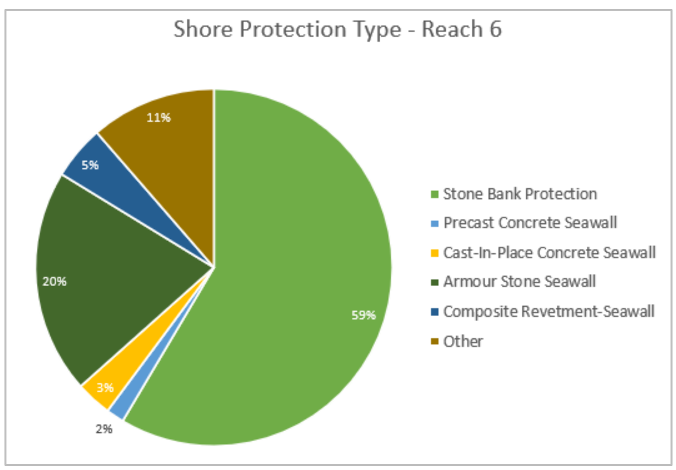
Eroding Bedrock Bluff and Steep/Deep Nearshore

Head of South Bay with Extensive Coastal Wetlands

Shoreline Characterization

- The shoreline for the eastern half of the reach is defined by a steep eroding bluff and limited residential development. Long Point Road is close to the edge of the eroding bluff in places. The nearshore is steep and deep.
- South Bay in the east is a shallow semi-sheltered embayment. The southeast shore features waterfront development and numerous boat docks.
- Erosion of bedrock headlands and bluffs supply material for cobble/shingle beaches (e.g. Little Bluff Barrier Beach).
- The Black Creek mouth defines the northern boundary of Reach 6. The creek features extensive riverine wetlands.
- Reach 6 shoreline is 96% natural and 4% armoured.
- Of the armoured portion of the shoreline, 59% is ad-hoc field stone or quarry stone bank protection, and 20% is stacked armour stone seawall.
- Tolerance for additional shoreline hardening is low.





Challenges associated with Natural Hazards

- Development pressure to build on the eroding bedrock bluffs.

- Sections of Long Point Road are close to the eroding bedrock bank/cliff.

Technical Basis for Natural Hazard Mapping

- Recession Rate for Erosion Hazard Limit (Stable Slope not included):

Geographic Area	Recession Rate (m/year)
Reach 5	0.15

- 100-year Flood Level and Wave Uprush Limit:

Reach	100-year Flood Level (m IGLD'85)	Horizontal Uprush Allowance (m)	Calculated Wave Uprush Elevation (m IGLD85')
High bank/bluff/cliff shoreline	76.08	15.0	80.0
Low bank shoreline	76.08	15.0	77.5

- Dynamic Beach(es): Coordinates in UTM Zone 18N, NAD 1983

Start	End	Recession Rate (m/year) or Stable	Dynamic Beach Name
340533, 4866322	340315, 4866567	Stable	Little Bluff
336138, 4867884	336095, 4868188	Stable	North of Port Milford
336330, 4868518	336535, 4868570	Stable	End of Wycott Lane

- Offshore Wave Climate:

WIS Station	ARI (years)	Depth (m)	Hs (m)	Tp (s)	DIR (deg)
91242	25	30	3.7	7.7	135 – 170
	100	30	4.1	8.0	135 – 170

Shoreline Management Recommendations

- **Preserve:** maintain natural shorelines, geodiversity, and vegetation to preserve resilience, natural protection, and ecological benefits (recession rates are generally low for bedrock shorelines).
- **Avoid:** ensure new development occurs outside of hazardous lands, and prohibit development/re-development of constrained lots affected by erosion.
- **Accommodate:** Floodproof buildings, raise foundations, and upgrade septic systems in flood prone areas as per mapping.
- **Retreat and Realign:** Investigate re-alignment of portions of Long Point Rd. exposed to significant erosion risk, and compare to "protect" cost. Move homes away from hazards on deep lots, where possible.
- **Protect:** Investigate traditional shoreline protection structure for Long Point Rd. and compare to "re-align" cost. Shore protection from Long Point Rd. to Little Bluff should be carefully designed for bedrock shoreline by a professional engineer. Hybrid grey/green shore protection should be considered for shorelines in South Bay (refer to Section 7.3). Monitor and maintain existing shoreline protection structures.

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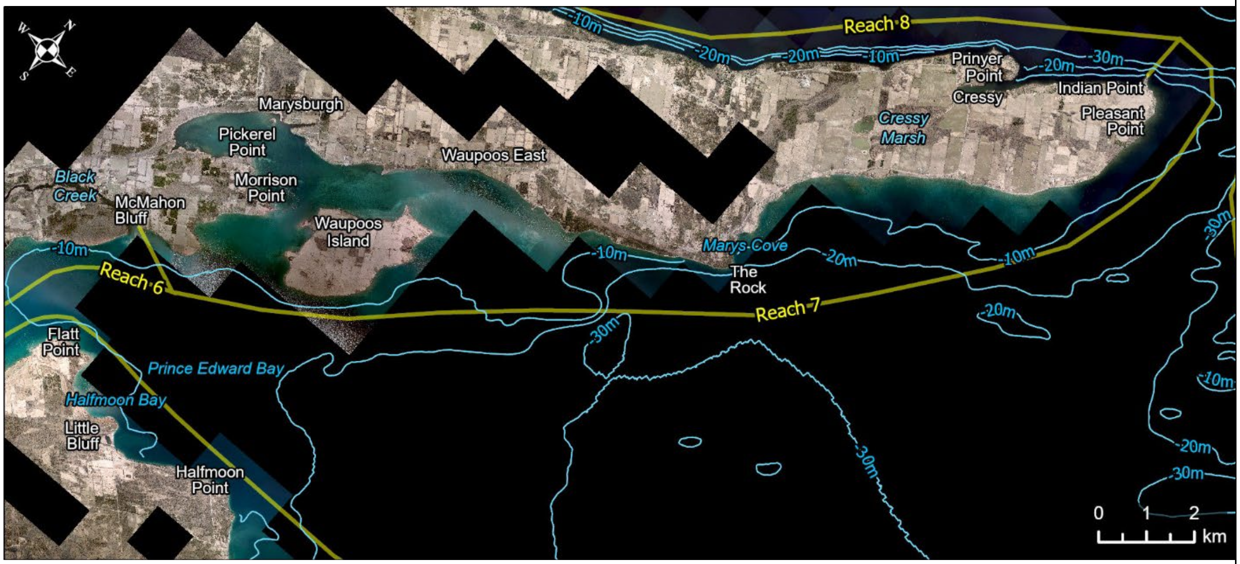
Reach 7 – Black River Mouth to Point Pleasant Lane



Local Conditions

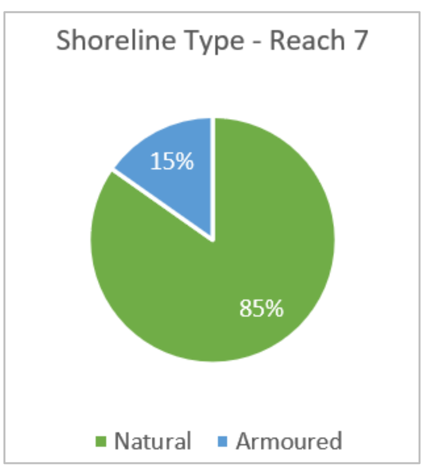
- Reach Length = approximately 45 km.
- Reach 7 features a variety of shoreline conditions, from exposed eroding bedrock banks and towering bedrock bluffs to sheltered bays and coastal wetlands west of Waupoos Island, including Smith Bay.
- The high bedrock bluff dominates the shoreline near Marys Cove.
- The Cressy Marsh, which is connected hydraulically to the shoreline at Reach 7 and 8, is located in the northeast portion of the Reach 7.
- Land elevations decrease from Waupoos towards Cressy Marsh and Cressy Lake Road, where the bedrock forms an eroding bank.
- Cressy Lakeside Road is directly on the edge of the eroding bank.

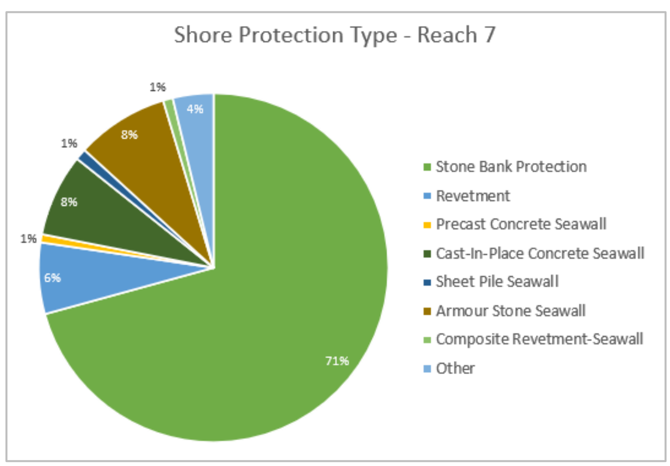
Smith Bay

Sheltered Side of Waupoos Island

Shoreline Characterization

- Shorelines around Morrison Point, Pickerel Point and Waupoos are generally sheltered from waves by Waupoos Island and feature significant coastal wetlands.
- The western end of the reach is generally characterized as low vegetated bank shoreline, with low wave energy. The central portion around Mary's Cove rises steeply in elevation and is characterized by a high bedrock cliff/escarpment. The east portion of the reach is low-lying, flood and erosion prone.
- Cressy Lakeside Road is located at the edge of the eroding bedrock shoreline near the east end of the Reach.
- Waupoos Marina features a floating breakwater made from old tires.
- Reach 7 shoreline is 85% natural and 15% armoured.
- Of the armoured portion of the shoreline, 71% is ad-hoc field stone or quarry stone bank protection, 8% is armour stone seawall, and 8% cast-in-place concrete seawall.
- Tolerance for additional shoreline hardening is low.





Challenges Associated with Natural Hazards

- The natural hazard challenges are relatively minor in Reach 7, with the exception of a few flood prone properties south of Cressy Marsh and Cressy Lakeside Road, and the eroding bedrock escarpment near Mary's Cove.
- Cressy Lakeside Road is located on the edge of an eroding low bank. It is the only ingress/egress route for properties in the area.

- Waupoos Marina is protected with an old floating tire breakwater which contributes rubber pollution to the lake.

Technical Basis for Natural Hazard Mapping

- Recession Rate for Erosion Hazard Limit (Stable Slope not included):

Geographic Area	Recession Rates (m/year)
Reach 7	0.15

- 100-year Flood Level and Wave Uprush Limit:

Reach	100-year Flood Level (m IGLD'85)	Horizontal Uprush Allowance (m)	Calculated Wave Uprush Elevation (m IGLD85')
Low banks reach-wide	76.08	15.0	77.5
Waupoos East, high bluff/cliff shoreline	76.08	15.0	80.0

- Dynamic Beach(es): Coordinates in UTM Zone 18N, NAD 1983

Start	End	Recession Rate (m/year) or Stable	Dynamic Beach Name
343943, 4875876	344177, 4875897	0.34	West of Cemetery Lane
346486, 4876771	346883, 4877037	0.15	Southwest of Marys Cove

- Offshore Wave Climate:

WIS Station	ARI (years)	Depth (m)	Hs (m)	Tp (s)	DIR (deg)
91242	25	30	3.7	7.7	135 – 170
	100	30	4.1	8.0	135 – 170
91247	25	27	4.6	8.2	160 – 185
	100	27	5.1	8.6	160 - 185

Shoreline Management Recommendations

- **Preserve:** maintain natural shorelines, geodiversity, and vegetation to preserve resilience, natural protection, and ecological benefits (recession rates are generally low for bedrock shorelines).
- **Avoid:** ensure new development occurs outside of hazardous lands, and prohibit development/re-development of constrained lots affected by erosion.
- **Accommodate:** Floodproof buildings, raise foundations, and upgrade septic systems in flood prone areas as per mapping.
- **Retreat and Realign:** Investigate re-alignment of portions of Cressy Lakeside Rd. exposed to significant erosion risk, and compare to "protect" cost. Move homes away from hazards on deep lots, where possible.
- **Protect:** Investigate traditional shoreline protection structure for Cressy Lakeside Rd. and compare to "re-align" cost. Replace floating tire breakwater at Waupoos Marina with modern, environmentally friendly floating breakwater. Shore protection from Waupoos to Cressy should be carefully designed for bedrock shoreline by a professional engineer. Hybrid grey/green shore protection should be considered for shorelines in sheltered areas behind Waupoos Island (refer to Section 7.3). Monitor and maintain existing shoreline protection structures.

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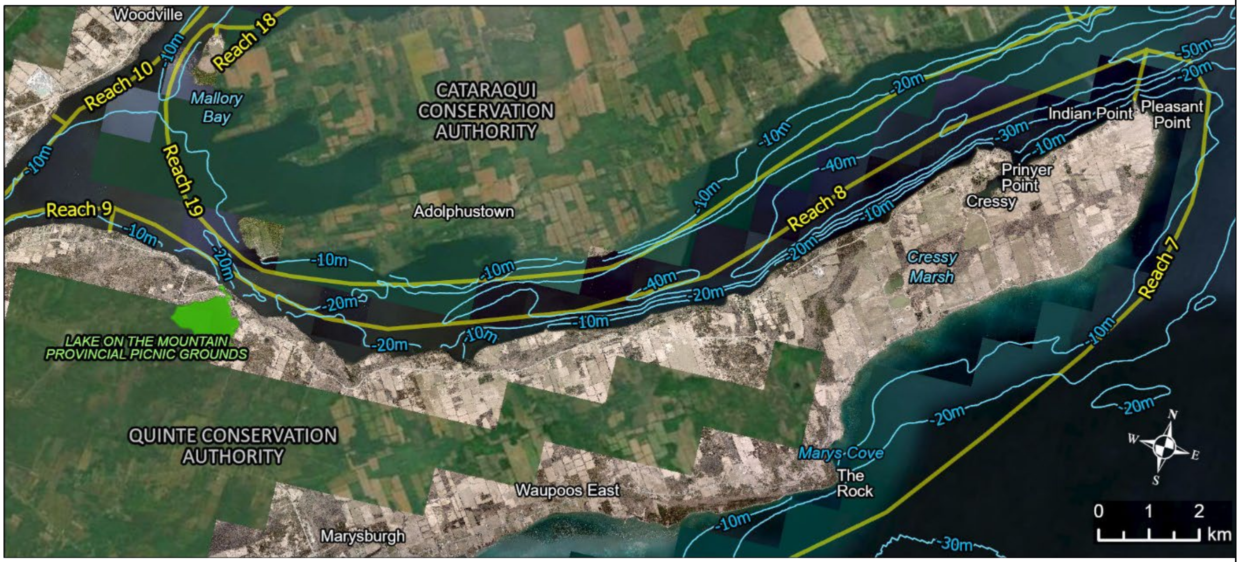
Reach 8 – Adolphus Reach



Local Conditions

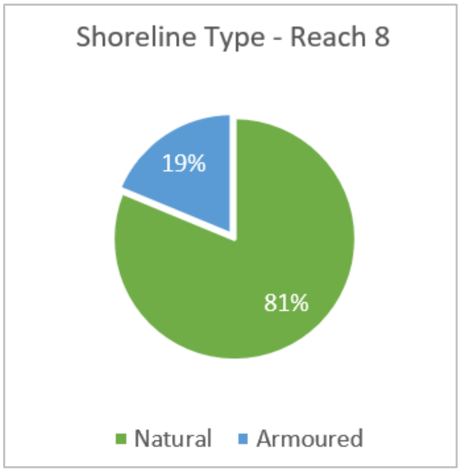
- Reach Length = approximately 28 km.
- The bedrock banks are low from Pleasant Point to Prinyer Cove.
- Land elevations increase towards Glenora, where the bedrock forms high bluffs at the waters edge or moves inland and benches are found at the waters edge.
- The Glenora Ferry Service transports people and vehicles across the Adolphus Reach.
- West of Lake on the Mountain, the bedrock escarpment moves inland, and the shoreline features a low bank/low plain to the Reach 8 boundary.

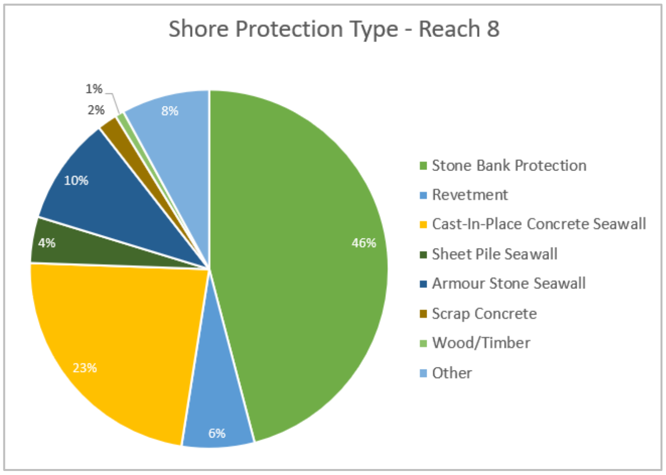
Low Plain Shore with Bedrock at the Waters Edge

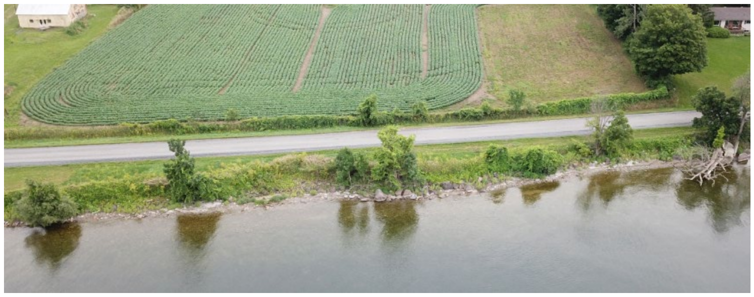
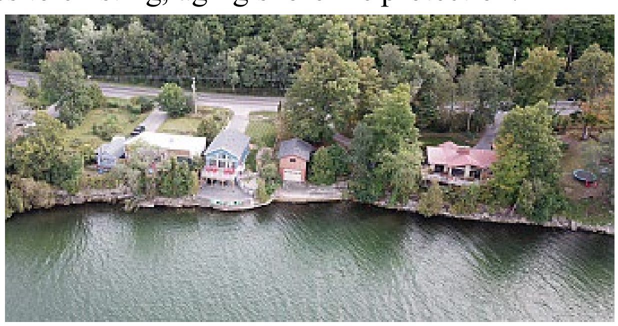
High Bluff Shoreline West of Glenora

Shoreline Characterization

- At the eastern end of Reach 8 the bedrock emerges in a low bank. Cressy Bayside Rd. is in close proximity to the top of bank for ~2 km.
- Prinyer Cove is a 1.5 km sheltered embayment off of Reach 8, with northeast exposure.
- Further west the bedrock forms a steep bluff at the waters edge. The bluff moves inland in places creating benches at lower elevations near the waterline with a low bank shoreline.
- The level of shoreline development generally increases moving west from Glenora towards Picton Bay.
- The Reach 8 shoreline is 81% natural and 19% armoured.
- Of the armoured portion of the shoreline, 46% is ad-hoc field stone or quarry stone bank protection, 23% is cast-in-place concrete seawall, and 10% is armour stone seawall.
- Tolerance for additional shoreline hardening is low.





Challenges Associated with Natural Hazards
• Coastal hazards in Reach 8 are relatively low, especially compared to the exposed southwest shoreline of Prince Edward County. • Cressy Bayside Rd. runs along the top of bank for approximately 2 km and may be affected by flooding and erosion during major storms coupled with high water levels.  • Aging ad-hoc shore protection structures are prevalent in and around Glenora.  • Many properties west of Glenora feature buildings close to the shoreline that require shore protection or upgrades to existing, aging shoreline protection. 

Technical Basis for Natural Hazard Mapping

- Recession Rate for Erosion Hazard Limit (Stable Slope not included):

Geographic Area	Recession Rates (m/year)
Reach 8	0.10

- 100-year Flood Level and Wave Uprush Limit:

Reach	100-year Flood Level (m IGLD'85)	Horizontal Uprush Allowance (m)	Calculated Wave Uprush Elevation (m IGLD85')
Reach 8	76.08	15.0	77.5

- Dynamic Beach(es): Coordinates in UTM Zone 18N, NAD 1983

Start	End	Recession Rate (m/year) or Stable	Dynamic Beach Name
n/a			

- Wave Climate (parametric hindcast):

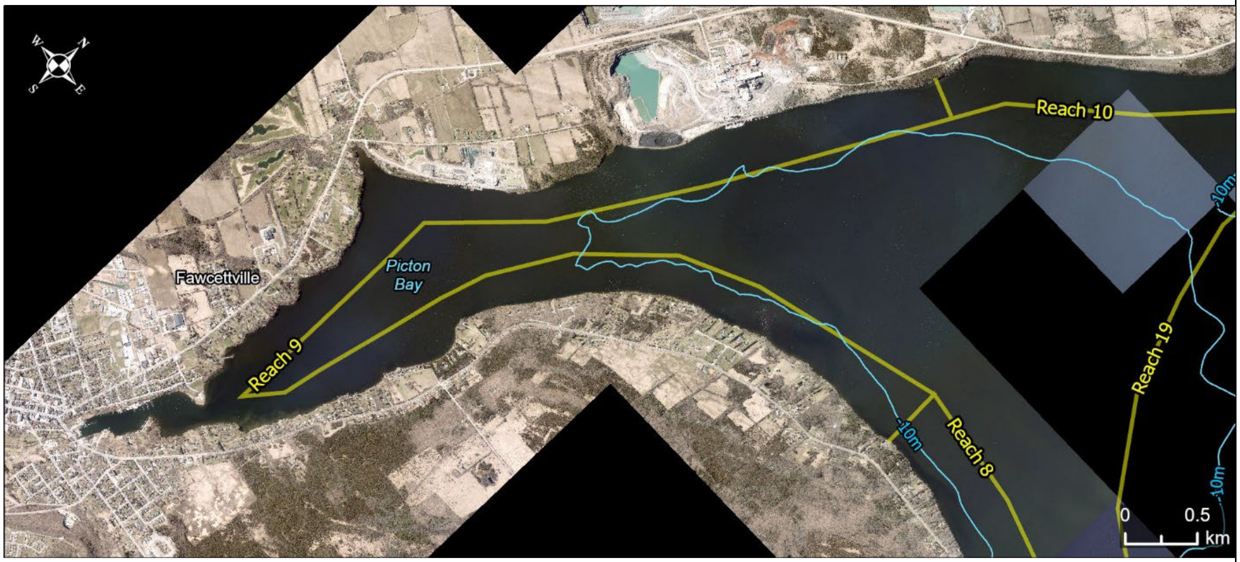
Location	ARI (years)	Depth (m)	Hs (m)	Tp (s)	DIR (deg)
Adolphus Reach	25	-	1.2 – 2.1	3.6 – 5.1	-
	100	-	1.6 – 2.6	3.9 – 5.5	-

Shoreline Management Recommendations

- **Preserve:** maintain natural shorelines, geodiversity, and vegetation to preserve resilience, natural protection, and ecological benefits.
- **Avoid:** ensure new development occurs outside of hazardous lands.
- **Accommodate:** floodproof buildings, raise foundations, and upgrade septic systems on flood prone lands.
- **Retreat and Realign:** relocate high risk homes and cottages away from the shoreline on flood or erosion prone properties with deep lots, where reasonable.
- **Protect:** monitor bank erosion and flooding of Cressy Bayside Rd. and mitigate as required with shoreline protection (refer to Section 7.3 of the SMP). Monitor and maintain existing shoreline infrastructure in Glenora. Hybrid grey/green erosion and flood protection schemes are recommended. Vegetated rip rap toe protection is recommended for steep embankments where shoreline erosion may lead to slope instabilities.

Use Disclaimer

Reach 9 – Picton Bay



Local Conditions

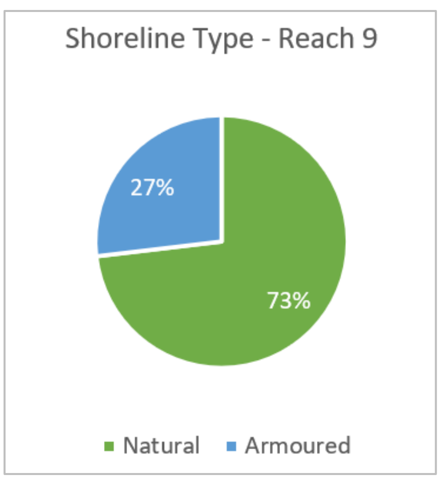
- Reach Length = approximately 15 km.
- Picton Bay is sheltered from all wave directions except northeast, which is not a frequent wind direction.
- The east shore of Reach 9 and the west side to Hallowell Mills Cove features residential development and several docks that are possible due to the calm, sheltered waters.
- The northwest shore of Reach 9 features the Lehigh Cement Company and other industrial port facilities.

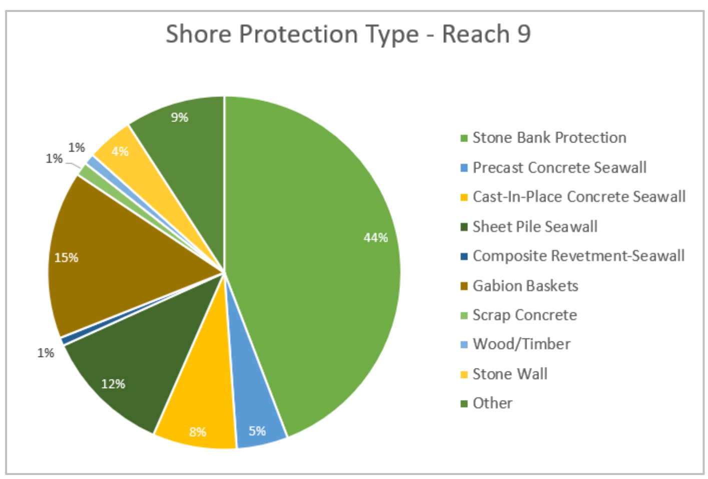
Floating Docks in Picton

Lehigh Cement Company

Shoreline Characterization (Natural vs. Hardened)

- The Town of Picton is located at the head of Picton Bay and features calm sheltered waters ideal for power boats and sail boats.
- Significant submergent and emergent vegetation exists within Picton Bay due to calm, sheltered waters.
- A heavily trafficked public boat launch and large marina is located near the end of the embayment.
- Significant industrial development and port lands exist on the northwest shoreline near the mouth of Picton Bay north of Hallowell Mills Cove. Water depths are deep in this area and the shoreline features a steep bedrock cliff.
- Reach 9 shoreline is 73% natural and 27% armoured.
- Of the armoured portion of the shoreline, 44% is ad-hoc field stone or quarry stone bank protection, 15% is stacked gabion basket, and 12% is engineered steel sheet piling.
- Tolerance for additional shoreline hardening is low.





Challenges associated with Natural Hazards

- The challenges and risks associated with natural hazards are low in Reach 9.
- Some aging shore protection requires repairs or replacement. All shoreline infrastructure requires monitoring and regular maintenance.

- Boat houses and fixed elevation docks may be vulnerable to high lake levels.

Technical Basis for Natural Hazard Mapping

- Recession Rate for Erosion Hazard Limit (Stable Slope not included):

Geographic Area	Recession Rate (m/year)
Reach 9	0.10

- 100-year Flood Level and Wave Uprush Limit:

Reach	100-year Flood Level (m IGLD'85)	Horizontal Uprush Allowance (m)	Calculated Wave Uprush Elevation (m IGLD85')
Picton Bay	76.10	15	76.9
Port Lands and Steep Bedrock Cliffs	76.10	15	78.8

- Dynamic Beach(es): Coordinates in UTM Zone 18N, NAD 1983

Start	End	Recession Rate (m/year) or Stable	Dynamic Beach Name
n/a			

- Wave Climate (parametric hindcast):

Location	ARI (years)	Depth (m)	Hs (m)	Tp (s)	DIR (deg)
Picton Bay	25	-	0.9 – 1.2	3.5 – 3.6	-
	100	-	1.0 – 1.6	3.6 – 3.9	-

Shoreline Management Recommendations

- **Preserve:** maintain natural shorelines, geodiversity, and vegetation to preserve resilience, natural protection, and ecological benefits.
- **Avoid:** ensure new development occurs outside of hazardous lands.
- **Accommodate:** floodproof buildings, raise foundations, and upgrade septic systems on flood prone lands.
- **Retreat and Realign:** relocate high risk homes and cottages away from the shoreline on flood or erosion prone properties with deep lots, where reasonable.
- **Protect:** monitor and maintain existing shoreline infrastructure in Picton Bay. Hybrid grey/green erosion and flood protection schemes are recommended. Vegetated rip rap toe protection is recommended for steep embankments where shoreline erosion may lead to slope instabilities.

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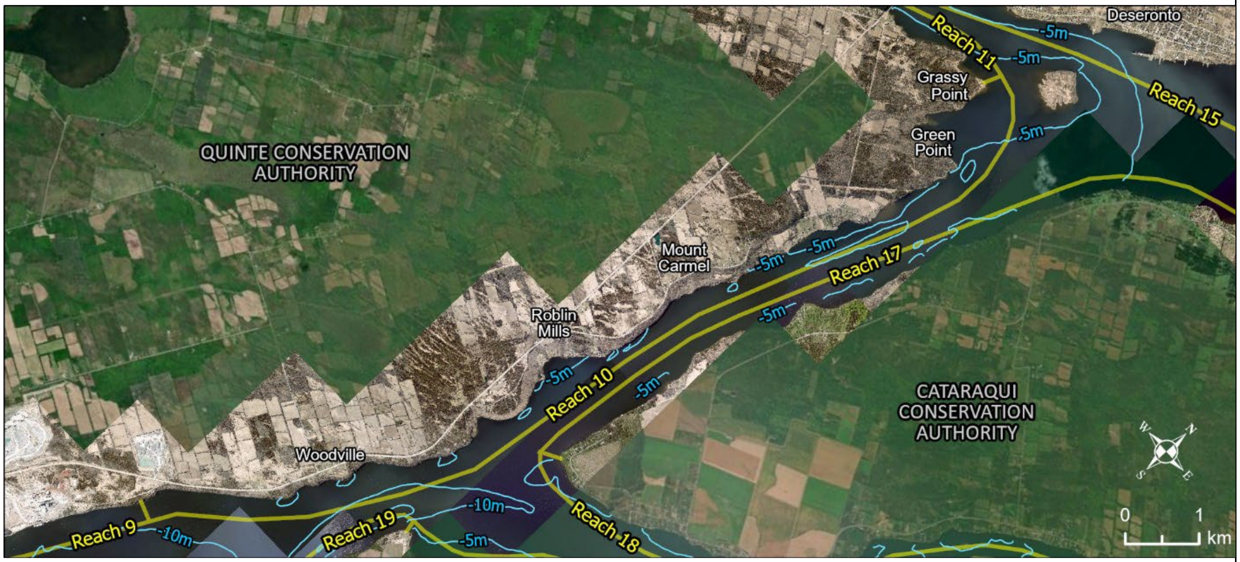
Reach 10 – Hayward Long Reach



Local Conditions

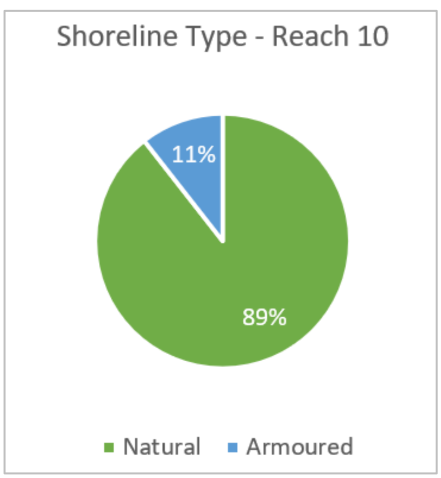
- Reach Length = approximately 16 km.
- Cataraqui Conservation Authority has jurisdiction over the east side of Hayward Long Reach.
- The shoreline alternates between high vegetated bluffs and low bench / low plain sections.
- Numerous boat docks (floating or removable) are present along the shoreline due to the small wave generation potential and sheltering provided in Reach 10.
- Shoreline protection is sporadic.

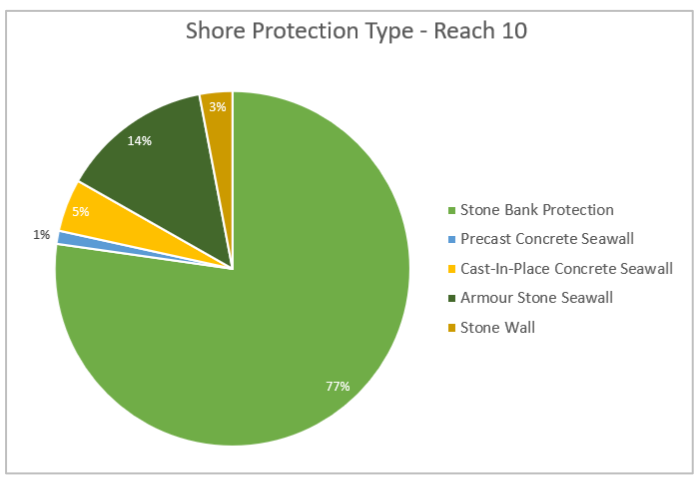
Bedrock Bluff with New Development and Tree Clearing on Slope

Low Plain Bedrock Shoreline near Green Point Lane

Shoreline Characterization

- The majority of the high bluff shoreline sections are well-vegetated, suggesting the slopes are generally stable.
- Similarly, due to limited wave generation in Reach 10, the low plain shorelines are also very stable and only limited exposures of eroding bedrock were observed.
- Some low-lying communities at the north end of the reach may experience flooding during periods of extreme lake levels.
- Reach 10 shoreline is 89% natural and 11% armoured.
- Of the armoured portion of the shoreline, 77% is ad-hoc field stone or quarry stone bank protection, 14% is armour stone seawall, and 5% is cast-in-place concrete seawall.
- Tolerance for additional shoreline hardening is low.





Challenges associated with Natural Hazards

- Given the limited fetch in Reach 10, wave heights are small relative to the Lake Ontario shoreline. Consequently, exposure to erosion and flooding hazards is also small compared to Reaches 2 to 7. Boat wakes are of similar concern to wind-generated waves.
- Wave uprush is unusually high for such a small wave climate due to the deep nearshore and steep slopes at the waterline throughout much of the reach.
- Tree removal on the bedrock bluffs may destabilize the slope and accelerate erosion.

- At the north boundary of Reach 10, several lots are low-lying and vulnerable to flooding.

Technical Basis for Natural Hazard Mapping

- Recession Rate for Erosion Hazard Limit (Stable Slope not included):

Geographic Area	Recession Rates (m/year)
Reach 10	0.10

- 100-year Flood Level and Wave Uprush Limit:

Reach	100-year Flood Level (m IGLD'85)	Horizontal Uprush Allowance (m)	Calculated Wave Uprush Elevation (m IGLD85')
Reach 10	76.10	15.0	78.8

- Dynamic Beach(es): Coordinates in UTM Zone 18N, NAD 1983

Start	End	Recession Rate (m/year) or Stable	Dynamic Beach Name
n/a			

- Wave Climate (parametric hindcast):

Location	ARI (years)	Depth (m)	Hs (m)	Tp (s)	DIR (deg)
Hayward Long Reach	25	-	0.9 – 1.1	3.5 – 3.8	-
	100	-	1.0 – 1.3	3.6 – 4.1	-

Shoreline Management Recommendations

- **Preserve:** maintain natural shorelines, geodiversity, and vegetation to preserve resilience, natural protection, and ecological benefits.
- **Avoid:** ensure new development occurs outside of hazardous lands.
- **Accommodate:** floodproof buildings, raise foundations, and upgrade septic systems on flood prone lands.
- **Retreat and Realign:** relocate high risk homes and cottages away from the shoreline on flood or erosion prone properties with deep lots, where reasonable.
- **Protect:** hybrid grey/green erosion and flood protection schemes are recommended where warranted. Vegetated rip rap toe protection is recommended for steep embankments where shoreline erosion may lead to slope instabilities.

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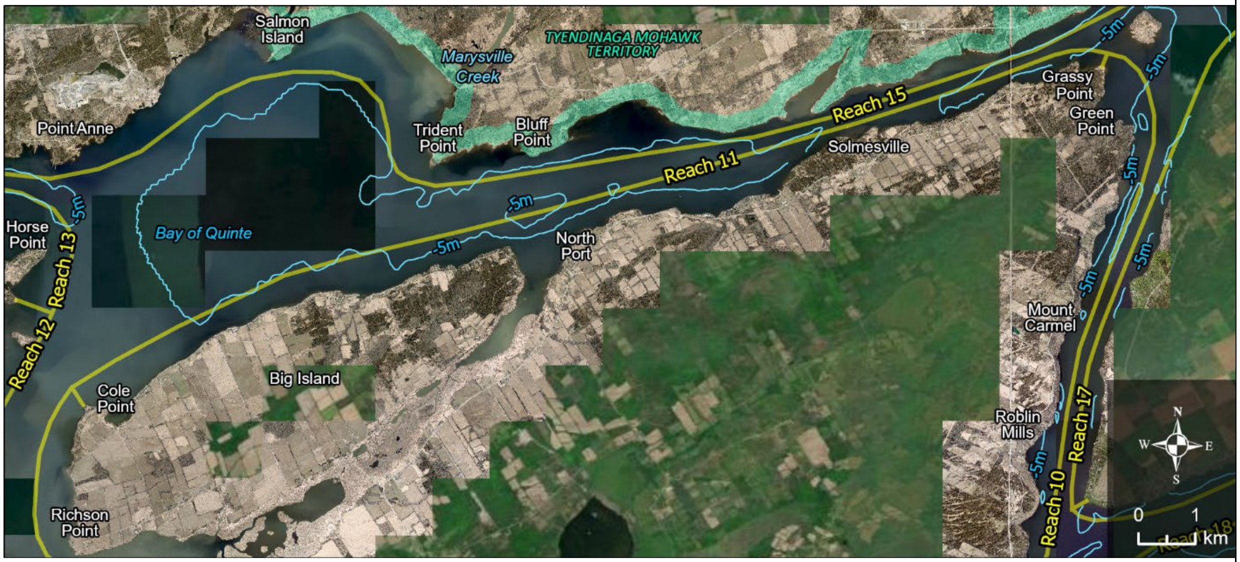
Reach 11 – Kimball Lane to Robinson Cove



Local Conditions

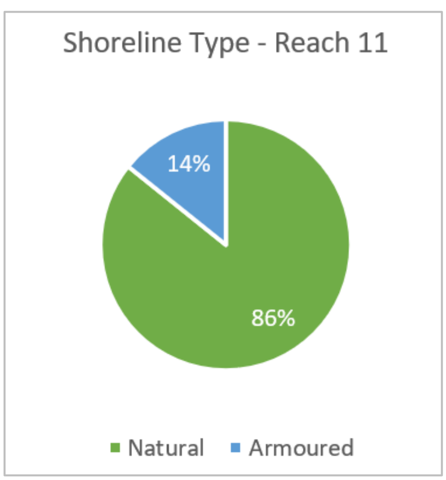
- Reach Length = approximately 32 km.
- Located on the south shore of the east-west portion of the Bay of Quinte.
- The eastern half of the reach has less wave exposure, shallow nearshore water depths and gently sloped terrain. Boat docks are prevalent.
- Exposures of eroding bedrock are visible in natural shorelines.
- Sheltered environments feature extensive coastal wetlands, especially south of Big Island.

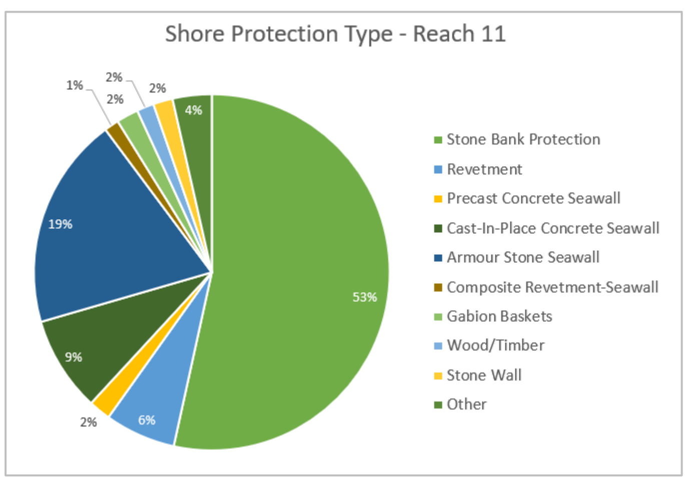
Low bank bedrock shoreline

Natural shoreline in rural setting

Shoreline Characterization

- Quinte Skyway Bridge provides access to Prince Edward County.
- Expansive wetlands sheltered behind Big Island.
- Low lying, flood prone lands with low-bank shorelines in several locations.
- Greater wave exposure than other parts of the Bay of Quinte due to the orientation and width of the bay in Reach 11, particularly along Big Island and North Port.
- Some exposures of eroding bedrock are visible along natural shorelines, particularly along north side of Big Island.
- Reach 11 shoreline is 86% natural and 14% armoured.
- Of the armoured portion of the shoreline, 53% is ad-hoc field stone or quarry stone bank protection, 19% is armour stone seawall, and 9% is cast-in-place concrete seawall.
- Tolerance for additional shoreline hardening is low.

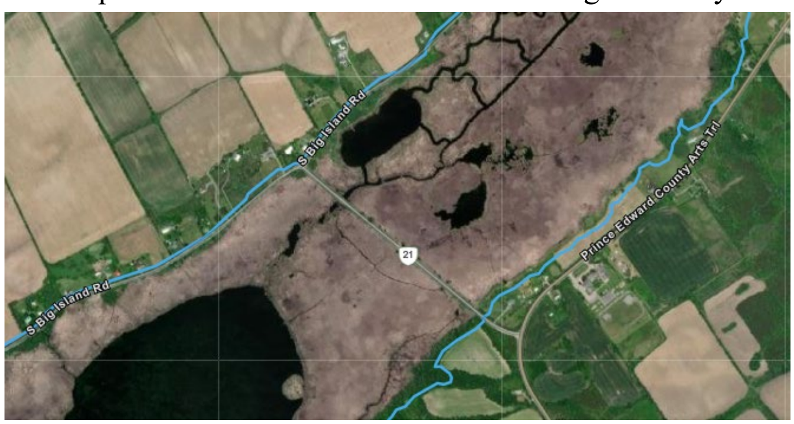




Challenges Associated with Natural Hazards

- The eastern half of the reach is a stable low plain shoreline with low wave exposure.
- More wave exposure and higher percentage of coastal armouring on the north shore of Big Island.

- Highway 21 is the only ingress/egress route to Big Island and it is in the Flood Hazard. Further studies are required to evaluate vehicle access during the 100-year flood level.



- Sections of Big Island (north side) are located within the Flood Hazard Limit, along with infrastructure (e.g., marina basin). This is a challenge in Robinson Cove as well.

Technical Basis for Natural Hazard Mapping

- Recession Rate for Erosion Hazard Limit (Stable Slope not included):

Geographic Area	Recession Rate (m/year)
Reach 11	0.10

- 100-year Flood Level and Wave Uprush Limit:

Reach	100-year Flood Level (m IGLD'85)	Horizontal Uprush Allowance (m)	Calculated Wave Uprush Elevation (m IGLD85')
Reach 11	76.10	15.0	77.1

- Dynamic Beach(es): Coordinates in UTM Zone 18N, NAD 1983

Start	End	Recession Rate (m/year) or Stable	Dynamic Beach Name
n/a			

- Wave Climate (parametric hindcast):

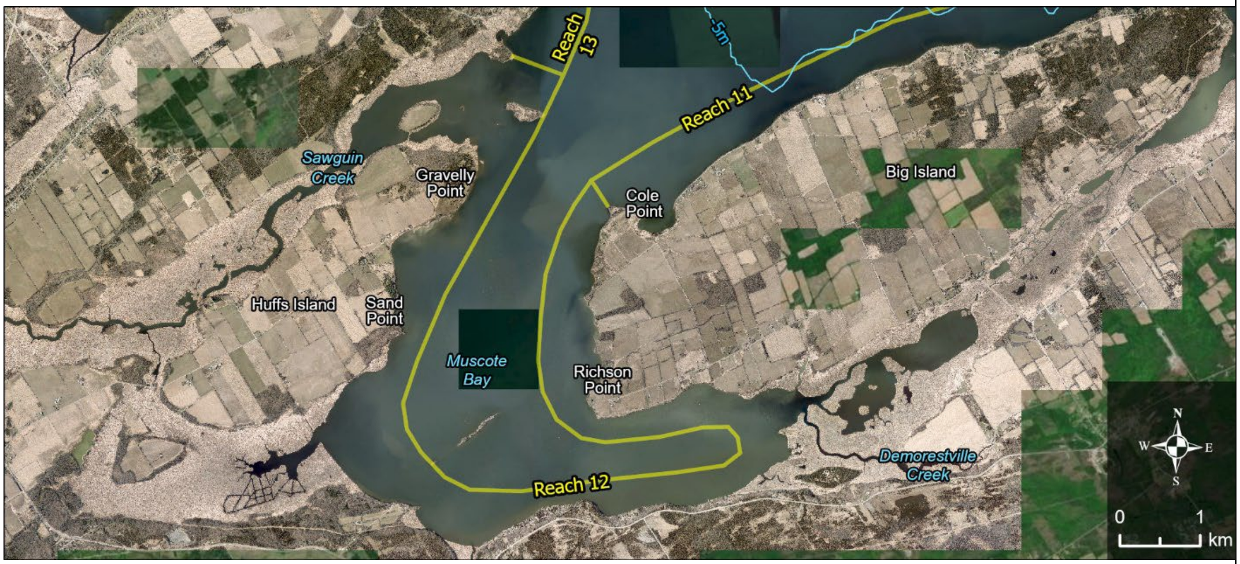
Location	ARI (years)	Depth (m)	Hs (m)	Tp (s)	DIR (deg)
Big Island to Gassy Point	25	-	0.9 – 1.2	3.3 – 4.1	-
	100	-	1.1 – 1.4	3.5 – 4.4	-

Shoreline Management Recommendations

- **Preserve:** maintain natural shorelines, geodiversity, and vegetation to preserve resilience, natural protection, and ecological benefits.
- **Avoid:** ensure new development occurs outside of hazardous lands, and prohibit development/re-development in areas that are inaccessible during major floods.
- **Accommodate:** site specific investigations are required for communities with safe access challenges, as identified through the hazard mapping. Floodproof buildings, raise foundations, and upgrade septic systems on flood prone lands. Emergency planning and preparedness for a major flooding event.
- **Retreat and Realign:** re-align driveways, roadways through trailer parks, cottage communities, etc. and relocate homes to highest ground, where possible.
- **Protect:** Nature-based or hybrid grey/green erosion and flood protection schemes are recommended, as discussed in Section 7.3.2 of the SMP. All existing shoreline protection should be monitored and maintained regularly. Existing infrastructure can be improved with nature-based components such as cobble toe protection or vegetated buffers. Failing concrete, steel and gabion basket structures should be replaced with hybrid grey/green structures before outright failure.

Use Disclaimer

Reach 12 – Muscote Bay



Local Conditions

- Reach Length = approximately 51 km.
- Muscote Bay is a large semi-sheltered embayment.
- A combination of rural land use and sheltering from the Bay of Quinte wave climate results in a very high percentage of natural shoreline in Reach 12 (nearly 100%).
- The wetlands associated with Big Island Marsh and Sawquin Creek Marsh are extensive throughout Reach 12 and recognized as provincially significant.
- Several sections of Highway 62 west of the Reach 12 shoreline are located within the Flood Hazard Limit and may be inaccessible during the 100-year flood event.

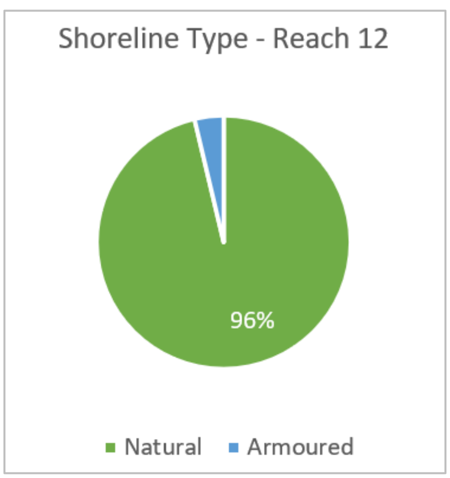
Natural Shoreline

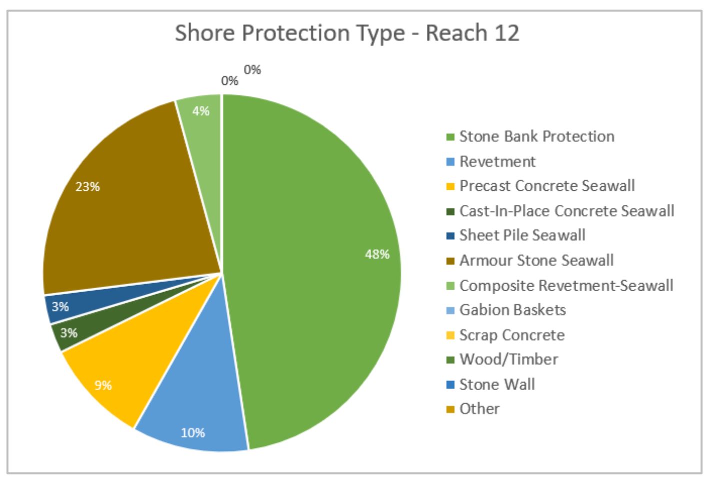
Big Island Marsh in Background

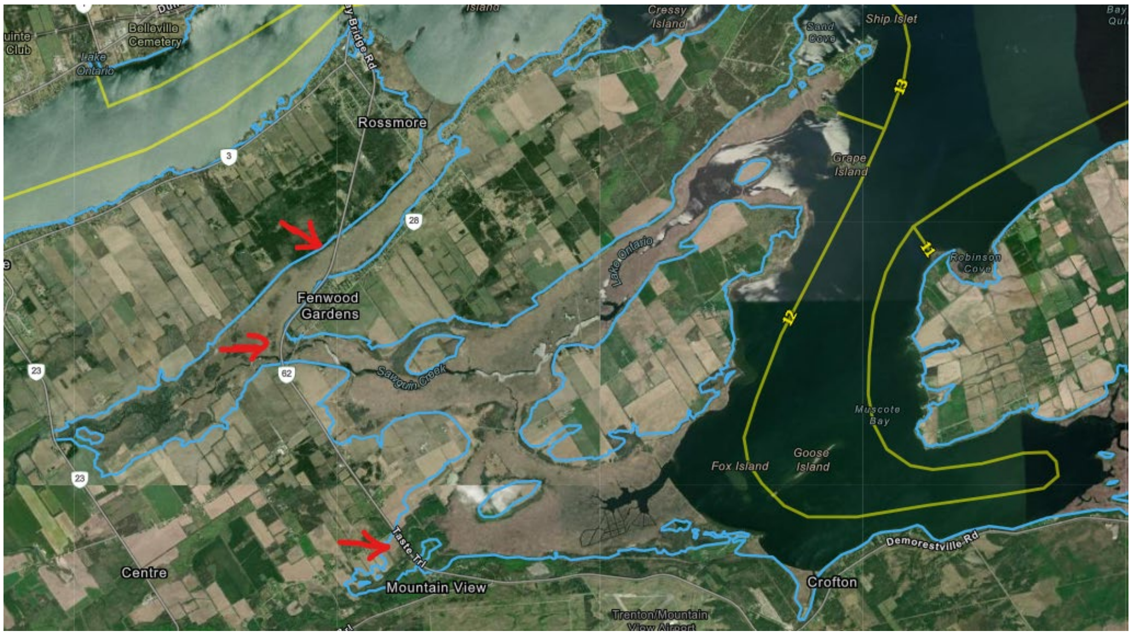
Shoreline Characterization (Natural vs. Hardened)

- Provincially Significant wetlands make up the majority of the shoreline in Reach 12, as seen in the map below.

- With the exception of the development along Demorestville Road at the south end of the bay, the rural agricultural land uses in Reach 12 result in minimal shoreline development.
- Reach 12 shoreline is 96% natural and 4% armoured, based on the entire shoreline length including coastal wetland areas.
- Of the armoured portion of the shoreline, 48% is ad-hoc field stone or quarry stone bank protection, 23% is armour stone seawall, and 10% is engineered revetment.
- Tolerance for additional shoreline hardening is low.





Challenges Associated with Natural Hazards
• With the high percentage of natural shoreline in Reach 12, challenges related to natural hazards are relatively low, especially compared to the exposed lake shoreline. • Three locations along Highway 62 that cross the Sawquin Creek Marshes west of the shoreline in Reach 12 are within the Flood Hazard Limit (see red arrows and blue Flood Hazard Limit line below). These areas require further local studies. 

Technical Basis for Natural Hazard Mapping

- Recession Rate for Erosion Hazard Limit (Stable Slope not included):

Geographic Area	Recession Rate (m/year)
Reach 12	0.10

- 100-year Flood Level and Wave Uprush Limit:

Reach	100-year Flood Level (m IGLD'85)	Horizontal Uprush Allowance (m)	Calculated Wave Uprush Elevation (m IGLD85')
Reach 12	76.10	15.0	77.0

- Dynamic Beach(es): Coordinates in UTM Zone 18N, NAD 1983

Start	End	Recession Rate (m/year) or Stable	Dynamic Beach Name
n/a			

- Wave Climate (parametric hindcast):

Location	ARI (years)	Depth (m)	Hs (m)	Tp (s)	DIR (deg)
Muscote Bay	25	-	0.4 – 0.7	2.6 – 3.1	-
	100	-	0.4 – 0.8	2.8 – 3.4	-

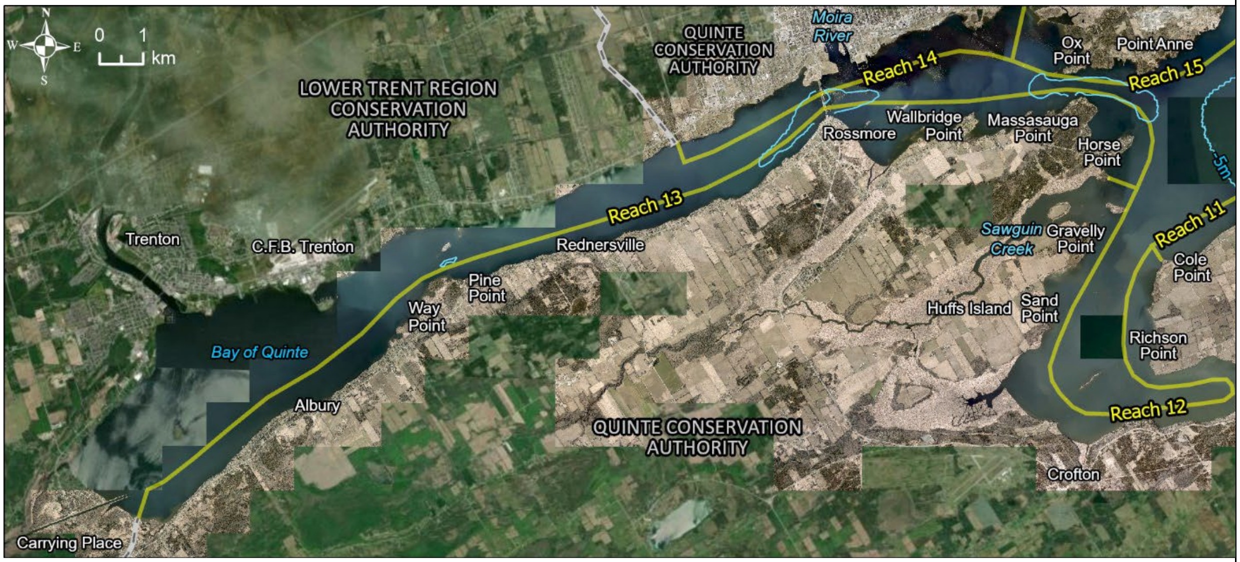
Shoreline Management Recommendations

- **Preserve:** maintain natural shorelines, geodiversity, and vegetation to preserve resilience, natural protection, and ecological benefits.
- **Avoid:** ensure new development occurs outside of hazardous lands, and prohibit development/re-development in areas that are inaccessible during major floods.
- **Accommodate:** site specific investigations are required for communities with safe access challenges, as identified through the hazard mapping. Floodproof buildings, raise foundations, and upgrade septic systems on flood prone lands. Emergency planning and preparedness for a major flooding event.
- **Retreat and Realign:** re-align driveways, roadways through trailer parks, cottage communities, etc. and relocate homes to highest ground, where possible.
- **Protect:** Nature-based or hybrid grey/green erosion and flood protection schemes are recommended, as discussed in Section 7.3.2 of the SMP. All existing shoreline protection should be monitored and maintained regularly. Existing infrastructure can be improved with nature-based components such as cobble toe protection or vegetated buffers. Failing concrete, steel and gabion basket structures should be replaced with hybrid grey/green structures before outright failure.

Use Disclaimer

The information in this reach summary was prepared for Quinte Conservation. If used by a third party, they agree that the information is subject to change without notice. The Consultants assume no responsibility for the consequences of such use or changes in the information. Under no circumstance will the Consultants be liable for direct, indirect, special, or incidental damages resulting from, arising out of, or in connection with the use of the information in this summary by a third party.

Reach 13 – Grave Island to Carrying Place



Local Conditions

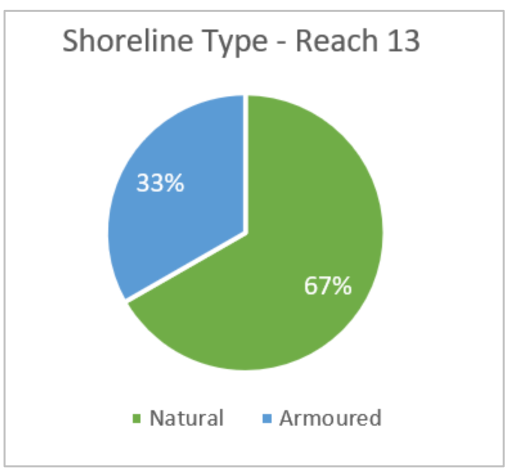
- Reach Length = approximately 49 km.
- The Reach is predominantly an east-west shoreline on the south side of the Bay of Quinte.
- In the east, from Grave Island to Bay Bridge, the coastal wetlands associated with Sawquin Creek Marsh as classified as provincially significant.
- Provincially significant wetlands are also found mid-way in the reach at Pine Point and then again in Carrying Place at the west boundary of the reach.
- The remainder of the shoreline is extensively developed with residences and features a high percentage of shoreline hardening.
- Shallow nearshore with dense beds of submerged aquatic vegetation.

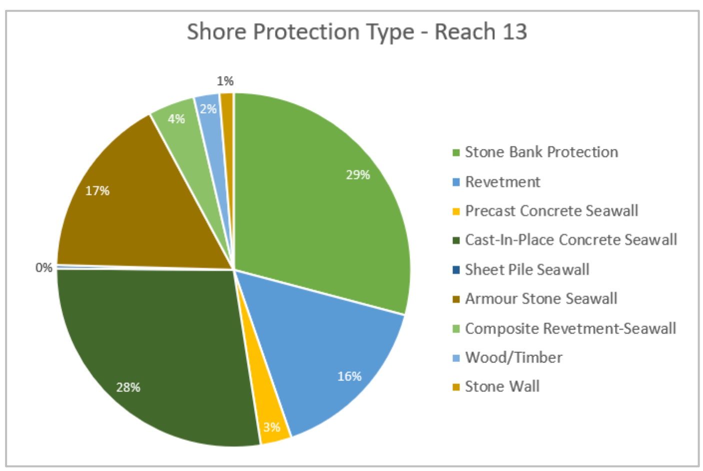
Developed Shoreline with Hardened Edge and Docks

Natural Shoreline Adjacent to Hardened Shoreline (right)

Shoreline Characterization

- Much of the shoreline is densely developed with residential waterfront properties.
- Old shoreline protection structures require maintenance. Future upgrades provide an opportunity to integrate nature-based and hybrid grey/green solutions.
- Backshore elevations increase west of the Bay Bridge towards Carrying Place.
- While various types of shore protection dominate the waters edge, sections of shoreline have been stabilized naturally and provide examples that could be replicated elsewhere (lower image).
- Reach 13 shoreline is 67% natural and 33% armoured, based on the entire shoreline length including coastal wetland areas.
- Of the armoured portion of the shoreline, 29% is ad-hoc field stone or quarry stone bank protection, 28% cast-in-place concrete seawall, 17% is armour stone seawall, and 16% is engineered revetment.
- Tolerance for additional shoreline hardening is low.



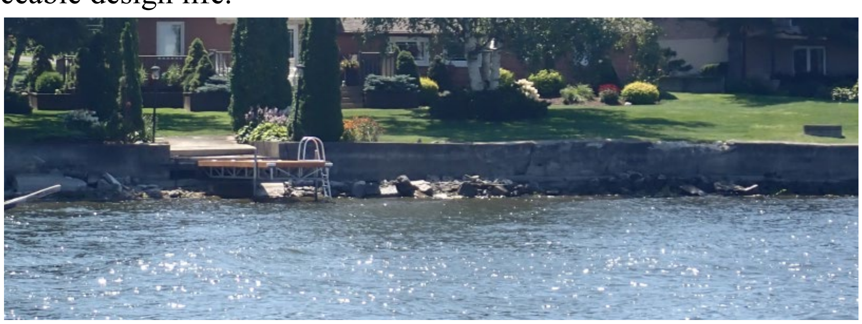


Challenges Associated with Natural Hazards

- Horse Point is accessible from Sunrise Drive. The majority of the road is below the 100-year flood level and the peninsula is within the Flood Hazard Limit (some of the homes are elevated above the 100-year flood level). Refer to the picture and map below.

- Fixed level docks are vulnerable to flooding and wave overtopping during periods of high lake levels.

- A significant amount of aging shoreline protection structures are present in Reach 13, including several examples of concrete seawalls that are close to or beyond the end of their serviceable design life.



Technical Basis for Natural Hazard Mapping

- Recession Rate for Erosion Hazard Limit (Stable Slope not included):

Geographic Area	Recession Rate (m/year)
Reach 13	0.10

- 100-year Flood Level and Wave Uprush Limit:

Reach	100-year Flood Level (m IGLD'85)	Horizontal Uprush Allowance (m)	Calculated Wave Uprush Elevation (m IGLD85')
Reach 13	76.10	15.0	77.1

- Dynamic Beach(es): Coordinates in UTM Zone 18N, NAD 1983

Start	End	Recession Rate (m/year) or Stable	Dynamic Beach Name
n/a			

- Wave Climate (parametric hindcast):

Location	ARI (years)	Depth (m)	Hs (m)	Tp (s)	DIR (deg)
Grave Island to	25	-	0.9 – 1.1	3.2 – 4.2	-
Carrying Place	100	-	1.0 – 1.2	3.4 – 4.5	-

Shoreline Management Recommendations

- **Preserve:** maintain natural shorelines, geodiversity, and vegetation to preserve resilience, natural protection, and ecological benefits.
- **Avoid:** ensure new development occurs outside of hazardous lands, and prohibit development/re-development in areas that are inaccessible during major floods.
- **Accommodate:** site specific investigations are required for communities with safe access challenges, as identified through the hazard mapping. Floodproof buildings, raise foundations, and upgrade septic systems on flood prone lands. Emergency planning and preparedness for a major flooding event.
- **Retreat and Realign:** re-align driveways, roadways through trailer parks, cottage communities, etc. and relocate homes to highest ground, where possible.
- **Protect:** Nature-based or hybrid grey/green erosion and flood protection schemes are recommended, as discussed in Section 7.3.2 of the SMP. All existing shoreline protection should be monitored and maintained regularly. Existing infrastructure can be improved with nature-based components such as cobble toe protection or vegetated buffers. Failing concrete, steel and gabion basket structures should be replaced with hybrid grey/green structures before outright failure.

Use Disclaimer

Reach 14 – Belleville

Local Conditions

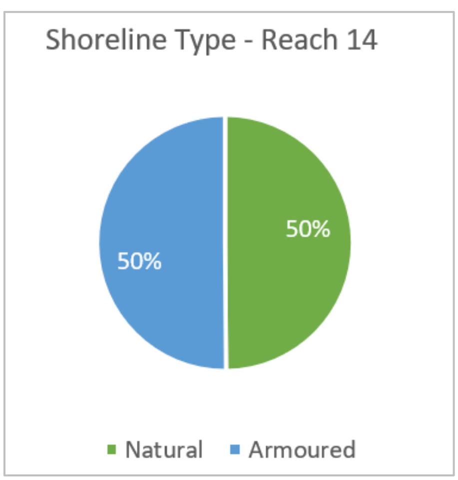
- Length = approximately 14 km.
- Reach 14 is a smaller reach centred on the community of Belleville on the north shore of the east-west section of the bay.
- The Bay Bridge connects Belleville to Prince Edward County in the centre of the reach at Zwick's Centennial Park.
- The Moira River empties into the bay in the centre of Belleville.
- The Belleville waterfront for 2 km east of the Moira River is protected with a series of public parks and is accessible to the community.
- Several marinas are located in or in close proximity to the river mouth due to the natural sheltering it provides.

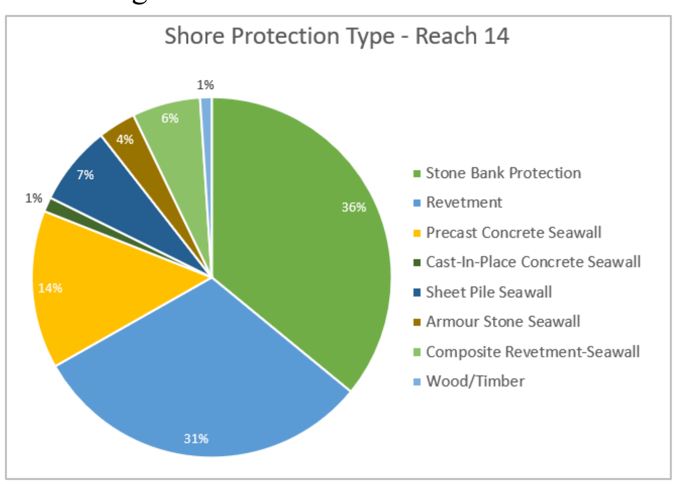
Mouth of the Moira River, Belleville

George Street Boat Launch

Shoreline Characterization

- The western portions of Reach 14 alternate between developed shoreline and natural conditions (top image).
- The majority of the Belleville waterfront is armoured with a variety of sloping rock structures and vertical walls (armour stone, concrete, or steel sheet pile).
- East of the Belleville waterfront more natural shoreline conditions return, and some nearshore habitat enhancements were observed (e.g., rock islands fronting hospital lands, bottom image).
- Much of the Reach 15 shoreline is public lands, featuring several parks and areas of other recreational uses.
- Much of the Belleville shoreline is low lying, as was made evident by flooding during periods of extreme lake levels in 2017 and 2019.
- Reach 14 shoreline approximately 50% natural and 50% armoured, making it the most armoured shoreline in the entire project geography.
- Of the armoured portion of the shoreline, 36% is ad-hoc field stone or quarry stone bank protection, 31% engineered revetment, 14% concrete seawall, and 7% is steel sheet pile.
- Tolerance for additional shoreline hardening is low.





Challenges Associated with Natural Hazards
• A significant area of Belleville on the east banks of the Moira River are within the Flood Hazard Limit. Refer to the map below illustrating municipal roads below the 100-year flood level (in red). Victoria Park and the lands north of Jane Forrester Park (Church, John, and George Streets) are all below the 100-year flood level, indicating that they would be flooded during non-storm conditions when lake levels are very high (e.g., 2019). • Similar challenges exist for the Crate Marina on the west banks of the river.  • High lake levels and erosion have damaged the existing shore protection in places, including at East Zwick's Centennial Park (pictured below). 

Technical Basis for Natural Hazard Mapping

- Recession Rate for Erosion Hazard Limit (Stable Slope not included):

Geographic Area	Recession Rates (m/year)
Reach 14	0.10

- 100-year Flood Level and Wave Uprush Limit:

Reach	100-year Flood Level (m IGLD'85)	Horizontal Uprush Allowance (m)	Calculated Wave Uprush Elevation (m IGLD85')
Reach 14	76.10	15.0	77.1

- Dynamic Beach(es): Coordinates in UTM Zone 18N, NAD 1983

Start	End	Recession Rate (m/year) or Stable	Dynamic Beach Name
n/a			

- Wave Climate (parametric hindcast):

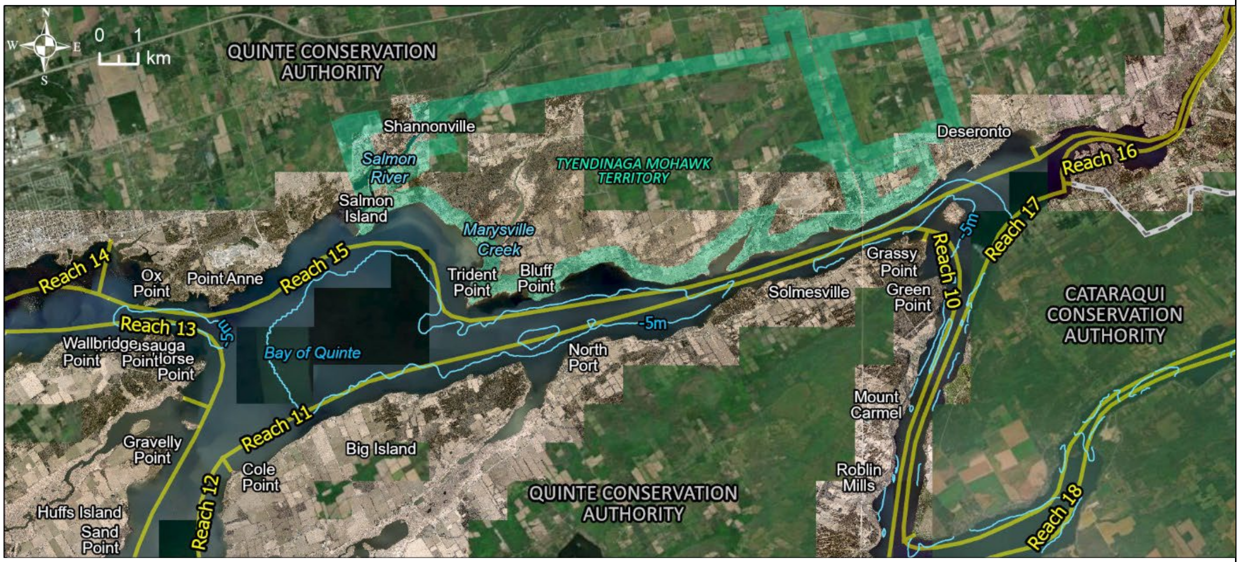
Location	ARI (years)	Depth (m)	Hs (m)	Tp (s)	DIR (deg)
Belleville	25	-	1.1	4.2	-
	100	-	1.2	4.5	-

Shoreline Management Recommendations

- **Preserve:** maintain natural shorelines, recreational spaces, geodiversity, and vegetation to preserve resilience, natural protection, and ecological benefits.
- **Avoid:** ensure new development occurs outside of hazardous lands, and prohibit development/re-development in areas that are inaccessible during major floods.
- **Accommodate:** site specific investigations are required for areas within Belleville where safe access is impeded during major flooding events, as identified through the hazard mapping. Site specific investigations should look for solutions to access issues in all existing communities based on the flooding hazard mapping and accounting for likely future impacts of climate change. Floodproof buildings, raise foundations, and upgrade septic systems on flood prone lands. Emergency planning and preparedness for a major flooding event.
- **Protect:** Nature-based or hybrid grey/green erosion and flood protection schemes are recommended, where feasible, as discussed in Section 7.3.2 of the SMP. All existing shoreline protection should be monitored and maintained regularly.

Use Disclaimer

Reach 15 – Mohawks of the Bay of Quinte to Deseronto



Local Conditions

- Length = approximately 48 km.
- Reach 15 extends from Belleville to Deseronto along the north shore of the bay and includes the Tyendinaga Mohawk Territory.
- The Lafarge Belleville Cement Regional Laboratory is located in the western portion of the reach and features a wharf at the shoreline.
- The Quinte Skyway Bridge provides access to Prince Edward County west of Deseronto.
- The waterfront for the community of Deseronto is centred on the Yacht Club, which was constructed on low lying lands.

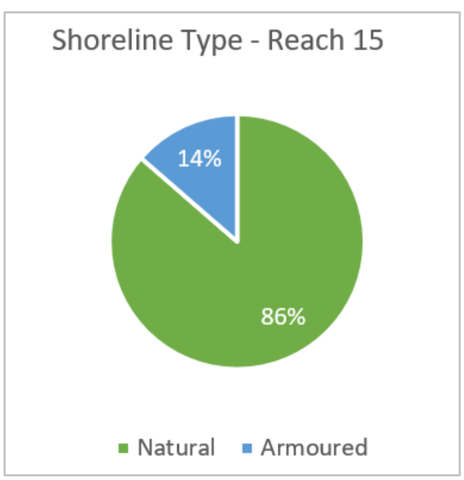
Low-lying Land Along Ridge Road

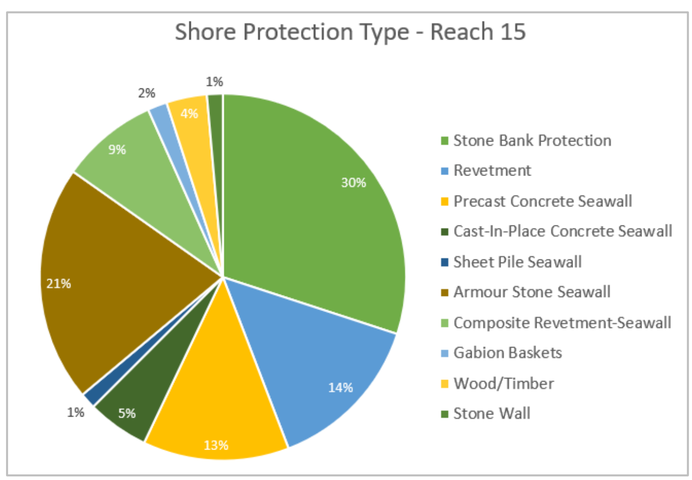
Gordon Road and Lower Sucker Creek

Shoreline Characterization

- The shoreline and interior lands are low lying in Reach 15 and slope gently to the interior based on the gradient of the underlying bedrock.
- These gently sloping shorelands support the formation of coastal wetlands. Reach 15 includes several provincially significant coastal wetlands, including the Blessington Creek Marsh, Lower Salmon River Wetland, Big Marsh Wetland, Bluff Point, Lower Sucker Creek, Airport Creek, and Forester's Island.

- The developed portions of the shoreline feature more natural shoreline conditions than was encountered in many other reaches in the study area.
- East of Deseronto into the mouth of the Napanee River the shoreline is largely in a natural state.
- The Reach 15 shoreline is approximately 86% natural and 14% armoured, based on the entire shoreline length including all coastal wetland areas.
- Of the armoured portion of the shoreline, 30% is ad-hoc field stone or quarry stone bank protection, 21% is armour stone seawall, and 14% is engineered revetment.
- Tolerance for additional shoreline hardening is low.

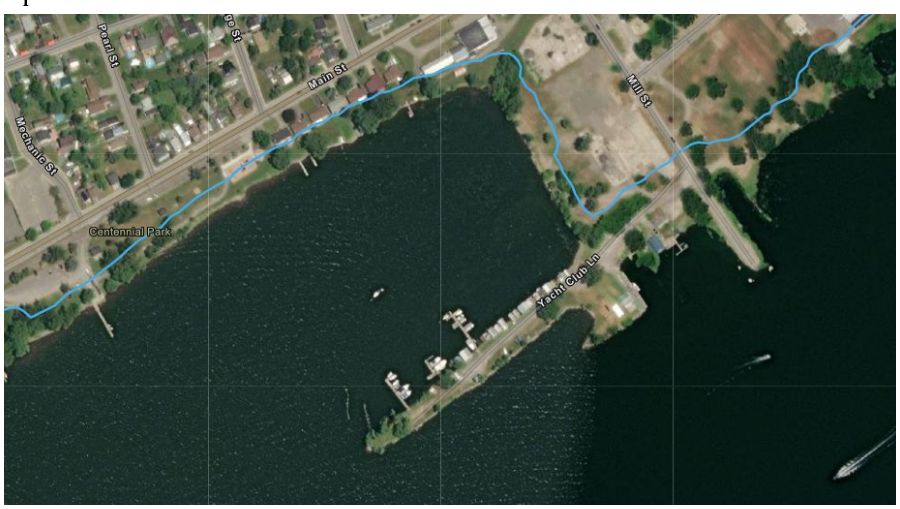




Challenges Associated with Natural Hazards

- The biggest challenge with natural hazards in Reach 15 is flooding.
- Several developments located on peninsulas along the lake, such as Gordon Road (pictured below), are within the Flood Hazard Limit and safe access on the road may not be possible during the 100-year flood level.

- Yacht Club Lane in Deseronto is within the Flood Hazard Limit and vulnerable to flooding impacts.



Technical Basis for Natural Hazard Mapping

- Recession Rate for Erosion Hazard Limit (Stable Slope not included):

Geographic Area	Recession Rate (m/year)
Reach 15	0.10

- 100-year Flood Level and Wave Uprush Limit:

Reach	100-year Flood Level (m IGLD'85)	Horizontal Uprush Allowance (m)	Calculated Wave Uprush Elevation (m IGLD85')
Reach 15	76.10	15.0	77.1

- Dynamic Beach(es): Coordinates in UTM Zone 18N, NAD 1983

Start	End	Recession Rate (m/year) or Stable	Dynamic Beach Name
n/a			

- Wave Climate (parametric hindcast):

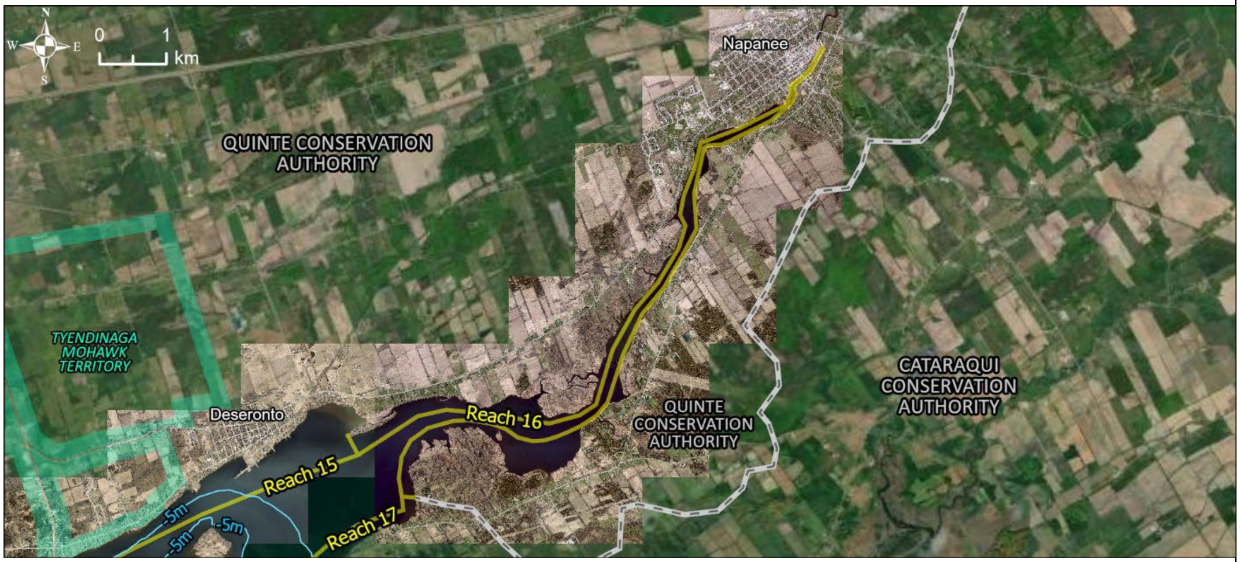
Location	ARI (years)	Depth (m)	Hs (m)	Tp (s)	DIR (deg)
Belleville to	25	-	0.9 – 1.2	3.3 – 4.3	-
Deseronto	100	-	1.1 – 1.3	3.5 – 4.6	-

Shoreline Management Recommendations

- **Preserve:** maintain natural shorelines, geodiversity, and vegetation to preserve resilience, natural protection, and ecological benefits.
- **Avoid:** ensure new development occurs outside of hazardous lands, and prohibit development/re-development in areas that are inaccessible during major floods.
- **Accommodate:** site specific investigations are required for communities with safe access challenges, as identified through the hazard mapping. Floodproof buildings, raise foundations, and upgrade septic systems on flood prone lands. Emergency planning and preparedness for a major flooding event.
- **Retreat and Realign:** re-align driveways, roadways through trailer parks, cottage communities, etc. and relocate homes to highest ground, where possible.
- **Protect:** Nature-based or hybrid grey/green erosion and flood protection schemes are recommended, as discussed in Section 7.3.2 of the SMP. All existing shoreline protection should be monitored and maintained regularly, particularly in the densely developed area surrounding Deseronto. Existing infrastructure can be improved with nature-based components such as cobble toe protection or vegetated buffers. Failing concrete, steel and gabion basket structures should be replaced with hybrid grey/green structures before outright failure.

Use Disclaimer

Reach 16 – Napanee River



Local Conditions

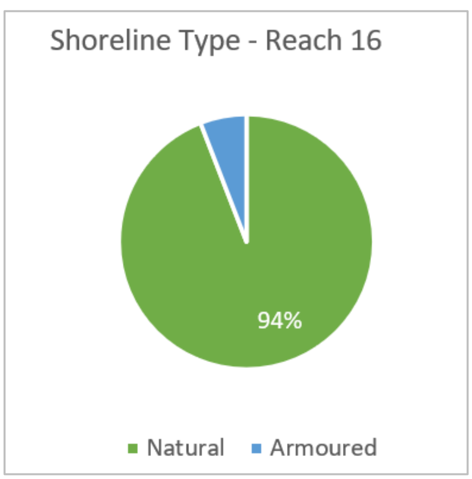
- Length = approximately 25 km.
- Reach 16 features the mouth of the Napanee River upstream to the Town of Napanee at the falls.
- Numerical models of major storm surge events predicted that Bay of Quinte storm surges are able to propagate up the river during strong winds from the west.
- The majority of the shoreline development is located in the northern half of the reach, near the Town of Napanee.

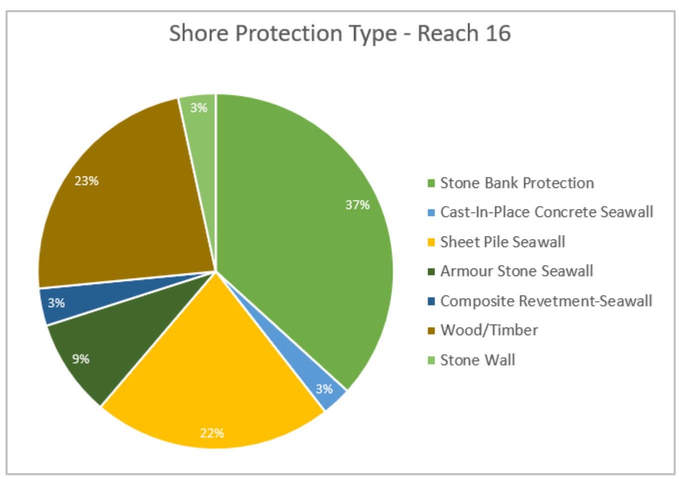
Mouth of Napanee River

Upstream Limit of Study on Napanee River at the Falls

Shoreline Characterization

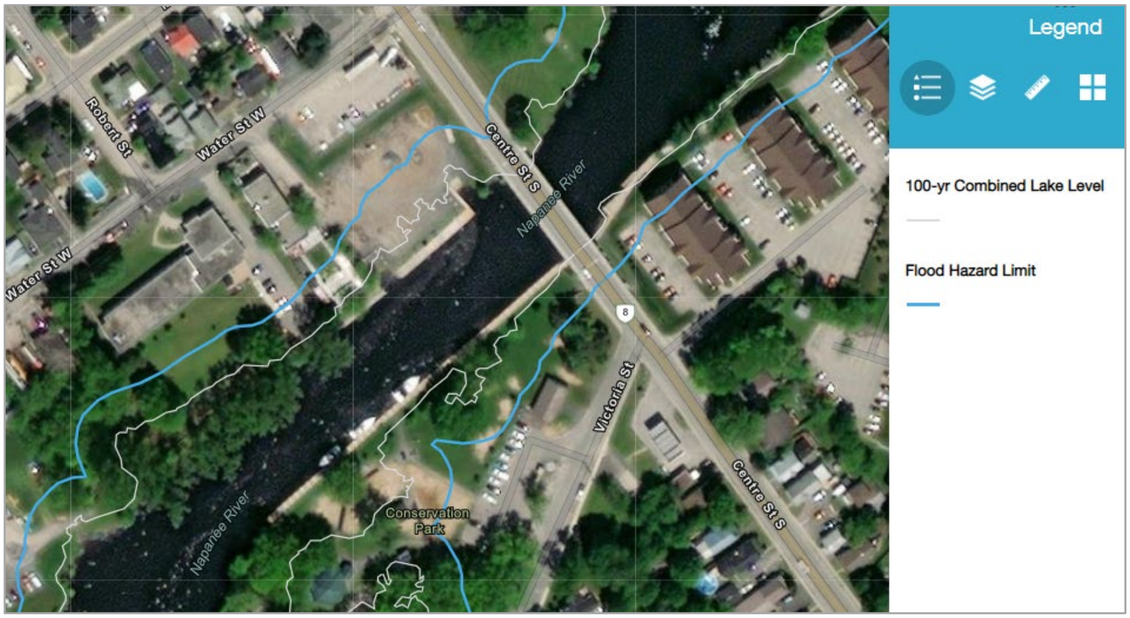
- From the falls to Centre Street, the riverbanks are partially armoured and confined to the bedrock channel.
- Below Centre Street, the riverbanks are generally in a natural state and the floodplain spills the banks in some locations.
- A significant portion of Reach 16 features provincially significant wetlands known as the Lower Napanee River Complex.
- The Reach 16 shoreline is approximately 94% natural and only 6% armoured, based on the entire shoreline length including coastal wetland areas.
- Of the armoured portion of the shoreline, 37% is ad-hoc field stone or quarry stone bank protection, 23% is wood or timber structures, and 22% is steel sheet pile.
- Tolerance for additional shoreline hardening is low.





Challenges associated with Natural Hazards

- For the lower portion of Reach 16 including the rivermouth there are no natural hazards since wetlands define the riverbanks and they are resilient to lake level fluctuations and storm impacts.
- At Centre Street South, the 100-year flood level is higher than the riverbanks, suggesting a storm surge that propagates up the river could flood the banks and low-lying infrastructure, such as parking lots. See map below.



Technical Basis for Natural Hazard Mapping

- Recession Rate for Erosion Hazard Limit (Stable Slope not included):

Geographic Area	Recession Rates (m/year)
Reach 16	0.10

- 100-year Flood Level and Wave Uprush Limit:

Reach	100-year Flood Level (m IGLD'85)	Horizontal Uprush Allowance (m)	Calculated Wave Uprush Elevation (m IGLD85')
Reach 16	76.15	15.0	76.8

- Dynamic Beach(es): Coordinates in UTM Zone 18N, NAD 1983

Start	End	Recession Rate (m/year) or Stable	Dynamic Beach Name
n/a			

- Wave Climate (parametric hindcast):

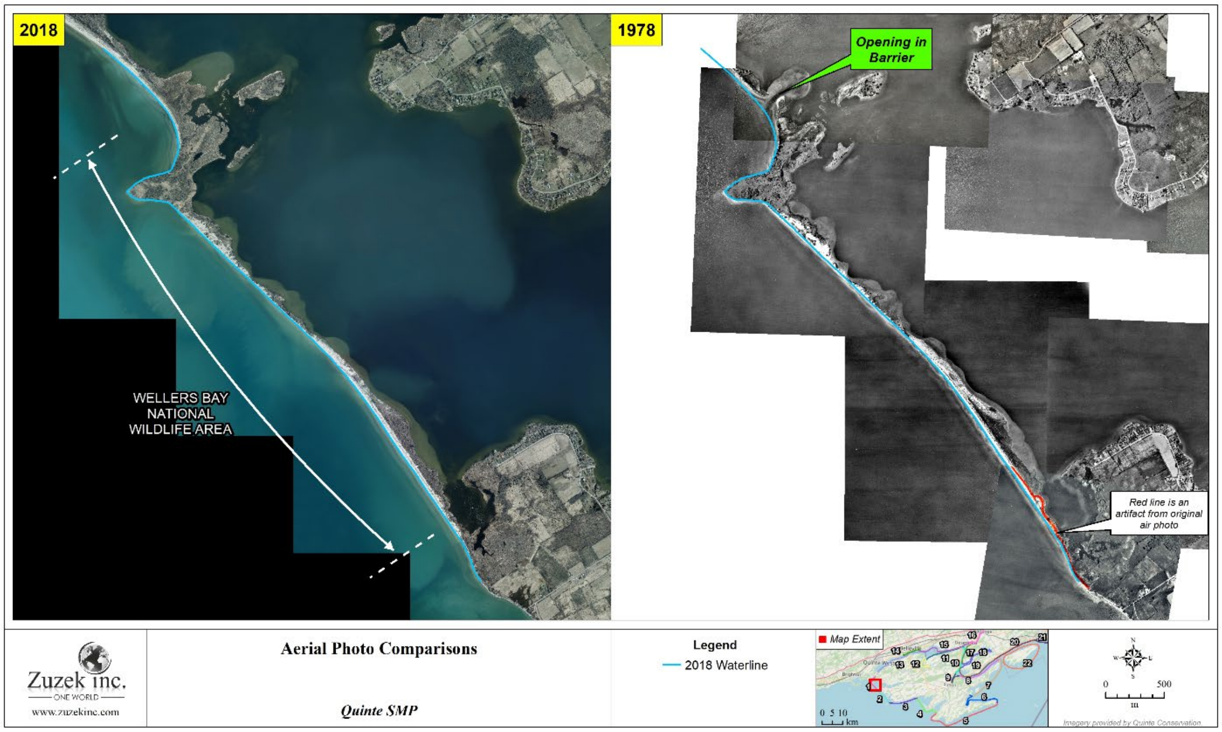
Location	ARI (years)	Depth (m)	Hs (m)	Tp (s)	DIR (deg)
Napanee River Mouth	25	-	1.2	4.3	-
	100	-	1.3	4.6	-
Napanee River	25	-	0.4	2.0	
	100	-	0.4	2.0	

Shoreline Management Recommendations

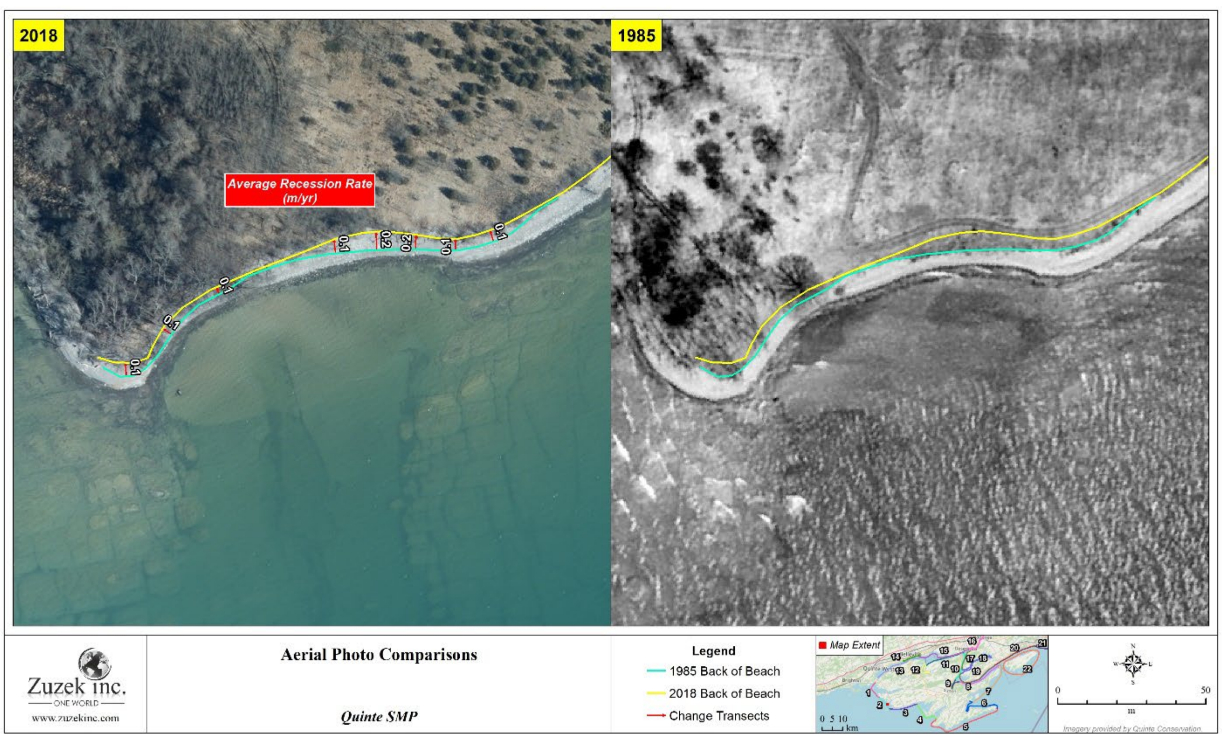
- **Preserve:** maintain natural shorelines, geodiversity, and vegetation to preserve resilience, natural protection, and ecological benefits.
- **Avoid:** ensure new development occurs outside of hazardous lands.
- **Accommodate:** Floodproof buildings, raise foundations, and upgrade septic systems on flood prone lands. Emergency planning and preparedness for a major flooding event.
- **Protect:** Nature-based or hybrid grey/green erosion and flood protection schemes are recommended, as discussed in Section 7.3.2 of the SMP. All existing shoreline protection should be monitored and maintained regularly. Existing infrastructure can be improved with nature-based components such as cobble toe protection or vegetated buffers. Failing concrete, steel and gabion basket structures should be replaced with hybrid grey/green structures before outright failure.

Use Disclaimer

APPENDIX B – Shoreline Change Analysis

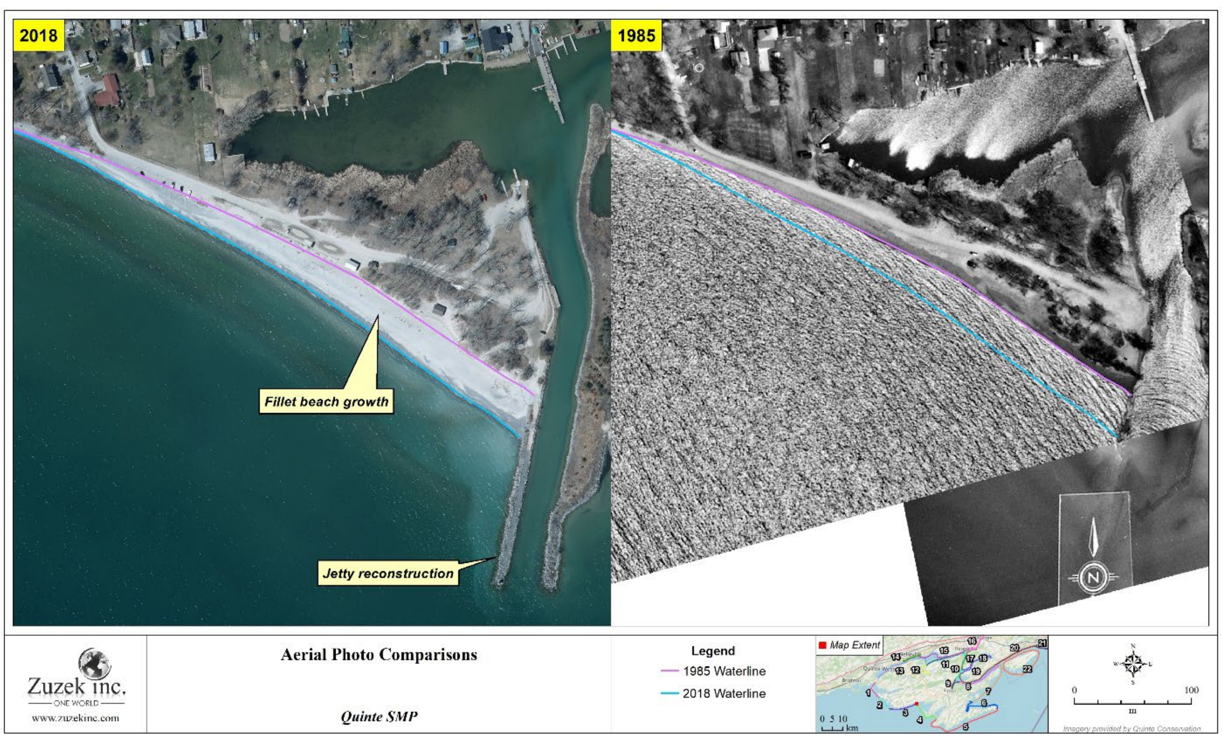


2018
1978
Opening in Barrier
WELLERS BAY NATIONAL WILDLIFE AREA
Red line is an artifact from original air photo
Zuzek inc.
ONE WORLD
www.zuzekinc.com
Aerial Photo Comparisons
Quinte SMP
Legend
2018 Waterline
Map Extent
0 5 10 km
0 500 m
Imagery provided by Quinte Conservation

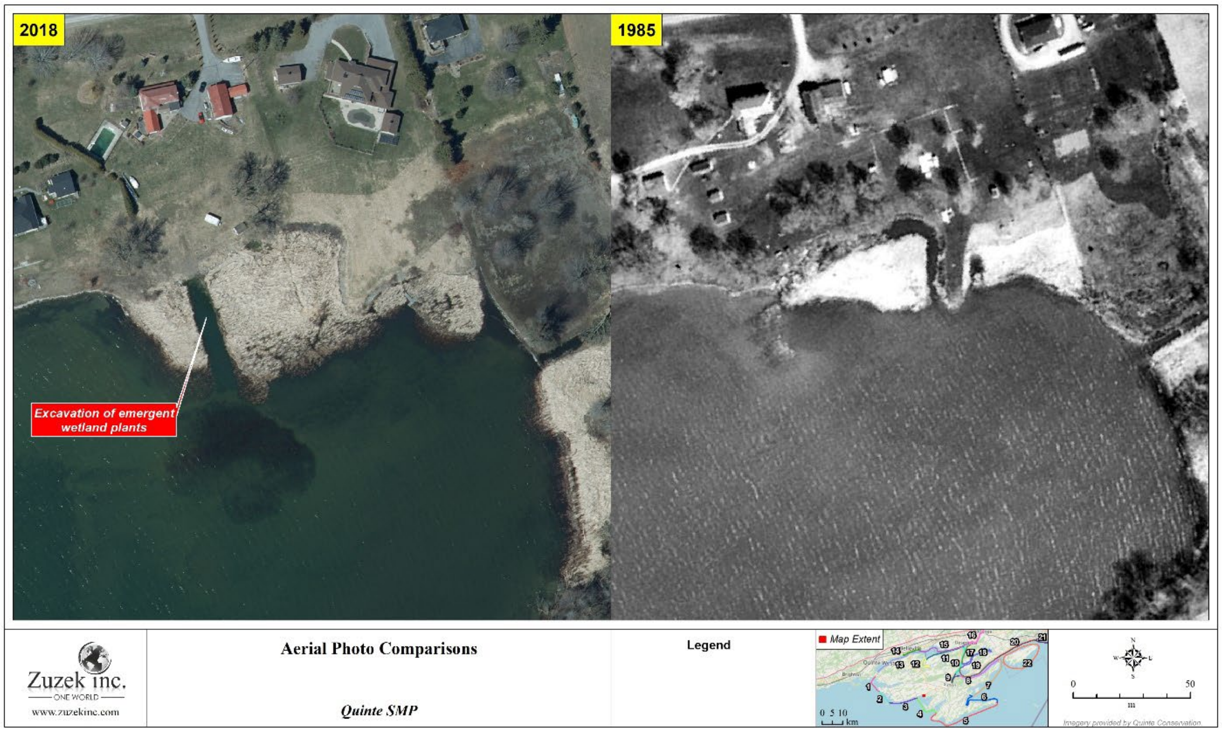


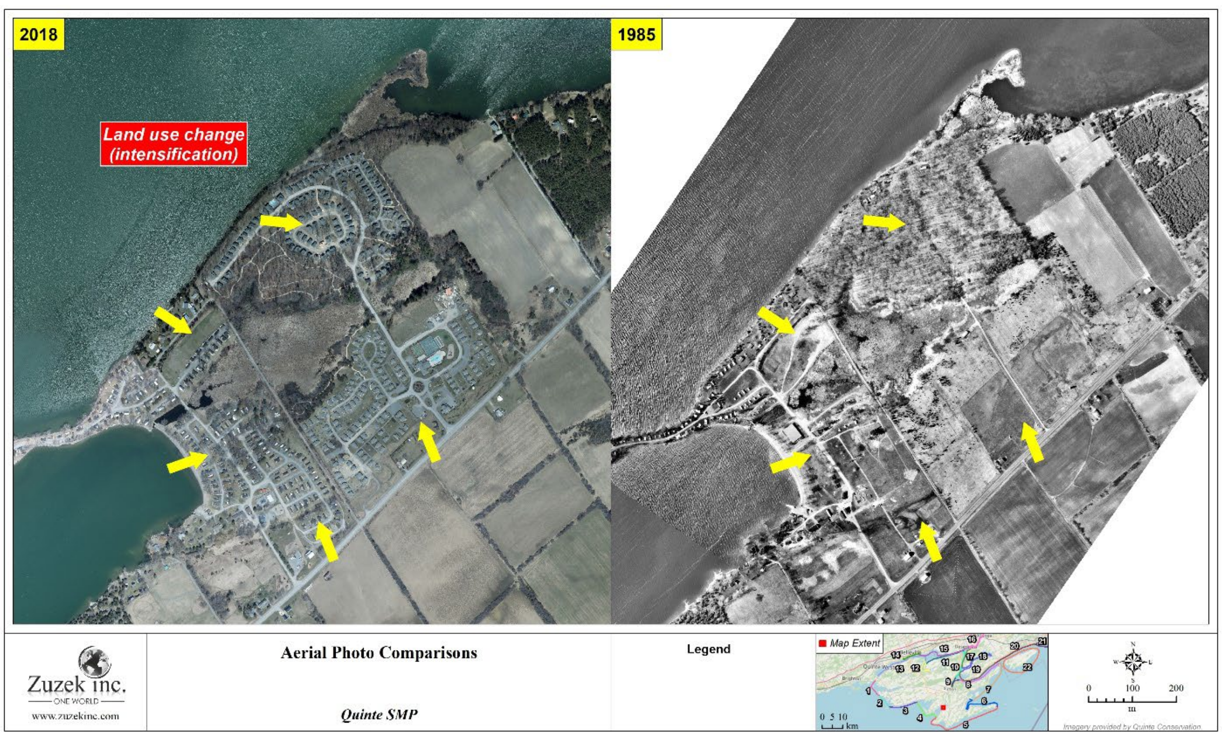
2018
1985
Average Recession Rate (m/yr)
Zuzek inc.
ONE WORLD
www.zuzekinc.com
Aerial Photo Comparisons
Quinte SMP
Legend
1985 Back of Beach
2018 Back of Beach
Change Transects
Map Extent
0 5 10 km
0 50 m
Imagery provided by Quinte Conservation

2018
1985
Average Recession Rate (m/yr)
0.1
0.2
0.2
Edge of bedrock shelf
Edge of bedrock shelf
Edge of bedrock shelf
Edge of bedrock shelf
Bank erosion due to increased wave energy, a result of lower bedrock depths and greater slope.
Zuzek inc.
ONE WORLD
www.zuzekinc.com
Aerial Photo Comparisons
Quinte SMP
Legend
1985 Back of Beach
2018 Back of Beach
Change Transects
Map Extent
0 5 10 km
0 50 m
Imagery provided by Quinte Conservation

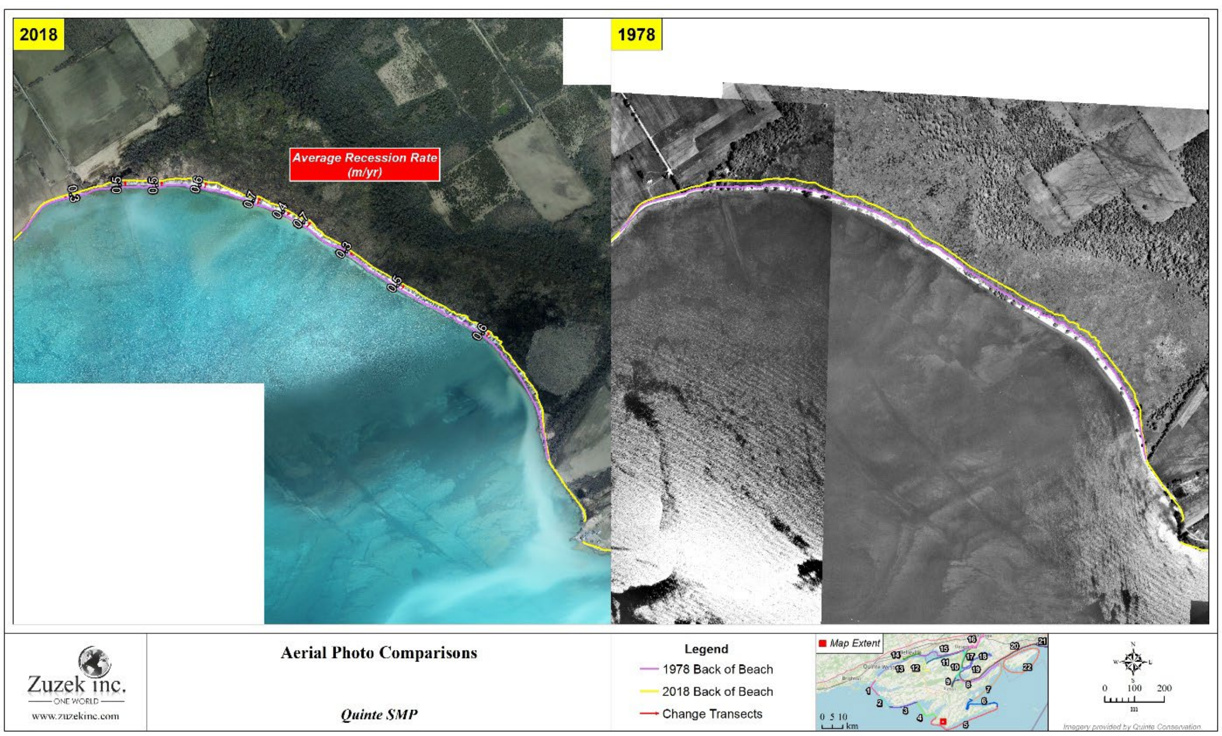


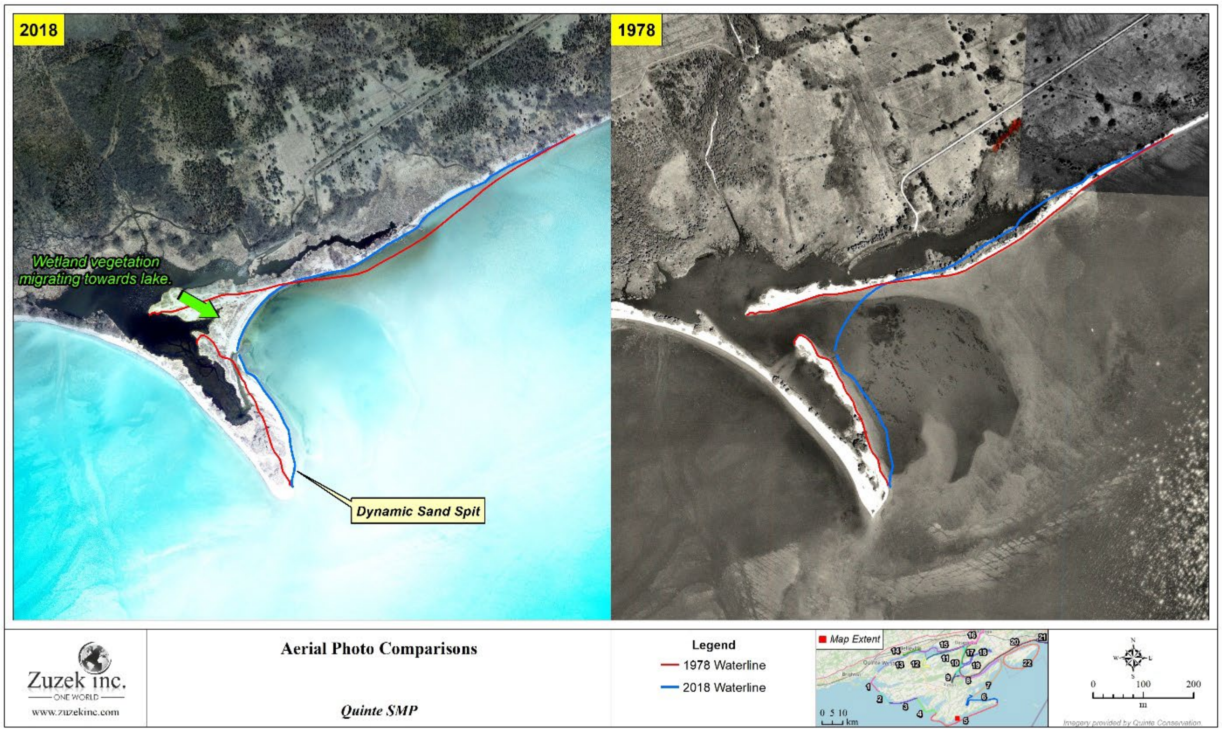
2018
1985
Fillet beach growth
Jetty reconstruction
Zuzek inc.
ONE WORLD
www.zuzekinc.com
Aerial Photo Comparisons
Quinte SMP
Legend
1985 Waterline
2018 Waterline
Map Extent
0 5 10 km
0 100 m
Imagery provided by Quinte Conservation

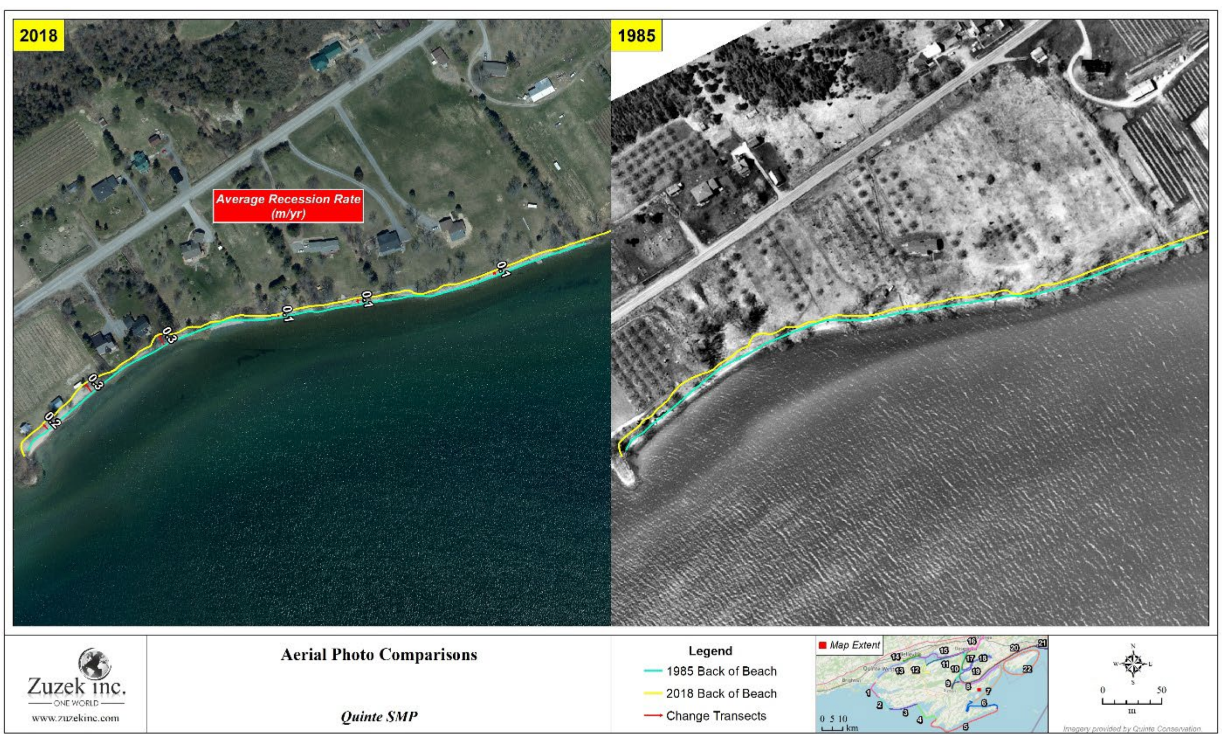

2018
1985
Excavation of emergent wetland plants
Zuzek inc.
ONE WORLD
www.zuzekinc.com
Aerial Photo Comparisons
Quinte SMP
Legend
Map Extent
0 5 10 km
0 50
m
Imagery provided by Quinte Conservation

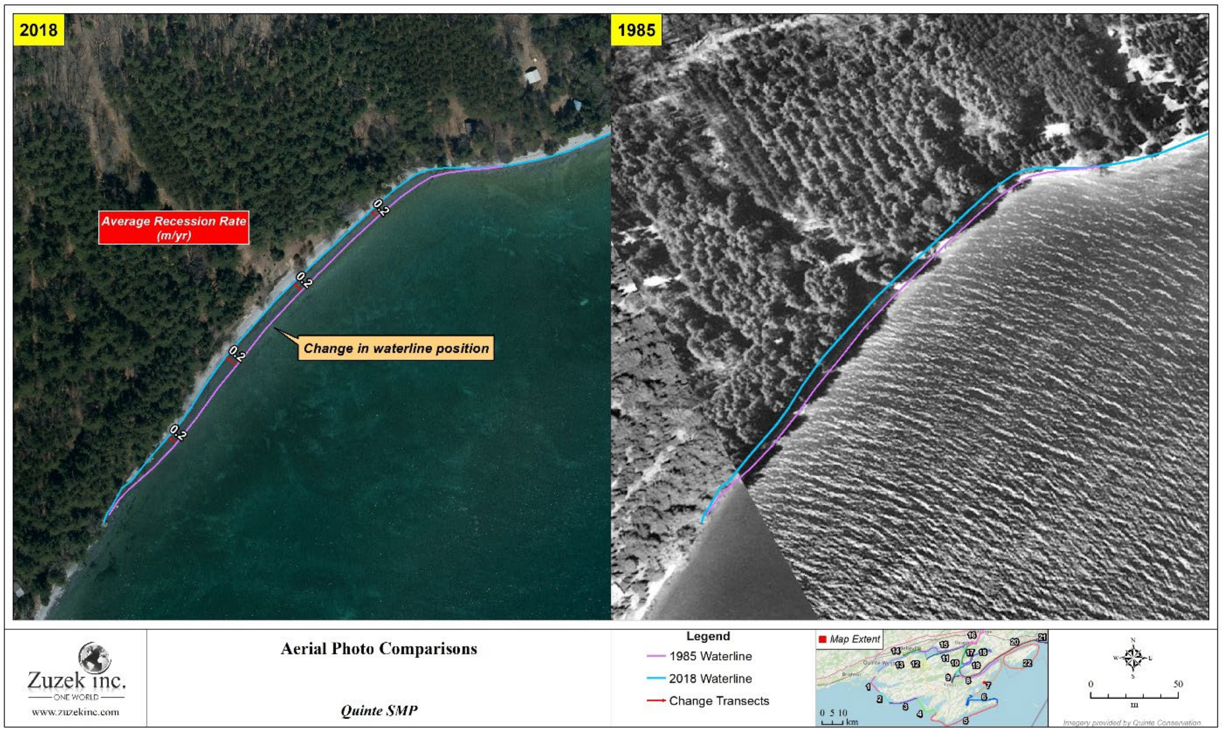

2018
1985
Land use change (intensification)
Zuzek inc.
ONE WORLD
www.zuzekinc.com
Aerial Photo Comparisons
Quinte SMP
Legend
Map Extent
0 5 10 km
0 100 200
m
Imagery provided by Quinte Conservation

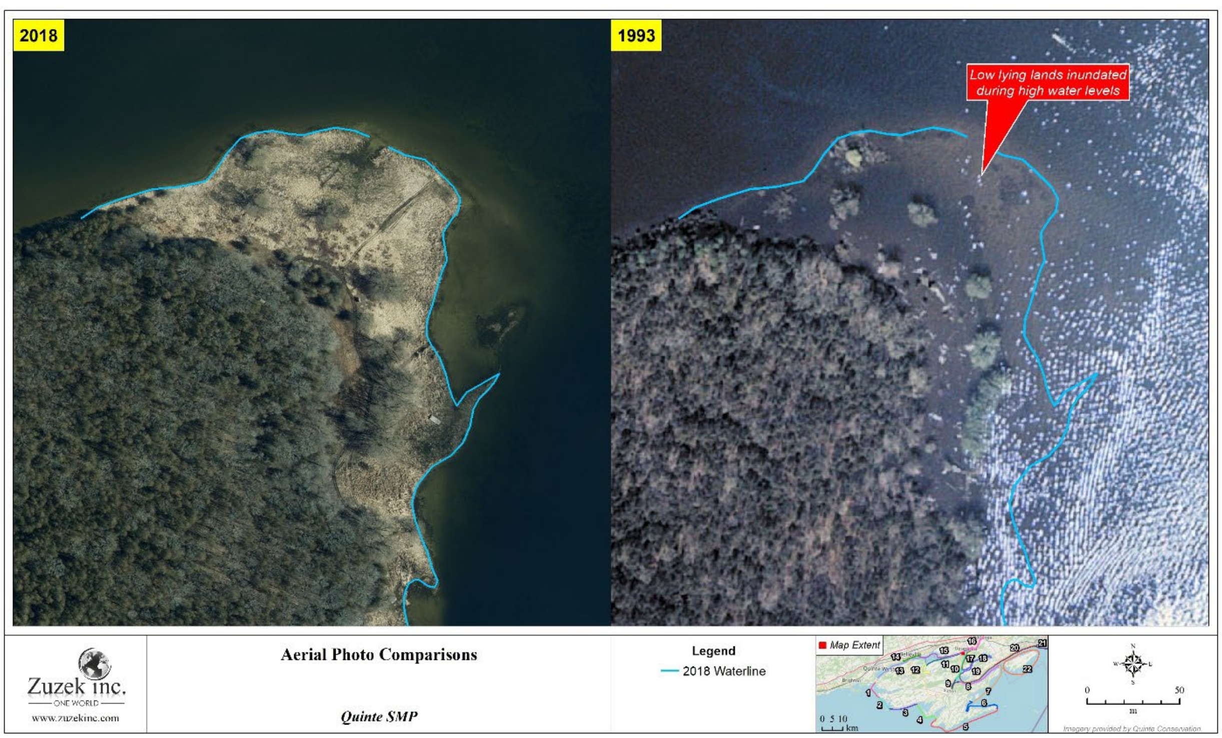

2018
1978
Quinte's Isle Campark
(recreational campground)
Zuzek inc.
ONE WORLD
www.zuzekinc.com
Aerial Photo Comparisons
Quinte SMP
Legend
Map Extent
Imagery provided by Quinte Conservation

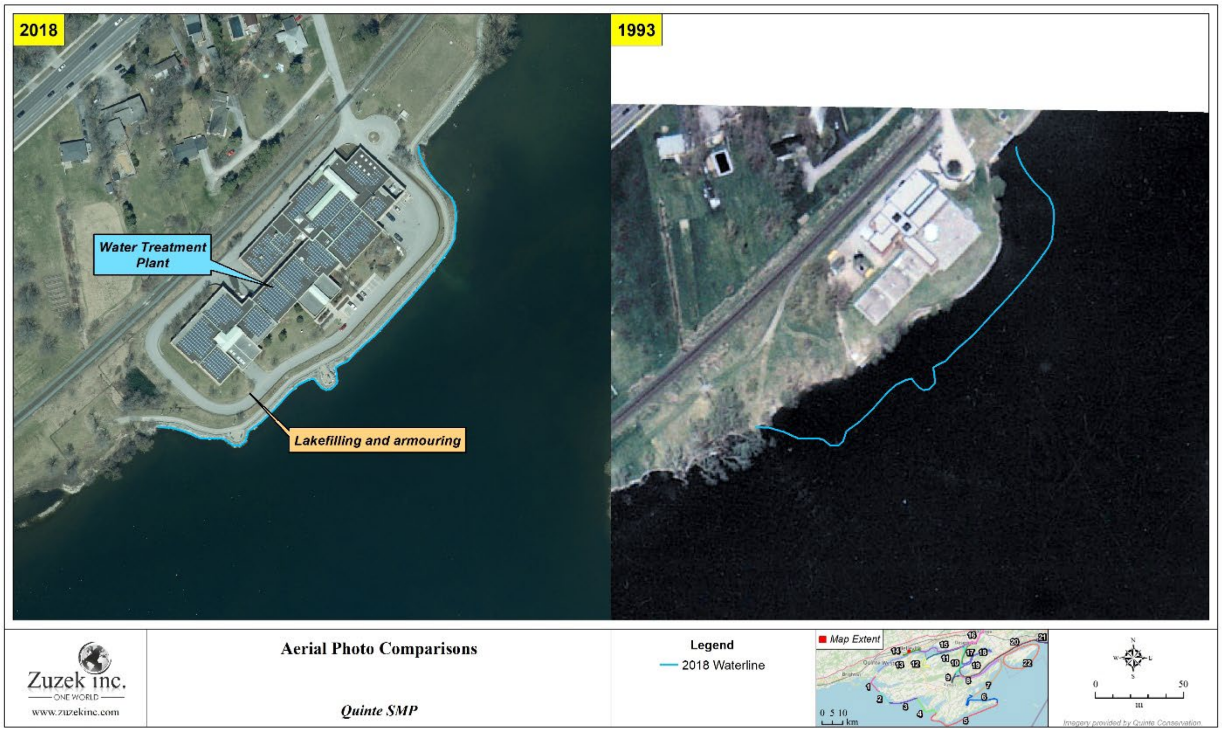

2018
1978
Average Recession Rate
(m/yr)
Zuzek inc.
ONE WORLD
www.zuzekinc.com
Aerial Photo Comparisons
Quinte SMP
Legend
1978 Back of Beach
2018 Back of Beach
Change Transects
Map Extent
Imagery provided by Quinte Conservation

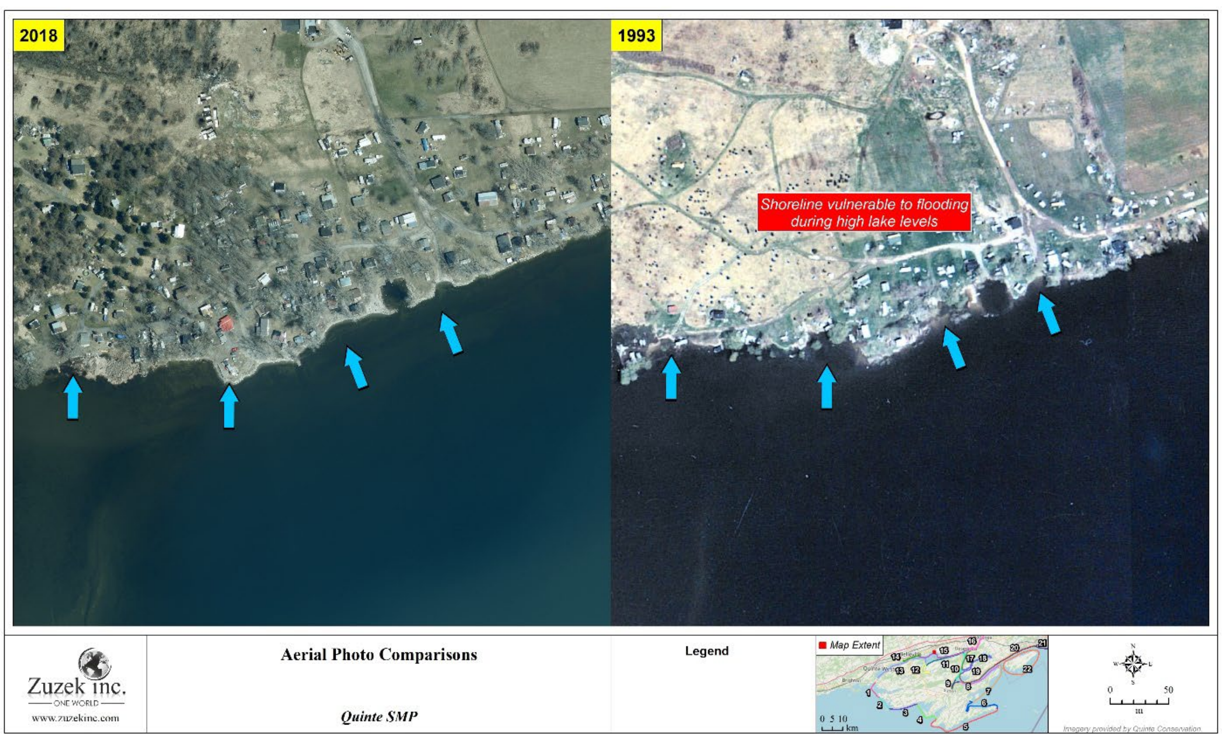

2018
1978
Wetland vegetation migrating towards lake.
Dynamic Sand Spit
Zuzek inc.
ONE WORLD
www.zuzekinc.com
Aerial Photo Comparisons
Quinte SMP
Legend
1978 Waterline
2018 Waterline
Map Extent
0 100 200
m
Imagery provided by Quinte Conservation


2018
1985
Average Recession Rate (m/yr)
0.1
0.1
0.1
0.3
0.3
0.2
Zuzek inc.
ONE WORLD
www.zuzekinc.com
Aerial Photo Comparisons
Quinte SMP
Legend
1985 Back of Beach
2018 Back of Beach
Change Transects
Map Extent
0 50
m
Imagery provided by Quinte Conservation


2018
1985
Average Recession Rate (m/yr)
0.2
0.2
0.2
0.2
Change in waterline position
Zuzek inc.
ONE WORLD
www.zuzekinc.com
Aerial Photo Comparisons
Quinte SMP
Legend
1985 Waterline
2018 Waterline
Change Transects
Map Extent
0 5 10 km
0 50 m
Imagery provided by Quinte Conservation


2018
1993
Low lying lands inundated during high water levels
Zuzek inc.
ONE WORLD
www.zuzekinc.com
Aerial Photo Comparisons
Quinte SMP
Legend
2018 Waterline
Map Extent
0 5 10 km
0 50 m
Imagery provided by Quinte Conservation

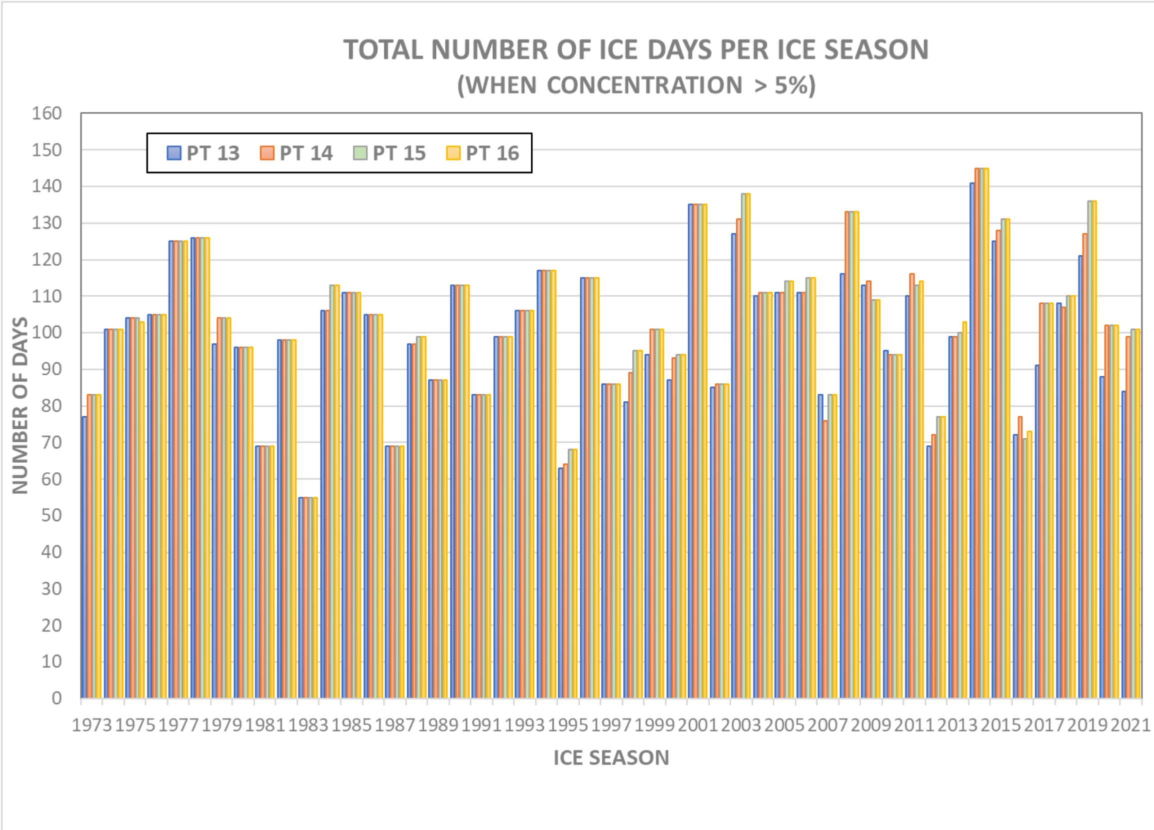

2018
1993
Water Treatment Plant
Lakefilling and armouring
Zuzek inc.
ONE WORLD
www.zuzekinc.com
Aerial Photo Comparisons
Quinte SMP
Legend
2018 Waterline
Map Extent
Imagery provided by Quinte Conservation

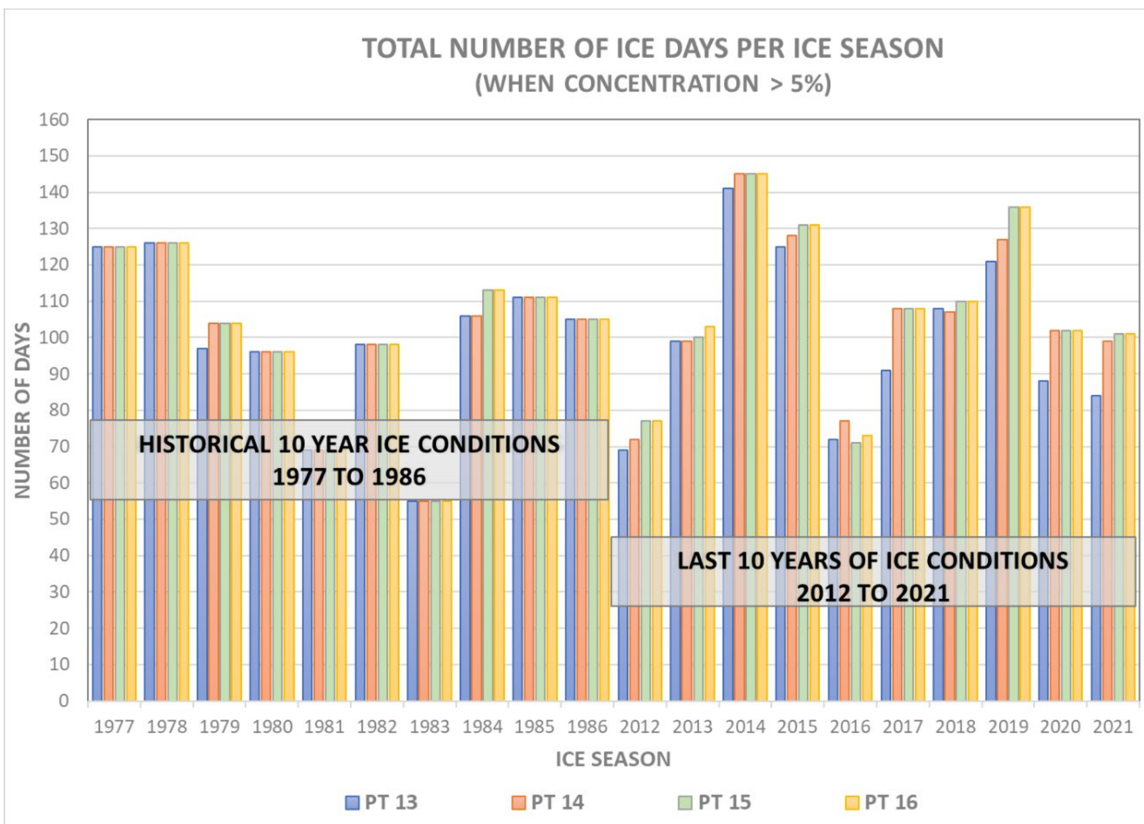

2018
1993
Shoreline vulnerable to flooding during high lake levels
Zuzek inc.
ONE WORLD
www.zuzekinc.com
Aerial Photo Comparisons
Quinte SMP
Legend
Map Extent
Imagery provided by Quinte Conservation


2018
1993
Lakefilling for shore protection
New shore protection in 2018 ortho
Zuzek inc.
ONE WORLD
www.zuzekinc.com
Aerial Photo Comparisons
Quinte SMP
Legend
2018 Waterline
Map Extent
0 5 10 km
0 50 m
Imagery provided by Quinte Conservation


2018
1993
Higher density of homes since 1993
Zuzek inc.
ONE WORLD
www.zuzekinc.com
Aerial Photo Comparisons
Quinte SMP
Legend
Map Extent
0 5 10 km
0 50 m
Imagery provided by Quinte Conservation

APPENDIX C – Ice Tool Analysis


TOTAL NUMBER OF ICE DAYS PER ICE SEASON
(WHEN CONCENTRATION > 5%)
PT 13
PT 14
PT 15
PT 16
NUMBER OF DAYS
ICE SEASON
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
1973
1975
1977
1979
1981
1983
1985
1987
1989
1991
1993
1995
1997
1999
2001
2003
2005
2007
2009
2011
2013
2015
2017
2019
2021


TOTAL NUMBER OF ICE DAYS PER ICE SEASON
(WHEN CONCENTRATION > 5%)
NUMBER OF DAYS
HISTORICAL 10 YEAR ICE CONDITIONS
1977 TO 1986
LAST 10 YEARS OF ICE CONDITIONS
2012 TO 2021
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
1977
1978
1979
1980
1981
1982
1983
1984
1985
1986
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
ICE SEASON
PT 13
PT 14
PT 15
PT 16