Hamilton Conservation Authority Shoreline Management Plan

Prepared for:

Hamilton Conservation Authority

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Prepared by:

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In association with:

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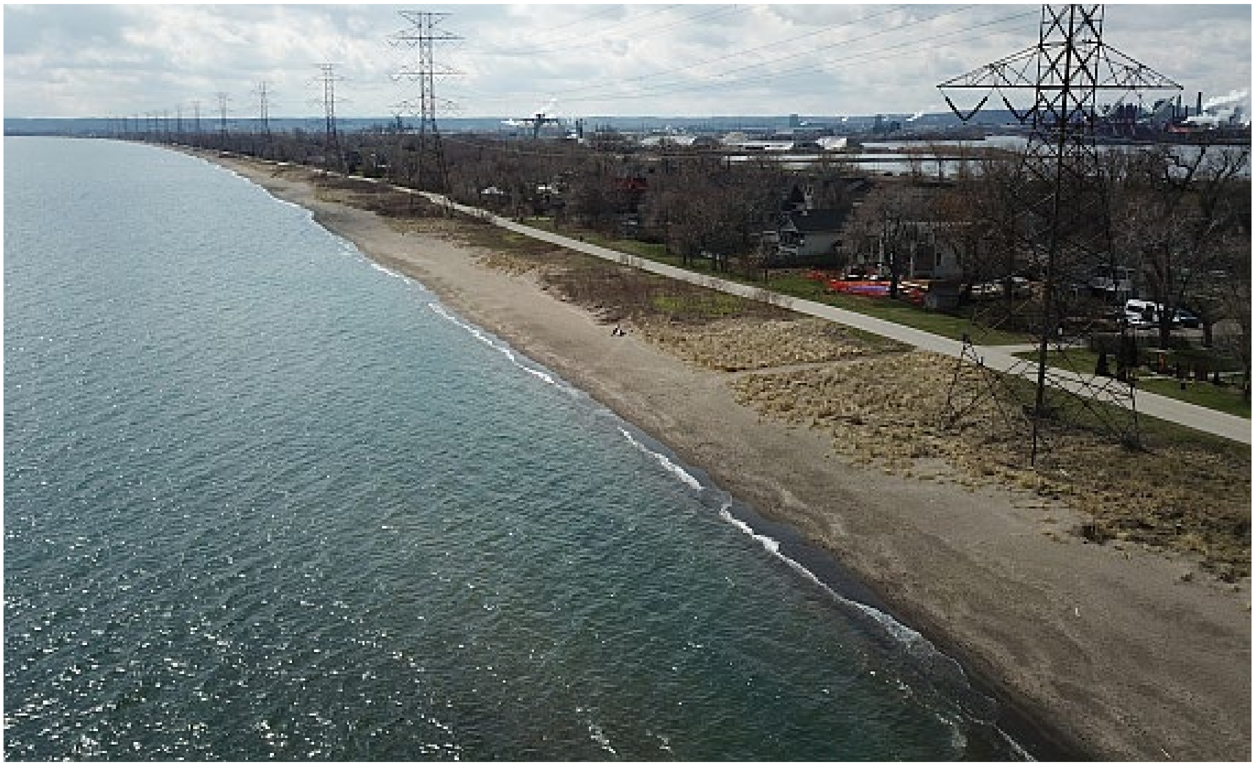
DHI

Hamilton Beach and Waterfront Trail



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EXECUTIVE SUMMARY

The Hamilton Conservation Authority's watershed and shoreline jurisdiction cover the southwestern end of Lake Ontario and the southern half of Hamilton Harbour. Refer to the study area map below. The shoreline is roughly 42 km in length, extending from Fifty Point Conservation Area on Lake Ontario to the Woodland Cemetery in Hamilton Harbour. The lake shoreline features extensive residential development and shoreline armouring. The harbour shoreline features intensive industrial development on the port lands, large marinas, and a lakefill park that provides public access to the shore.

The Hamilton Conservation Authority (HCA) regulates development, interference with wetlands, and alterations to shorelines and watercourses under Ontario Regulation 161/06. Development is generally prohibited on the lands adjacent to Lake Ontario and Hamilton Harbour under the HCA jurisdiction if they are part of the *flooding*, *erosion*, or *dynamic beach hazard.* These hazards are defined in the Provincial Policy Statement (PPS, 2020) and have been mapped for this Shoreline Management Plan. The HCA may grant permission for development in or on the regulated lands in accordance with the regulations.

Prior to mapping the shoreline hazards, field work was completed to collect oblique photographs of the entire shoreline and bathymetric data at shore perpendicular profiles. The shoreline was sub-divided into nine reaches based on geology, shoreline morphology, erosion and sedimentation processes, land use, and significant natural features.

Technical work was completed to establish long-term recession rates and complete updated statistical analysis on lake level extremes at the Burlington water level gauge. Numerical modelling tools were used to evaluate spatial variability in storm surge and nearshore wave conditions in the lake and harbour. The outputs from the data collection and technical analysis were used to map the *flooding*, *erosion*, and *dynamic beach hazards* for the study area.

Shoreline management recommendations based on the study principles of sustainable coastal development, integrated coastal management, and resilient coastal communities were developed for eight shoreline reaches. The recommendations followed the hierarchical approach to hazard risk reduction outlined in the **PARAP** framework, including: **P**reserve natural shorelines, **A**void further development on hazardous lands, **R**etreat from and **R**e-align hazardous lands, **A**ccommodate coastal hazards, and **P**rotect infrastructure and other assets with nature-based solutions and traditional engineered structures.

The study concluded that the Lake Ontario shoreline within the HCA watershed is highly erosive, especially on the lake bottom at the toe of existing shoreline protection structures. Maintenance or upgrading of existing shoreline protection structures will be a forever commitment to protect the dense residential development. Over time, the *erosion* and *flooding hazards* may become too severe to support ongoing residential development. In such cases, a planned retreat protocol should be developed to relocate buildings and infrastructure further inland.

Hamilton Beach provides almost 8 km of public open space, a waterfront trail, and sandy beaches. The historical sediment sources for this beach have all but disappeared and littoral drift is negatively impacted by lakefill barriers and harbour jetties, which will lead to further management challenges during periods of high lake levels, such as beach, dune, and bank erosion. The implementation of nature-based solutions to increase the resilience of the beach are encouraged, such as dune restoration and beach nourishment, avoiding hard armouring where possible.

The shoreline in the port lands and recreational amenities in the harbour are all heavily armoured. These shoreline protection structures should be monitored regularly with maintenance completed in a timely manner. Where possible, habitat enhancement projects, such as rock shoals and islands, should be incorporated into future shoreline protection and maintenance projects.

Monitoring of the bluffs fronting the Woodland Cemetery in Reach 8 should be completed annually, as signs of slope instability were observed. The shoreline is presently unprotected. Given the low wave energy environment and shallow conditions close to shore, there may be opportunities for innovative nature-based solutions that will protect the bluffs from further erosion and enhance nearshore habitat.

GLOSSARY OF TERMS

Dynamic Beach Hazard – 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. The *dynamic beach hazard* limit consists of the *flooding hazard* limit plus a dynamic beach allowance.

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.

Erosion Hazard – the loss of land, due to human or natural processes, that poses a threat to life and property. The *erosion hazard* limit is determined using considerations that include the 100 year erosion rate (the average annual rate of recession extended over a one hundred year time span), an allowance for slope stability, and an erosion access allowance.

Flooding Hazard – areas adjacent to the shoreline subject to flood risk. Along the shorelines of the Great Lakes – St. Lawrence River System, the *flooding hazard* limit is based on the one hundred year flood level plus an allowance for wave uprush and other water-related hazards.

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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1.0 INTRODUCTION

Zuzek Inc. in partnership with SJL Engineering Inc. (SJL) and DHI were retained by the Hamilton Conservation Authority (HCA) to update the existing coastal hazard mapping and prepare this Shoreline Management Plan (SMP). Section one outlines the principles and objectives of the SMP, summarizes the report structure, and provides vertical datum conversions. A map of the HCA boundary along the shoreline is provided in Figure 1.1.

Figure 1.1 Hamilton Conservation boundary

1.1 Principles and Objectives for the SMP

The development of this 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 balance between the environment, society, natural physical processes, and the economy when making management decisions along the coast, planning for new development, and reducing exposure to natural hazards.

- Integrated Coastal Management (ICM): ICM is a dynamic, multi-disciplinary, and iterative process of promoting the sustainable management of our coastal zones. ICM seeks, over the long-term, to balance environmental, economic, social, cultural, and recreational objectives, all within the limits of a dynamic coastal ecosystem. ICM 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 and unique ecological habitat. If sediment transport is not a dominant process, management recommendations should be developed for shoreline reaches with similar physical, ecological, and land use characteristics.

- Resilient Coastal Communities: Resilience is the capacity of social, economic, ecological, and physical systems in coastal areas to cope with a hazardous event, trend, or disturbance, responding and reorganizing in ways that maintain their essential function, identity, and structure, while also building capacity for learning, innovative and equitable adaptation, and transformation (Zuzek Inc., 2023). The management recommendations developed for the SMP provide direction to increase resilience of coastal communities and habitat.

Objectives of the Shoreline Management Plan:

- Update coastal hazard mapping using the best available data and technical analyses for the entire HCA shoreline of Lake Ontario and Hamilton Harbour.
- Preserve natural shorelines, while maintaining public access where possible.
- Develop reach specific coastal management recommendations to protect nature, avoid future development on hazardous lands, retreat and re-align hazardous land uses, accommodate hazards with adaptation strategies, and protect existing development and infrastructure exposed to coastal hazards with nature-based solutions, green-grey hybrid solutions, and traditional engineered structures.
- Increase the resilience of coastal communities, beaches, and habitat.

1.2 Report Structure

The report is organized into eight principal sections and covers the legislation and technical direction guiding the SMP (Chapter 2), field investigations and data collection (Chapter 3), technical analysis (Chapter 4), hazard mapping (Chapter 5), public engagement (Chapter 6), shoreline management recommendations (Chapter 7), and finally the study conclusions and recommendations (Chapter 8). The HCA shoreline has been divided into 8 shoreline reaches (sections of shoreline), with a summary of each reach provided in Appendix B. These summaries include a reach overview, ecosystem classification, shoreline classification, challenges associated with natural hazards, variables for hazard mapping, and shoreline management recommendations. Contact HCA for additional details not presented herein or for copies of the shoreline hazard mapping generated for this SMP.

1.3 Conversion 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 0.52 m from IGLD’85 to get CGVD2013
Convert IGLD’85 Elevation to CGVD28	Subtract 0.09 m from IGLD’85 to get CGVD28
Convert CGVD2013 Elevation to IGLD’85	Add 0.52 m to CGVD2013
Convert CGVD28 Elevation to IGLD’85	Add 0.09 m to CGVD1928

2.0 LEGISLATION AND TECHNICAL DIRECTION

The relevant legislation and technical documents that guide shoreline management and hazard mapping in Ontario are reviewed in the following sections.

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 governs 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. The Act provides that 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. A draft 2023 document is currently under review but not implemented at the time of this SMP preparation. The existing 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 PPS 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 shorelines. Existing 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.

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 humanmade 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, 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 of Ontario, municipalities and Conservation Authorities to work together”. It should also be noted that Section 3.1.3 of the PPS 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 Natural Resources, and Forestry (MNRF) was completing technical studies on new methods for the inclusion of climate change factors in regulatory hazard mapping. However, there is presently no published guidance on how to include the impacts of climate change when mapping the *flooding*, *erosion*, and *dynamic beach hazards* in Ontario.

2.2 Conservation Authorities Act and Ontario Regulation 97/04

The responsibility and mandate for Conservation Authorities (CAs) to regulate activities on hazardous lands is outlined in Section 28(1) of the *Conservation Authorities Act* (1990). If changes to the *Act* are made in the future, this SMP may require updating. 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 general 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.

- 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:

- **Flooding Hazard:** the 100-year flood level plus an allowance for wave uprush and other water related hazards.

- **Erosion Hazard:** the future shoreline position accounting for shoreline recession over a 100-year planning horizon plus a stable slope allowance.

- **Dynamic Beach Hazard:** the shoreline area susceptible to profile changes due to wind and wave action on the shoreline, delineated as the *flooding hazard* plus an additional 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 development is not impacted by natural hazards and the control of flooding, erosion, dynamic beaches, pollution or the conservation of land will not be affected by the development.

2.2.1 Hamilton Conservation Ontario Regulation 161/06

Ontario Regulation 161/06 provides the HCA with the authority to regulate development, interference with wetlands, and alterations to shorelines and watercourses. The regulation was originally approved on May 4, 2006. Commensurate with the CA Act (discussed above), development is prohibited on the lands adjacent to the shoreline of Lake Ontario and Hamilton Harbour that may be affected by flooding, erosion, or dynamic beaches based on the furthest landward extent of the following:

- The 100 year flood level, plus the appropriate allowance for wave uprush and other related hazards.
- The predicted long term stable slope projected from the existing stable toe of the slope or from the predicted location of the toe of the slope as that location may have shifted as a result of shoreline erosion over a 100-year period.

- Where a dynamic beach is associated with the waterfront lands, an allowance of 30 metres inland to accommodate dynamic beach movement.
- An additional allowance of 15 metres inland.

The inland extent of the furthest landward limit of the three hazards and an additional 15 m allowance is collectively known as the 'Regulation Limit'. HCA may grant permission for development in or on the regulated lands if, in its opinion, the development is not affected by the hazards, and the control of flooding, erosion, dynamic beaches, pollution, or the conservation of land will not be affected by the development.

2.3 Guidance Documents

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

2.3.1 Technical Guide 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). The potential release date for the updated document is unknown.

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:

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

- **Erosion Hazard:** 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 Hazard:** in the absence of detailed technical information, the dynamic beach extent is the cumulative horizontal setback that includes the 100-year flood level, the 15 m wave uprush limit, and an additional 30 m allowance for the dynamic nature of beach movements.

3.0 FIELD INVESTGIATION AND DATA AQUISITION

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

3.1 Oblique Aerial Photographs and Site Observations

More than 1,100 oblique aerial photographs of the HCA shoreline were captured during April 2022 using an unmanned aerial vehicle (UAV). The photographs were geotagged and compiled into a georeferenced photographic database covering the entire HCA shorelines on Lake Ontario and within Hamilton Harbour. The photo database was an important source of information for the characterization of the project shoreline and the development of a shoreline inventory, as discussed in Section **Error! Reference source not found.**. The photo database also provided the study team with the ability to view and assess portions of the shoreline that would otherwise have been largely inaccessible by land, due to private land ownership or physical constraints. Figure 3.1 provides a map showing the locations of all geotagged photographs captured for the project.

Figure 3.1 Locations of the 1,100+ georeferenced aerial oblique photographs of the HCA shoreline captured for the project

The UAV used to capture the 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 above lake level, a horizontal distance of 60 – 100 m offshore, and with shore parallel spacing of individual images established such that overlap between subsequent photos was generally achieved. This allowed for complete coverage of the HCA shoreline of Lake Ontario and Hamilton Harbour with sufficient resolution to assess the shoreline characteristics including the presence, condition, and type of shoreline protection structures. Where appropriate, images were captured from a higher elevation to provide an increased range of view. This included areas such as the Hamilton Port Lands and Cootes Paradise which features a largely natural, undeveloped shoreline. Sample photographs of the HCA shoreline from the compiled photo database are provided in Figure 3.2 to Figure 3.5.

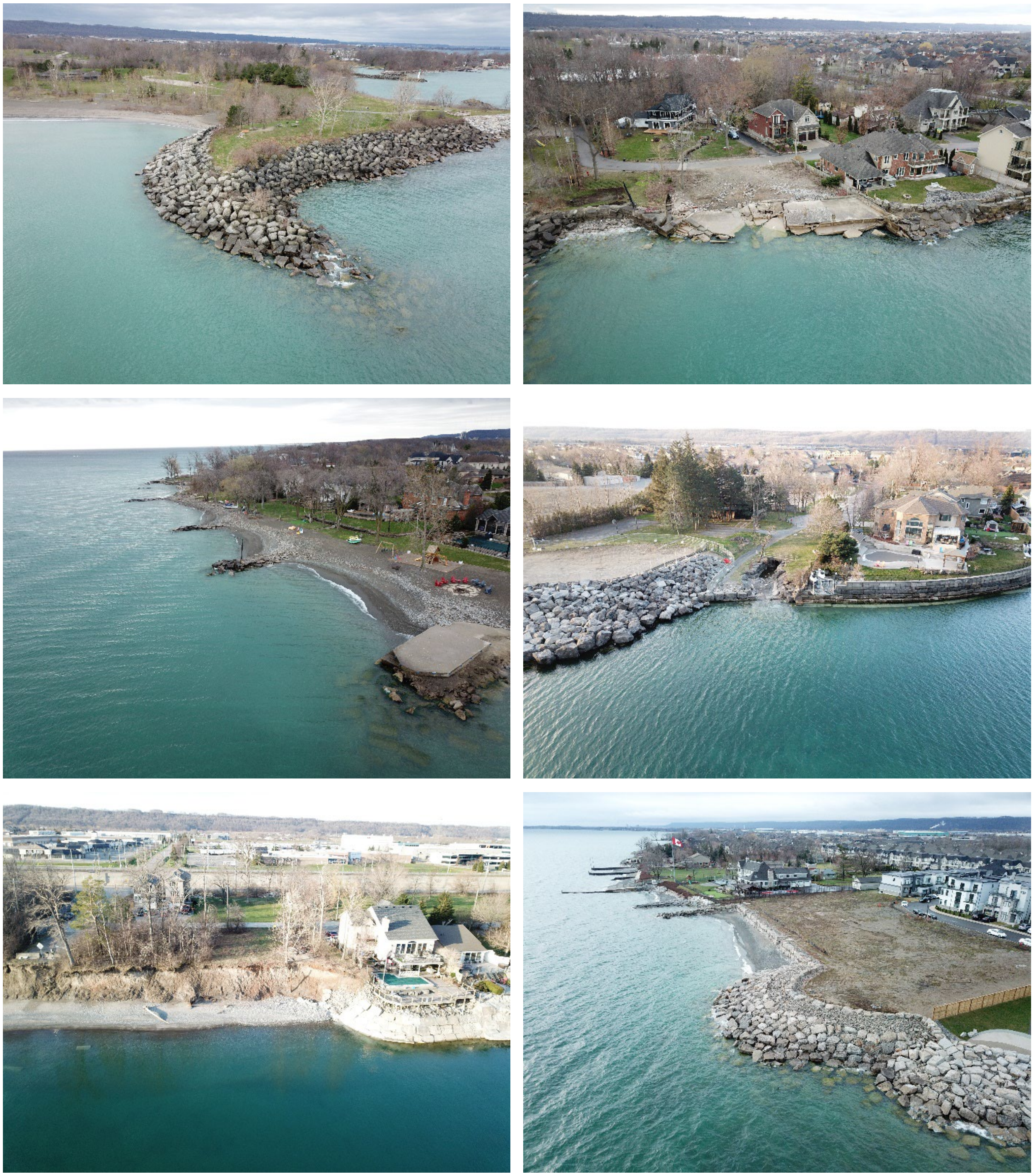

Figure 3.2 Sample photographs from the HCA shoreline photographic database between Fifty Point and Jones Road (Stoney Creek)

Figure 3.3 Sample photographs from the HCA shoreline photo database between Jones Road (Stoney Creek), and Hamilton Beach

Figure 3.4 Sample photographs of Hamilton Beach from the HCA shoreline photo database

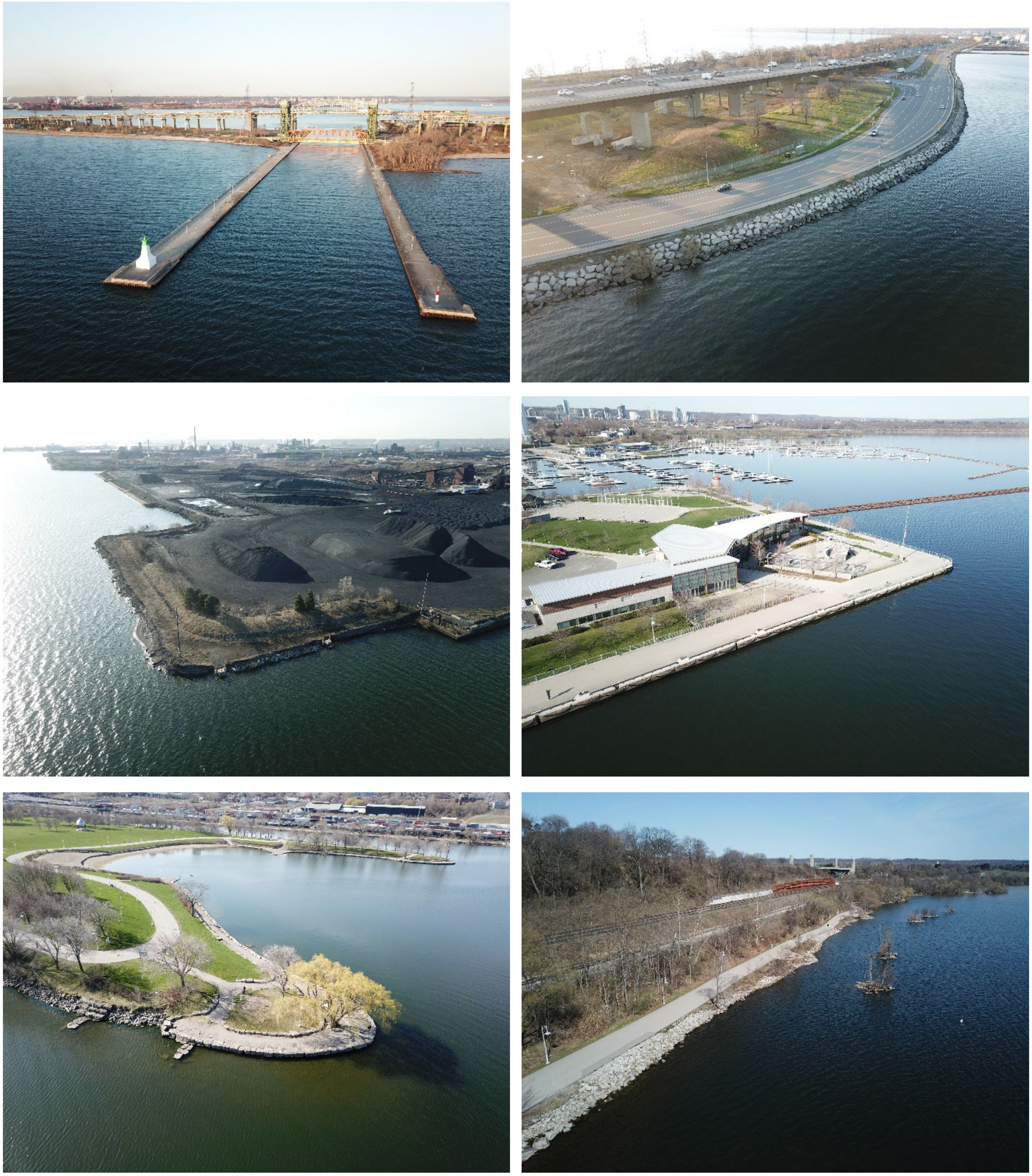

Figure 3.5 Sample photographs from the HCA shoreline photo database within Hamilton Harbour

3.2 Bathymetric Data

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

3.2.1 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 available for the Lake Ontario and Hamilton Harbour shorelines.

NONNA-10 bathymetry was downloaded as tiled raster datasets and then mosaiced to form a single raster (Figure 3.6). This raster was used to extract offshore bathymetry profile data as well as to generate bathymetric contours for mapping.

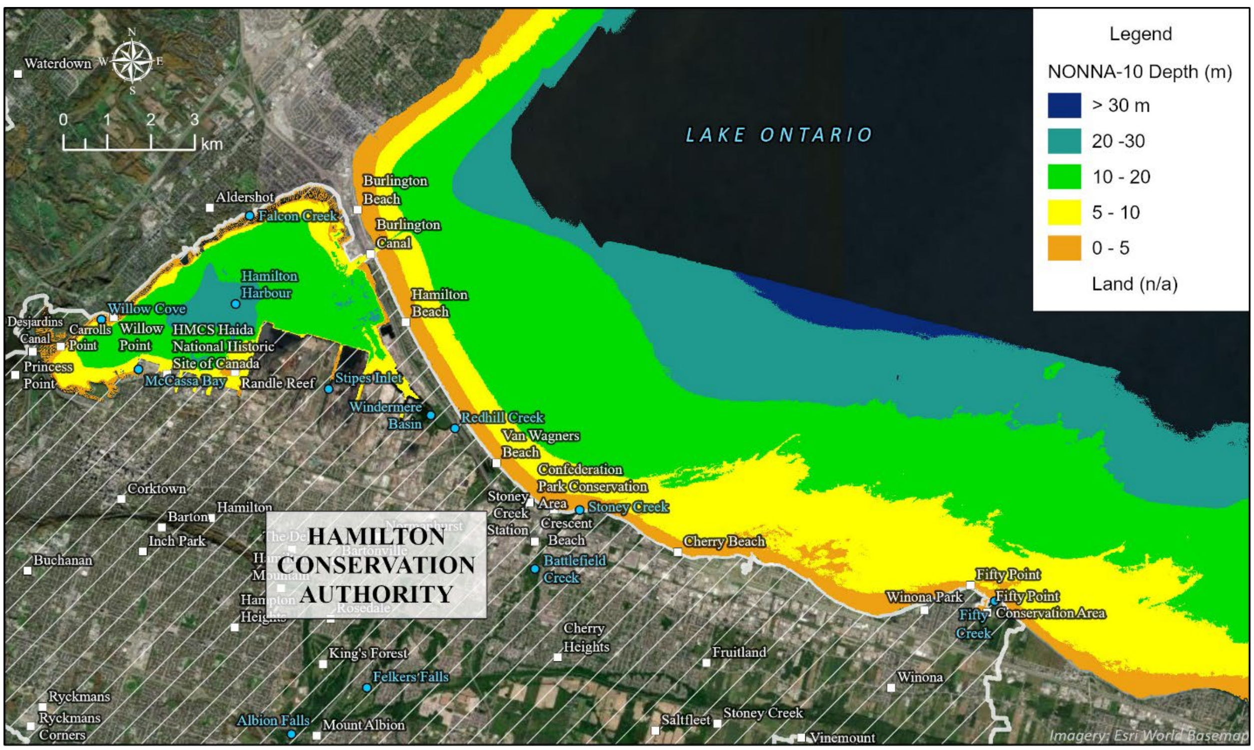

Figure 3.6 CHS NONNA-10 bathymetry

3.2.2 Summer 2022 Nearshore Survey

Staff from Zuzek Inc. conducted a nearshore bathymetry survey from September 17-18, 2022. The raw data was collected with a SOLIX, 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 3.7. The unit autocorrects for the depth of the transducer below the lake surface, with depths recorded every second.

Figure 3.7 SOLIX data collection unit and transducer mount

A total of 29 recordings were collected within the project study area. See Figure 3.8 for an overview of the bathymetry data collected.

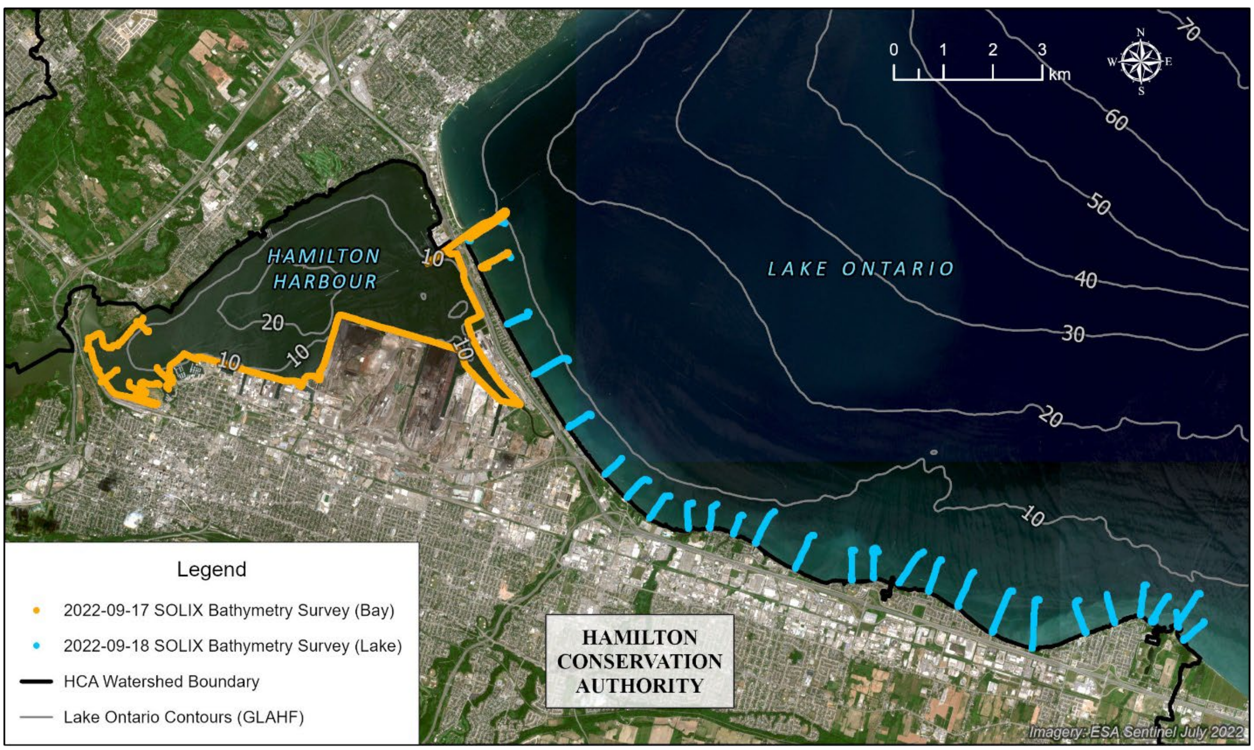

Figure 3.8 August 2021 SOLIX bathymetry survey

The depth readings for each survey were corrected using an average of hourly measured water levels for the day of the survey, from the Burlington water level gauge (#13150) acquired from the Government of Canada (Fisheries and Oceans) water level website. 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 in on Sept 18, 2022, was 74.58 m IGLD'85, taken from the

Burlington gauge. A SOLIX depth of -1.5 m would translate to a corrected elevation of 73.08 m (74.58 + (-1.5)).

The hourly water level data for Burlington can be found here: https://tides.gc.ca/en/stations/13150/

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 3.9 at the Fifty Point headland. In the downward imaging (right), individual armour stones at the toe of the headland are visible transitioning to a sand bottom further offshore. The cross-section (middle) records the armour stone and sand lake bottom. The boat location is noted in the left panel.

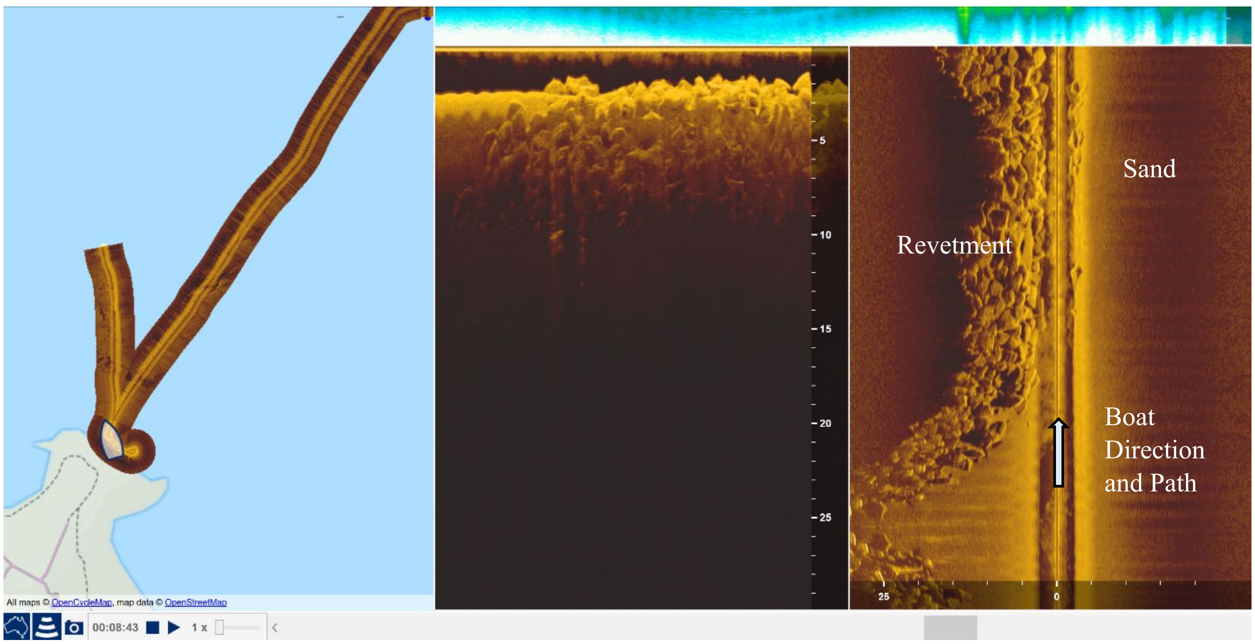

Figure 3.9 Sonar imaging of lake bottom at Fifty Point

3.3 2021 Topographic LiDAR

Topographic LiDAR was collected in the Spring of 2021 by Natural Resources Canada (NRCan) as part of a national strategy to increase coverage of high-resolution elevation data across the country. This dataset and derivative products are available to download through the Canadian Open Government website (https://open.canada.ca/data/en/dataset/957782bf-847c-4644-a757-e383c0057995).

The 2021 LiDAR acquisition is the most recent LiDAR collection that provides complete coverage of the Lake Ontario shoreline and Hamilton Harbour. Digital Terrain Model (DTM) raster products were downloaded from Open Government and mosaiced into one raster covering the study area (Figure 3.10). The DTM's have a horizontal resolution of 1 metre and elevations are referenced to the Canadian Geodetic Vertical Datum of 2013 (CGVD2013). The DTM mosaic was converted to an IGLD'85 vertical datum by adding 0.52 m to all elevations within the DTM. Refer to Section 3.3.1 for additional information on vertical datum conversions.

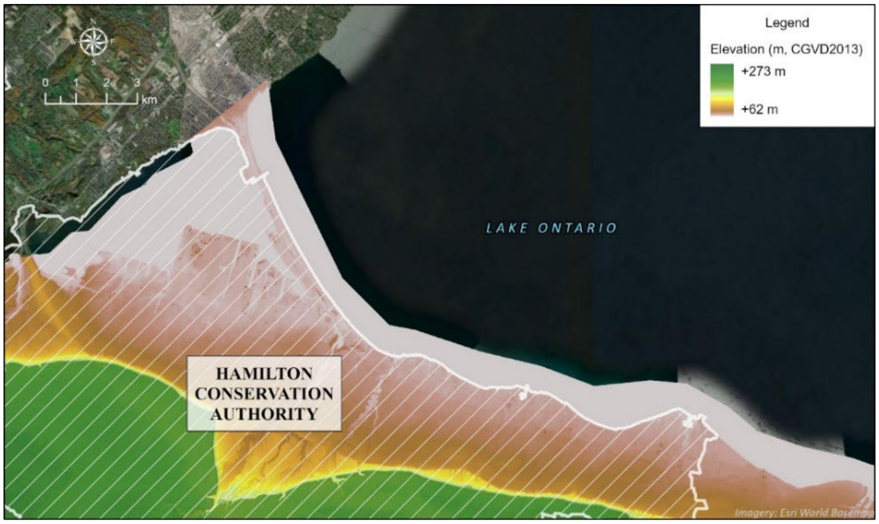

Figure 3.10 NRCan 2021 LiDAR elevation coverage

3.3.1 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 the HCA watershed and surrounding areas 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 52 cm higher than the CGVD2013 datum. The IGLD'85 datum is an average of 9 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)
UniqueNo	Location	Easting	Northing	Zone	CGVD2013 (m)	CGVD28 (m)	IGLD85 (m)	IGLD85 - CGVD13	IGLD85 - CGVD28
XXU9555	Burlington pier (SE side)	597941.6	4794838.0	17	75.91	76.34	76.44	0.53	0.10
91U003	Hydro tower	598878.4	4792414.1	17	76.17	76.60	76.69	0.53	0.09
65U076	Pumping station	591700.5	4791418.4	17	79.17	79.61	79.70	0.52	0.09
65U138	Concrete bridge	599583.6	4790752.0	17	77.10	77.55	77.63	0.52	0.08
61U9508	Sewer drain, N of QEW	601804.9	4788785.6	17	78.57	79.02	79.10	0.52	0.08
75U182	Reg. Road 50 bridge over QEW	610787.8	4785704.8	17	90.83	91.28	91.35	0.52	0.07
75U004	Ontario Hydro office	586344.5	4791348.1	17	79.85	80.28	80.37	0.52	0.09
74D8493	Fruitland Road	605727.8	4787179.3	17	82.77	83.22	83.29	0.52	0.07
643001	Pier, north side of ship canal	597265.1	4794529.9	17	76.08	76.52	76.62	0.53	0.10
							Average Difference (m):	**0.52**	**0.09**

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

3.4 Shoreline Characterization and Reaches

To map hazards and develop shoreline management recommendations, the shoreline geology, geography, presence of significant natural features, and type of ecosystem was used to characterize the HCA shoreline and develop nine reaches as described in the following sections.

3.4.1 Geology

Mapping of the surficial sediment for the study area is available from the Ontario Geological Survey (2010). Refer to the map in Figure 3.11. Areas with bedrock exposures, such as the Niagara Escarpment, are not mapped. The shoreline from Fifty Point to Confederation Park features sediment that was deposited during previous glacial periods, such as glacial till (consolidated cohesive sediment that forms at the base of glaciers). The shoreline from Confederation Park to the federal navigation channel consists of lacustrine sediment, sands and gravels, deposited in the modern lake environment (the existing post-glacial period). These sediments were eroded from the shore and lake bottom and transported northwest to form the historical barrier bar that separated Hamilton Harbour from Lake Ontario. The port lands on the south shore of Hamilton Harbour were constructed of lake fill, classified as fluvial sediment. Finally, the southwest and west shorelines of Hamilton Harbour feature glaciolacustrine sediment, deposited in lake environments during glacial periods.

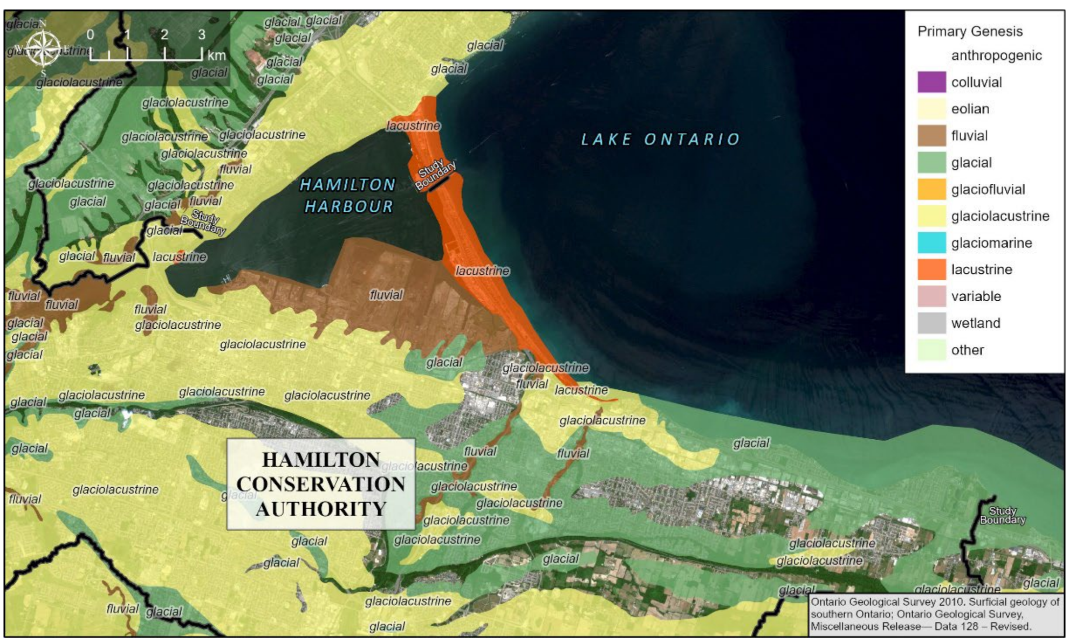

Figure 3.11 Surficial Geology of Southern Ontario (Ontario Geological Survey, 2010)

3.4.2 Littoral Cells and Sediment Transport

Lake Ontario littoral cells were identified and described by Reinders (1988) using available information. The Lake Ontario HCA shoreline from Fifty Point to the federal navigation channel is part of a large littoral cell that historically extended from Jordon Harbour to the Burlington Bar (the bar is now divided by the navigation channel and referred to locally as Hamilton Beach and

Burlington Beach). It is important to note the Reinders report is more than 35 years old and was based on even older physical information. Based on current site observations, it would appear this original large littoral cell (42 km in length) has now been broken into smaller sub-cells by lakefill projects (e.g., Fifty Point) and other shoreline infrastructure such as the jetty at the Newport Yacht Club.

The Reinders report (1988) suggests that about 50% of the shoreline was armoured by 1981. Estimates from the 2022 orthophotographs suggest this percentage is much higher today for the HCA shoreline from Fifty Point to Confederation Park (see Appendix A for further details).

While the information presented by Reinders in 1988 is quite dated, there is some relevant historical information for the SMP. First, the primary source of new sand and gravel in the littoral cell was natural bank and lakebed erosion. Waves and currents historically transport this sediment from Jordon Harbour west to the Burlington Bar. Today, the historical littoral cell is sub-divided into a series of much smaller sub-cells and the overall sediment supply to the depositional end of the littoral cell, namely the Burlington Bar (i.e. Hamilton Beach), has been dramatically reduced.

3.4.3 Significant Natural Features

The presence of significant natural coastal features along the HCA shoreline was assessed with the Great Lakes Shoreline Ecosystem (GLSE) inventory. The dataset provides polygon coverage of land conditions at different scales, from an ecological and habitat perspective. The polygons associated with the community scale classification are provided in Figure 3.12 for Hamilton Beach (Reach 4). The narrow beach shoreline is mapped as the yellow polygon at the waters edge. Marsh, meadow, and shrubland associated with Redhill Creek are also mapped. However, inland of the shoreline class, the majority of the lands are classified as constructed (black hatching). This constructed class is for hardened surfaces (e.g., roads, driveways), buildings, and landscaped terrain.

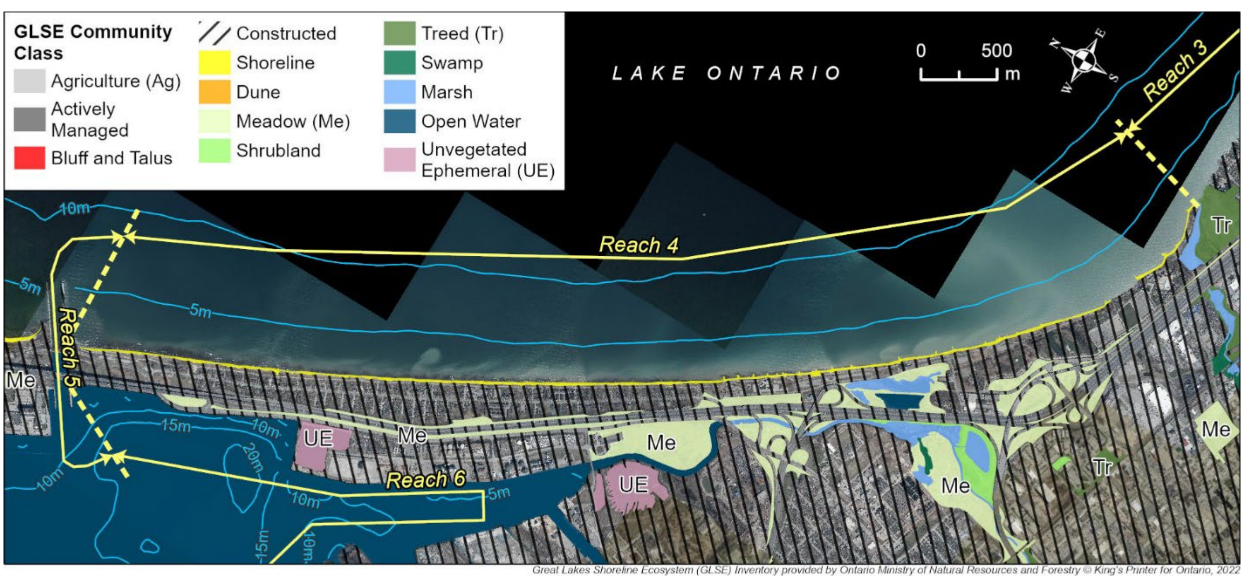

Figure 3.12 Reach 4 shoreline ecosystem mapping from MNRF

3.4.4 Reach Boundaries

Nine shoreline reaches were defined for the HCA shoreline following the field work in Spring 2022 and assessment of wave energy exposure, shoreline and nearshore geology, shoreline morphology, physical processes such as erosion and sediment transport, development type and density, and shoreline ecosystem mapping from the GLSE mapping. The results are mapped in Figure 3.13. The reaches are introduced below and full summaries including maps of the reach limits, the shoreline ecosystem conditions, statistics on shoreline armouring, exposure to natural hazards, and the shoreline management recommendations for each are provided in Appendix A.

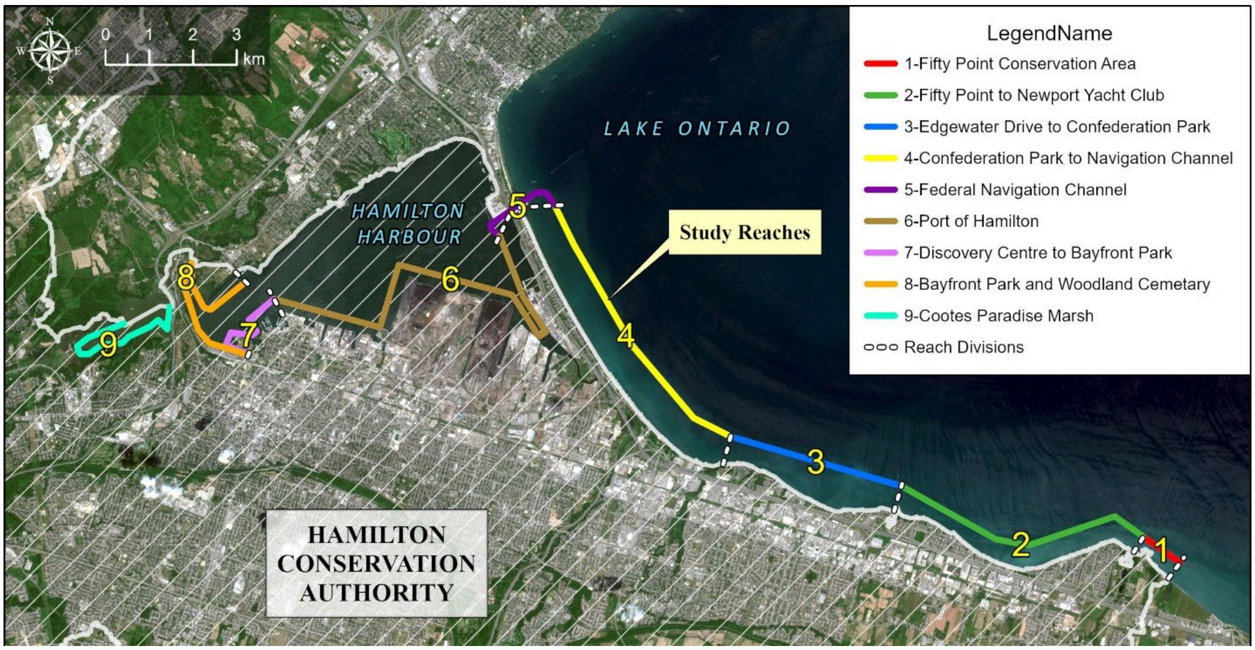

Figure 3.13 Reach boundaries for SMP

- **Reach 1 – Fifty Point Conservation Area**: The easternmost reach of the SMP begins at the east HCA boundary and includes the beach, artificial headland and marina basin of the Fifty Point Conservation Area.

- **Reach 2 – Fifty Point to Newport Yacht Club**: Reach 2 features extensive residential development and shoreline armouring between the Fifty Point Conservation Area and the Newport Yacht Club.

- **Reach 3 – Edgewater Drive to Confederation Park**: Reach 3 features a mixture of single family and multi-unit residential development and extensive shoreline armouring.

- **Reach 4 – Confederation Park to Navigation Channel**: Reach 4 is predominantly a sandy shoreline with some groins in the southern portion that influence beach stability and some beach-curb type structures protecting landside development including a mixed-use pathway.

- **Reach 5 – Federal Navigation Channel**: The federal navigation channel is contained within Reach 5 and the HCA has limited jurisdiction in this area.

- **Reach 6 – Port of Hamilton**: The port lands of Hamilton Harbour are contained within Reach 6.

- **Reach 7 – Discovery Centre to Bayfront Park**: Reach 7 features multiple public access nodes to the harbour, including the Discovery Centre, marinas, and Bayfront Park.

- **Reach 8 – Bayfront Park and Woodland Cemetery**: The armoured waterfront trail defines the southeastern portion of Reach 8, while the northern half features mostly natural shoreline conditions and the vegetated bluffs adjacent to the Woodland Cemetery.

- **Reach 9 – Cootes Paradise Marsh**: The Cootes Paradise Marsh and surrounding Nature Sanctuary define Reach 9.

3.4.5 Shoreline Hardening

A comprehensive shoreline inventory was developed as a component of the study to document the state of the HCA shoreline as of April 2022. 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. Each shoreline segment added to the shoreline inventory 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, prominent headland, wetland, tributary, emergent shoal, etc.

- **Shoreline protection type (for hardened shorelines):** primary and secondary (where applicable) shoreline protection structure (i.e. armour stone revetment, precast concrete seawall, stacked armour stone seawall, sheet pile seawall, ad-hoc stone bank protection, groyne, etc.)

- **Level of design (for hardened shorelines):** a description of the overall level of design of the shoreline protection structure (i.e. well-engineered, moderately engineered, ad-hoc, etc.)

- **Overall structure condition (for hardened shorelines):** description of the overall structure condition (i.e. excellent, good, moderate, poor, or failed)

- **Other significant shoreline infrastructure**: presence of other significant shoreline infrastructure such as an outfall, permanent dock, boat ramp, marina, etc.

The completed database was used to assess statistics pertaining to the project shoreline. Statistics were tabulated for each project reach and for the total project shoreline. Refer to Section 3.4.4

for the delineation of project reaches. Of the approximately 55 km of documented shoreline, roughly 29 km was deemed to feature some form of shoreline protection, representing 53% of the total project shoreline. The remaining 47% of the shoreline was deemed to be in a predominantly natural state. For the largely privately owned Lake Ontario shoreline from Fifty Point to Confederation Park (Reaches 1 – 3), the percentage of armoured shoreline is roughly 85%. Within Hamilton Harbour (Reaches 6 – 8), approximately 72% of the shoreline is armoured, largely due to the extensive port lands that exist along the Hamilton Waterfront. The ratio of hardened versus natural shoreline varies significantly from reach to reach in conjunction with the level of development. Reaches 3 and 7 both featured shorelines that are nearly 95% armoured. By contrast, Reach 4 (Hamilton Beach) and Reach 9 (Cootes Paradise) are only 10% and 2% armoured, respectively. Additional details on shoreline hardening within each project reach are documented in the reach summaries provided in Appendix A.

4.0 TECHNICAL ANALYSIS

The technical work completed for the SMP to map coastal hazards is summarized in Section 4.0, including the shoreline change assessment, storm surge analysis, and wave modelling.

4.1 Shoreline Change Assessment

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.

4.1.1 Historical Aerial Photos

Aerial photo coverage of the study area was provided by the HCA for three temporal periods: April 1967, June 1990, and April 2020 (SWOOP2020). The 1967 aerial photos are black and white and have scale of approximately 1:10,000 (see Figure 4.1). The 1990 aerial photos are colour and have a scale of 1:20,000 (refer to Figure 4.2). The SWOOP2020 photos are high resolution colour and have a ground resolution of 16 cm (presented in Figure 4.3).

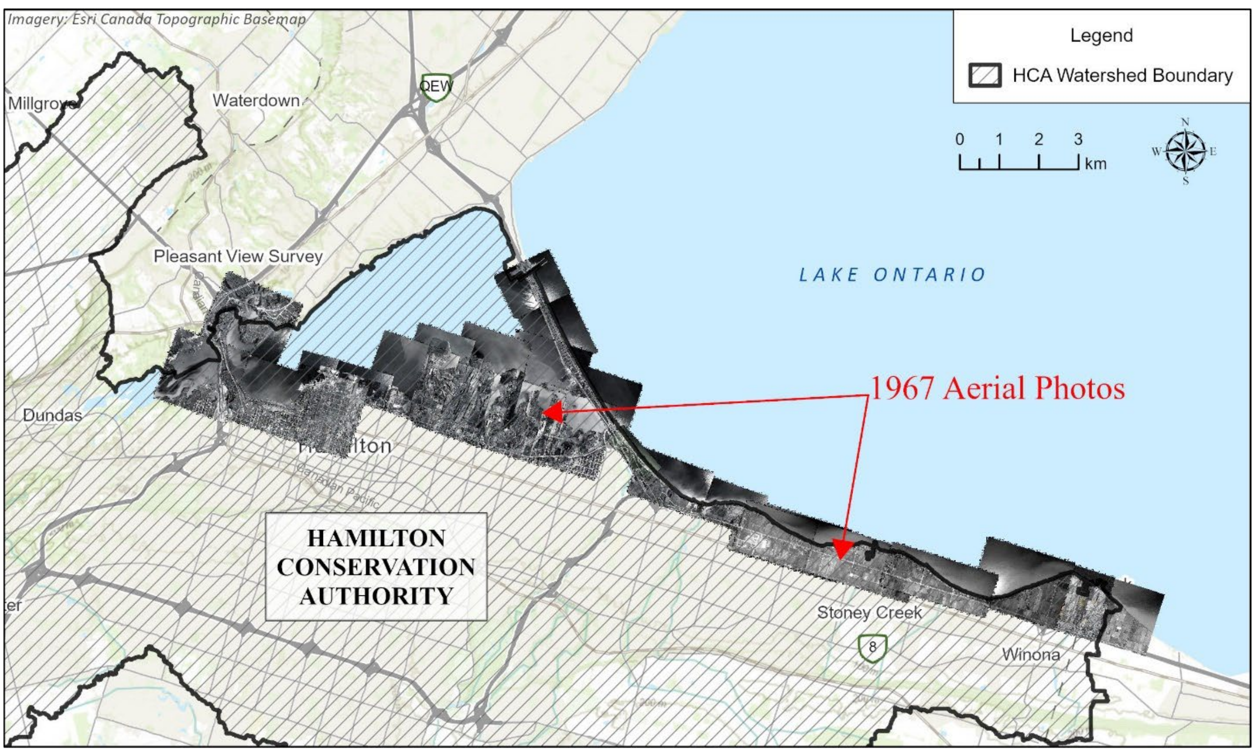

Figure 4.1 1967 aerial photo coverage

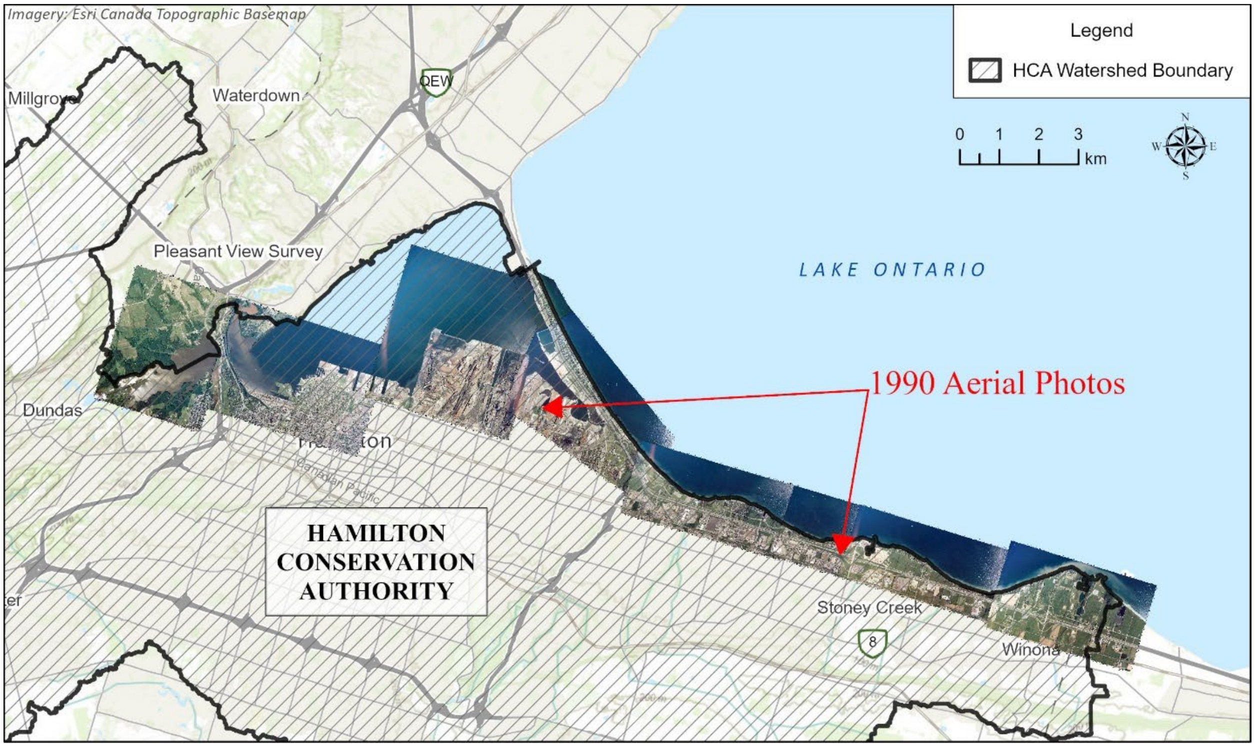

Figure 4.2 1990 aerial photo coverage

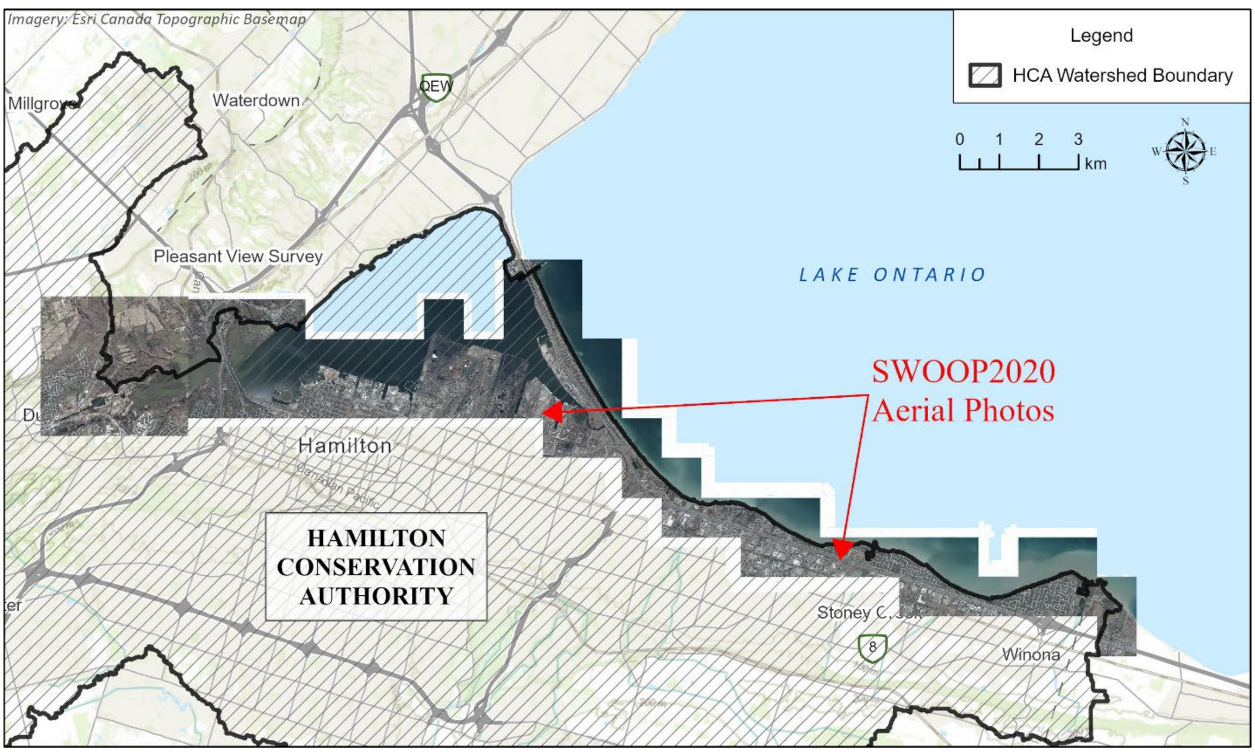

Figure 4.3 2020 aerial photo coverage

4.1.2 Georeferencing Historical Aerial Photographs

Zuzek Inc. obtained additional aerial photos dated 1934 and 1952 from the McMaster University Library, online access. Coverage for the 1934 period was limited to the Van Wagner's beach area, while coverage for 1952 was limited to a stretch of shoreline near Lewis Road and the QEW.

The 1934 and 1952 photos were geo-referenced with ArcGIS software primarily using 2020 orthophotographs as the base imagery. In some cases, the 1967 and 1990 orthophotos were used in conjunction with 2020 photos. 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 for 1934 and 1952 are 2.1 m and 1.1 m respectively. 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, the horizontal error is divided by the temporal period of the shoreline change analysis. For example, the 1.1 m RMS error for the 1952 photo series in Reach 1 translates to a potential annualized error of 0.02 m/yr when comparing shoreline positions to the 2020 orthophotograph. Provided the rate of change from 1952 to 2020 is greater than 0.02 m/yr, there is confidence in the rate. If the RMS error for a specific period, once annualized to a rate of change, was greater than the actual erosion measurement between the photos (e.g., 1952 to 2020), the photograph was not used in the shoreline change analysis.

An example of the registration process for a historical aerial photo is illustrated in Figure 4.4. The yellow arrows point to the ground control used, which are the red X's. 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.

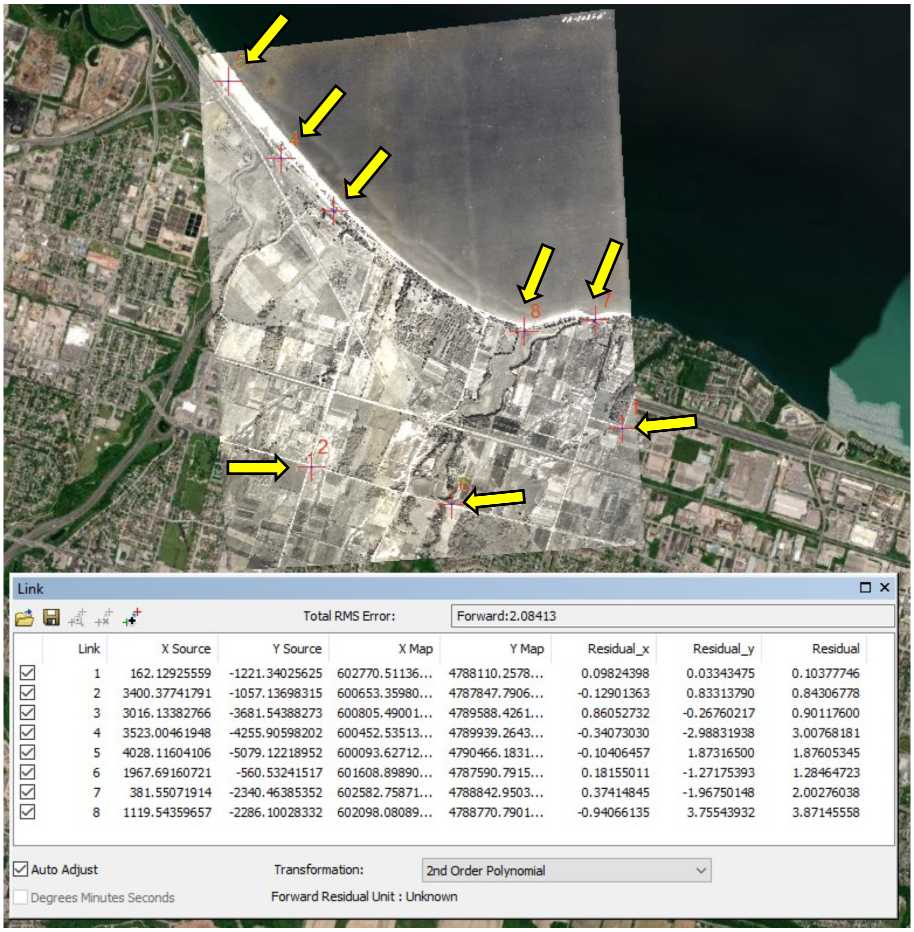

Figure 4.4 Ground control selection during photo registration

4.1.3 Long-term Recession and Accretion Rates

The project shoreline was reviewed in GIS to identify areas suitable for measuring long-term shoreline change rates. This involved visual checks of possible shoreline and land use changes between historic aerial photos and the 2020 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. The 2021 topographic LiDAR discussed in Section 3.3 was used to derive a top of bluff position at the Lewis Road site. Historical measurements from Cherry Beach were documented in an International Joint Commission report (Baird, 2006) which relied on top of bluff position data prior to shoreline armouring at the site. Refer to Section 4.1.4 for additional details.

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 1952 photo and 2021 LiDAR was 10 m, then the annualized rate is 0.14 m (10 / (2021-1952)).

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 (Zuzek et al, 2003). The long-term recession rate for an area was based on the sum of the AARR and one annualized standard deviation. Erosion transects for a section of eroding bank shoreline at Lewis Road are presented in Figure 4.5. Transects were generated for three temporal periods: 1952 to 1990, 1990 to 2015, and 2015 to 2021. For 1952 to 1990, there are 20 transects that featured an AARR of 0.11 m/yr and an annualized standard deviation of 0.04 m/yr. The long-term recession rates for mapping the erosion hazard would therefore be 0.15 m/yr. For the 1990 to 2015 period, the AARR plus one annualized standard deviation was 1.09 m/yr. From 2015 to 2021, the AARR plus one annualized standard deviation was 1.44 m/yr. As expected, the standard deviation was highest over the shortest temporal period from 2015 to 2020.

When the recession transects were evaluated for the period from 1990 to 2021, the AARR was 0.96 m/yr and the annualized standard deviation was 0.20 m/yr, resulting in a long-term recession rate for mapping the erosion hazard of 1.16 m/yr.

Figure 1.1 Hamilton Conservation boundary

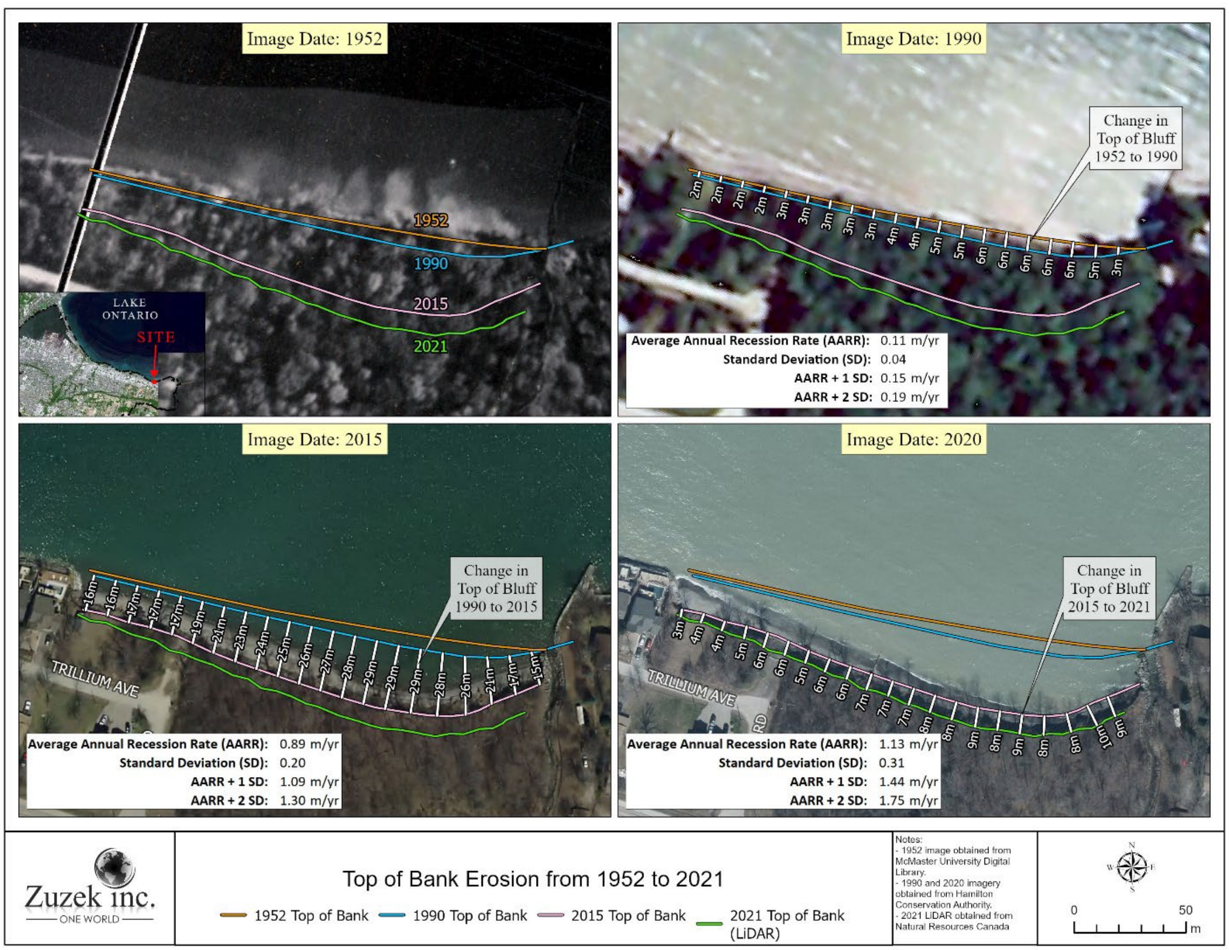

Figure 4.5 Top of bank transects for the 1952 to 1990, 1990 to 2015, and 2015 to 2020

Due to the high degree of shoreline modifications and armouring in Hamilton Harbour, it was not possible to calculate reliable long-term recession rates. Minor bluff erosion at Woodland Cemetery was observed during the boat survey but a rate of change could not be measured due to the dense vegetation on the slope in the imagery and the presumed low rate of recession. Expert judgement was used to establish a long-term recession rate of 0.1 m/yr or 10 m for the 100-year planning horizon that considers local soils and the wave climate in the harbour. This approach is consistent with other Shoreline Management Plans on Lake Ontario (Zuzek Inc., 2022).

4.1.4 IJC Cherry Beach Erosion Site

Cherry Beach was selected as a detailed study site for the International Joint Commission (IJC) water level regulation study for Lake Ontario and the St. Lawrence River (Baird, 2006). The conditions of the eroding bank in August 2003 were capture in an oblique photograph (Figure 4.6) prior do being armoured. The site in April 2022, photographed for this SMP, is presented in Figure 4.7. The long term recession rate at the site, from 1954 to 2002 was 0.53 m/yr. This rate provides valuable information on the historical rate of bank recession prior to armouring.

Figure 4.6 Oblique photograph of Cherry Beach on August 9, 2003 (note location of highway overpass)

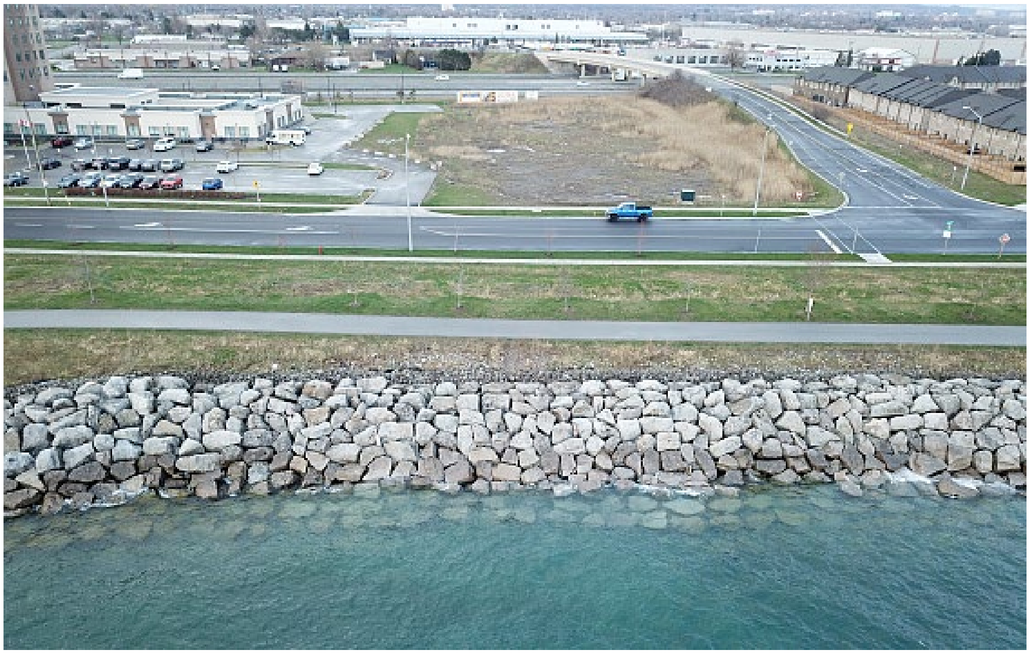

Figure 4.7 Armoured shoreline at Cherry Beach, April 2022 (note location of highway overpass)

4.1.5 Niagara Peninsula Conservation Authority SMP Update

The updated Niagara Peninsula Conservation Authority (NPCA) Shoreline Management Plan published measured recession rates for the shoreline adjacent to the eastern boundary of the HCA shoreline. Rates for this portion of shoreline published previously in 1994 were estimated at 1.3 m/yr. Based on updated technical analysis using aerial photographs from 1954 to 2006, the rates were modified to 1.2 and 0.8 m/yr for Reaches 1 and 2 respectively in the updated SMP.

While not within the HCA watershed, these rates were measured for the adjacent shoreline that features similar eroding bank conditions and wave exposure to the eastern end of the HCA shoreline. They provide defensible data on the erodibility of the glacial sediment banks for this region of Lake Ontario.

4.1.6 Shoreline Change Rates for Hamilton Beach

Shoreline change at Hamilton Beach has been influenced by human activities and infrastructure since the implementation of a navigation channel into Hamilton Harbour nearly 200-years ago. The first rock-filled timber crib jetties at this location were constructed in 1826 (Weeks-Mifflin and Mifflin, 1989). Moreover, the shoreline updrift of the beach in the littoral cell was 50% armoured more than 40 years ago (1981), so significant reductions in sediment supply have been a reality for many decades.

To evaluate changes in the beach position over the last 90 years, historical aerial photographs from 1934, 1952, 1967, 1990 were obtained and compared to the waterline position in 2020. The waterline positions were digitized for each period and adjusted to account for the Lake Ontario monthly mean water level at the time the photograph was taken (obtained from Fisheries and Oceans Canada). Refer to Table 4.1 for the photo date and corresponding monthly mean water level. The waterline position in each photo, except 1990, were corrected to a lake level of 75.14 m, which corresponds to the water level captured in the 1990 image. The 1990 image was selected as the base image since the water level at the time of photo acquisition was in the mid-range of the levels associated with the historical imagery and the photo was a high quality image. This process involves moving the waterline position inland if the lake level was lower than 75.14 m at the time the photo was taken (e.g., November 1934) and lakeward if the water level was higher than 75.14 m (e.g., April 2020) using an average beach slope of 1:10 (V:H). The beach slope was established by evaluating natural slopes using the 2021 topographic LiDAR. Table 4.1 provides the final horizontal correction made to the water line in each historical aerial photo.

Table 4.1 Water levels for aerial photos

Date	Monthly Mean Water Level (m, IGLD85)	Water Level Difference (m)	Slope	Horizontal Correction (m)
1934-07-30	74.14	1.00	1:10	10
1934-11-03	73.75	1.39	1:10	13.9
1952-05-01	75.72	-0.58	1:10	-5.8
1967-04-20	74.77	0.37	1:10	3.7
1990-06-11	75.14	0.00	1:10	0
2020-04	75.32	-0.18	1:10	-1.8

Reach 4 was subdivided into sub-reaches based on trends in the historical shoreline position, with 4-A corresponding to the southern portion of Reach 4, and 4-G corresponding to the northern portion of Reach 4 adjacent to the federal navigation channel. The historical shorelines corrected to the 1990 water level are presented in Figure 4.8 for Reach 4-E. While there were small erosion and accretion trends from 1934 to 2020, the shoreline position was generally consistent and determined to be dynamically stable within this portion of Hamilton Beach over the last several decades.

The waterline position for Reach 4-D, presented in Figure 4.9, show a clear erosion trend from 1934 to 1969, and again from 1990 to 2020. Reach 4-D is immediately downdrift (north) of the armour stone groin field built sometime prior to the 1967 aerial, which may be having a negative impact on this section of Hamilton Beach. Maps with the historical waterlines for the remaining sub-reaches are presented in Appendix B.

The observed shoreline trend, based on changes in the waterline position over the last several decades, is summarized for the eight sub-reaches within Reach 4 (Hamilton Beach) in Figure 4.10 below. One sub-reach (4-D) was classified as having a historical erosion trend, five were classified as dynamically stable, and one (4-G) featured both erosion and dynamic stability within the same sub-reach over the periods of comparison.

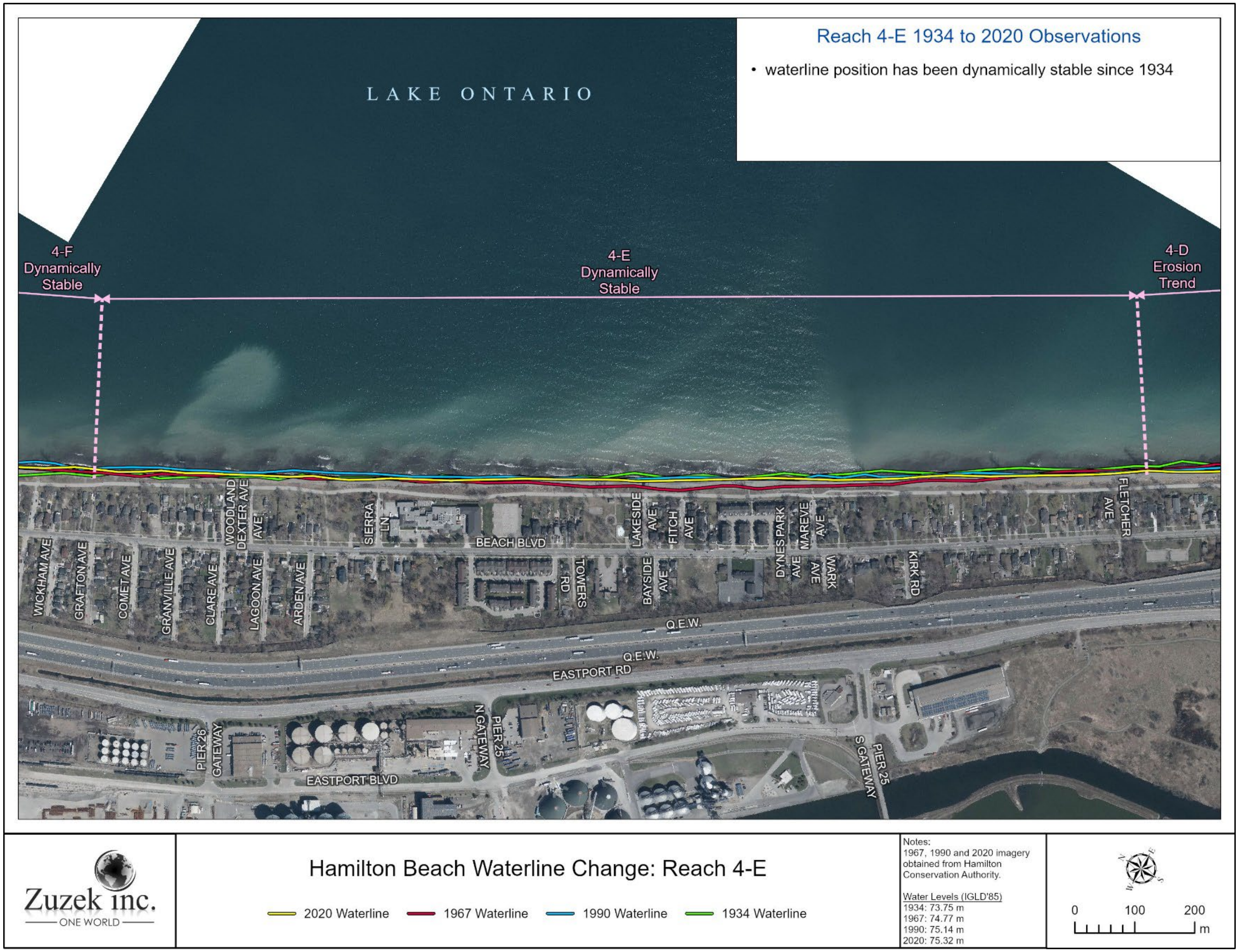

Figure 4.8 Dynamically stable shoreline in Reach 4-E

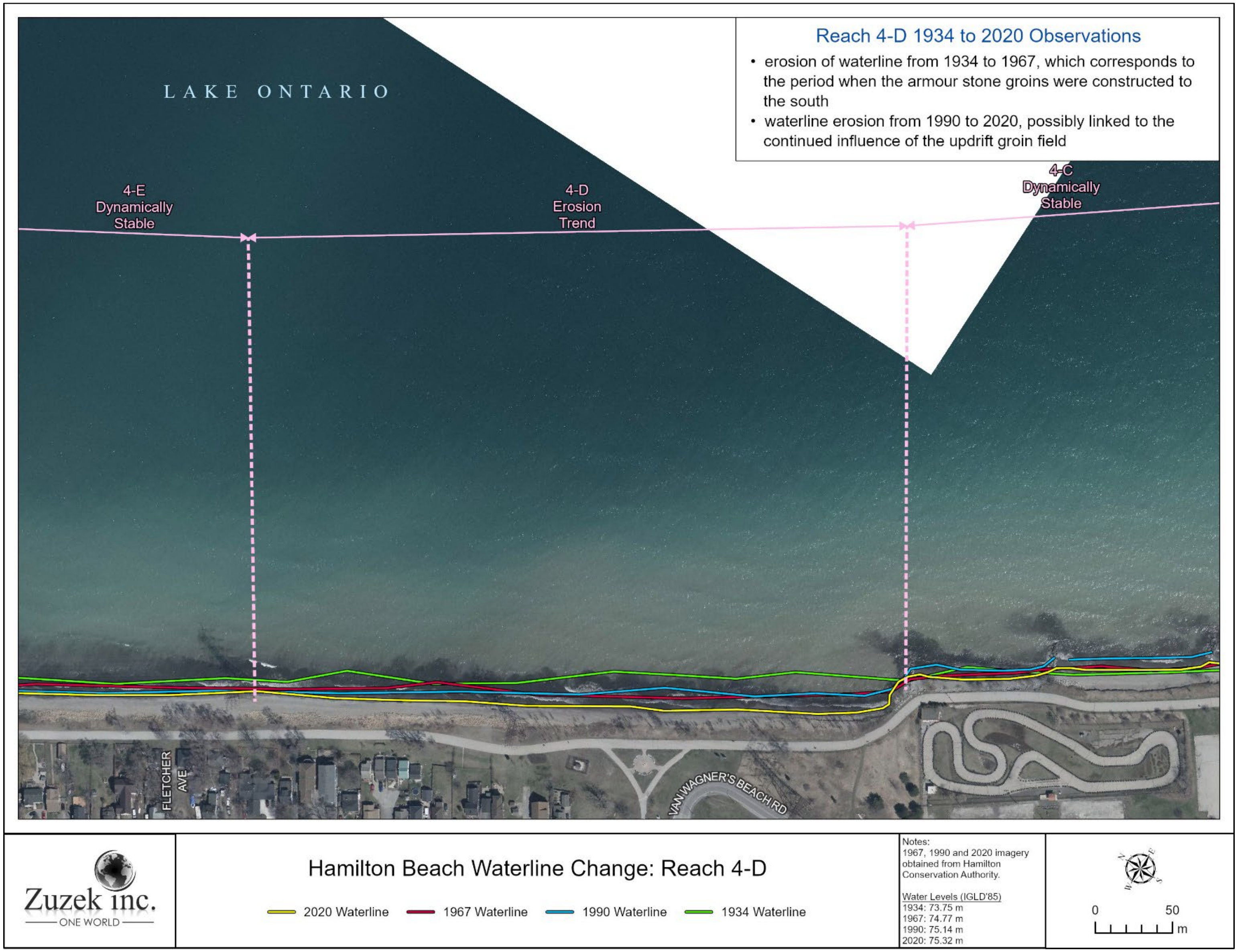

Figure 4.9 Eroding shoreline in Reach 4-D (downdrift of groin field)

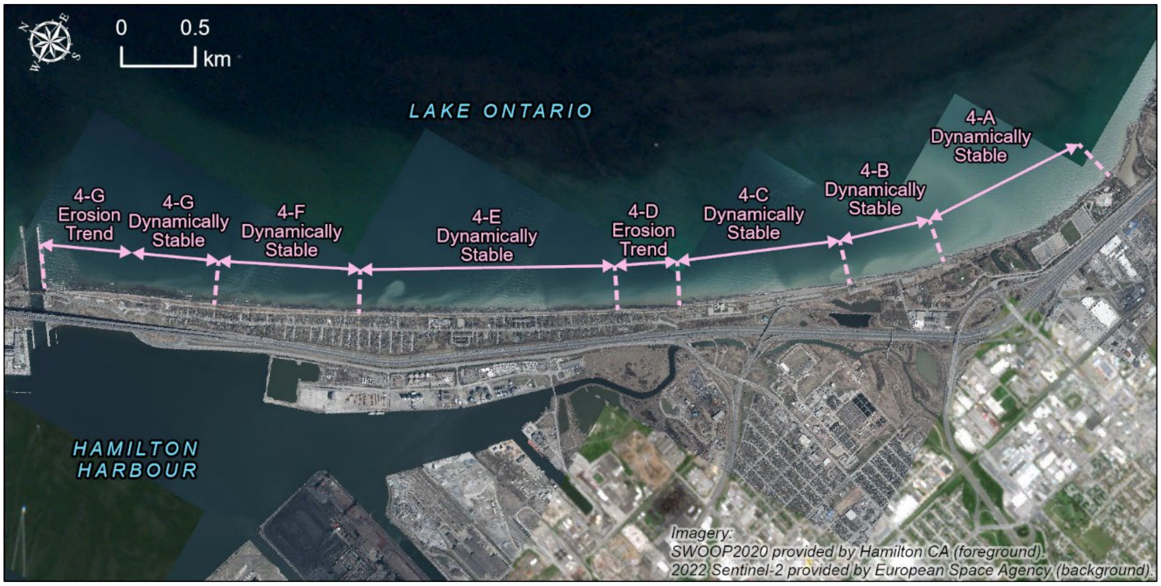

Figure 4.10 Summary of recent shoreline trend for Reach 4

4.1.7 Fillet Beach Volume Estimates

Waterlines were digitized for the fillet beaches at the Newport Yacht Club and Fifty Point using the 1967, 1990, and 2020 temporal periods. These years capture both pre- and post-construction conditions and illustrate the growth of the fillet beach at each location. The waterlines were corrected using the same method discussed in Section 4.1.6.

Refer to Figure 4.11 for an illustration of fillet beach evolution at Fifty Point. The exact date of the lake filling is unknown. The 1967 aerial represents a pre-construction condition, whereas the 1990 represents a post-construction condition with the fillet beach only partially developed. In 2020, the fillet beach is approaching full capacity. Using GIS, the growth in the footprint (area) of the fillet beach from 1967 to 2020 was estimated to be 17,700 m^2. The vertical difference in elevation between the lakeward toe of the fillet beach (in-water) and the landward top of the beach was estimated to be in the range of +6 to +7m. This represents a fillet beach volume between 106,000 m^3 to 124,000m^3.

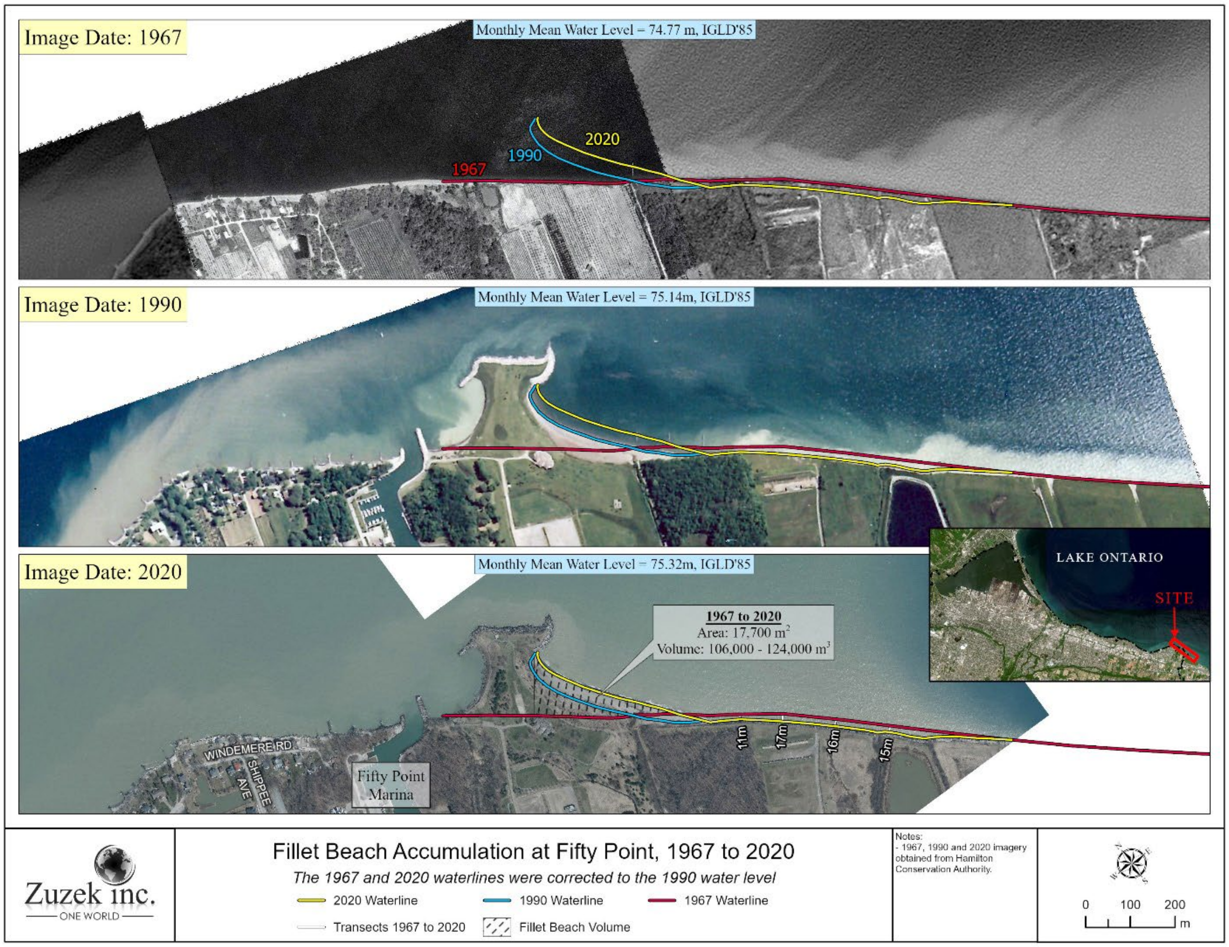

Figure 4.11 Fillet beach evolution at Fifty Point

Refer to Figure 4.12 for an illustration of the fillet beach evolution at the Newport Yacht Club. The exact date of construction of the rubble mound breakwater is unknown. The 1967 aerial represents a pre-construction condition. In 1990, the jetty was fully constructed but the fillet beach had not yet accumulated much sediment and appears to have eroded slightly landward of the 1967 waterline position. In 2020, the fillet beach is near full capacity and considered stable. Using GIS, the growth of the fillet beach from 1967 to 2020 in terms of its footprint (area) was estimated to be 12,900 m^2. The vertical difference in elevation between the lakeward toe of the fillet beach (in-water) and the landward top of the beach was estimated to be in the range of +4 to +5m. This represents a fillet beach volume between 51,000 m^3 and 64,000 m^3.

Figure 4.12 Fillet beach evolution at the Newport Yacht Club

4.1.8 Lake Bottom Erosion and Profile Comparisons

For the cohesive shorelines found in Reaches 1 to 3, erosion is not limited to the banks above water. The entire lake bottom erodes over time out to a depth of 8 to 10 m below chart datum. Since the eroded cohesive glacial sediment cannot reconstitute itself in the nearshore environment, lake bottom erosion is irreversible. Based on field work in Stoney Creek, Davidson-Arnott (1986) showed that the rate of lake bottom erosion increased in an onshore direction. For example, annual vertical downcutting (erosion) rates of 11 mm/yr were documented in 6.4 m water depth versus 35 mm/yr in 2.3 m water depth. The downcutting was attributed to several factors, including erosion by shear stresses associated with wave orbital motion, turbulence due to breaking waves, abrasion of the till surface by the movement of sediment particles, and softening of a thin surface layer by cyclic loading and unloading of the till surface due to the oscillatory nature of the wave motions (Davidson-Arnott, 1986).

Philpott (1983) calculated lake bottom downcutting rates on Lake Erie and also found that the rates increased in shallow water, where wave energy dissipation was greatest, and the nearshore profile geometry maintained a constant shape or morphology over time as the cohesive shoreline eroded inland. With the extensive development and construction of shoreline protection structures between Fifty Point and Confederation Park (Reach 1 to 3), the rate of horizontal shoreline recession has decreased. However, as depicted in Figure 4.13, the lake bottom continues to erode lakeward of shore parallel structures (top panel). Eventually, lake bottom downcutting undermines the shoreline protection and structures settle or fail (bottom panel). Within the study area, these types of failures lead to repairs, upgrades or new protection structures, with the relics of past infrastructure remaining on the lakebed. This cycle of structure repairs and failures will continue indefinitely, as the nearshore will continue to deepen, and progressively larger waves will impact the shoreline protection structures well into the future.

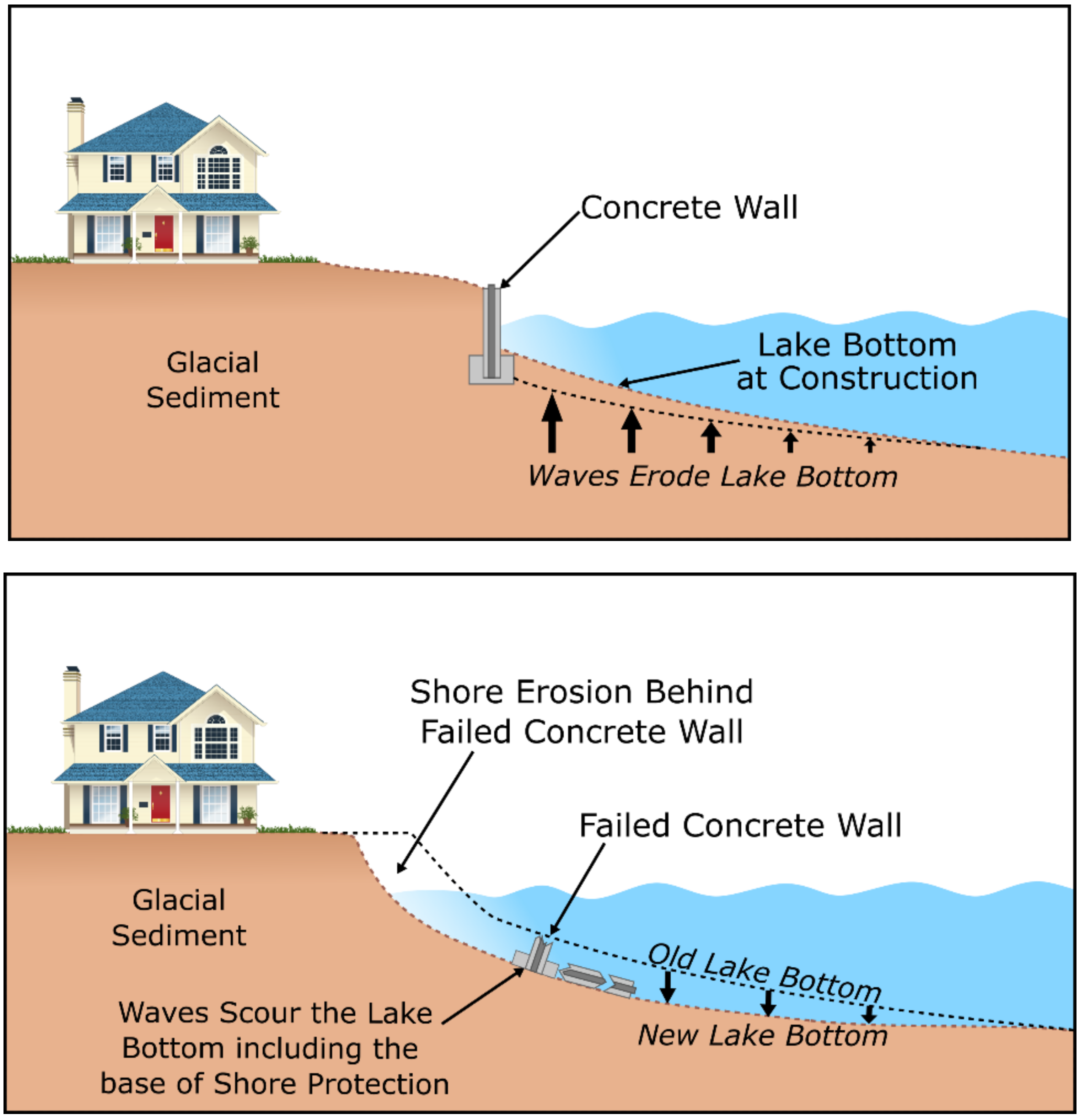

Figure 4.13 Influence of lake bottom downcutting (erosion) on shore protection structures

A sample of the September, 2022 lake bottom profile data collected for this study combined with the 2021 NRCan topographic LiDAR is presented in Figure 4.14 for the sandy fillet beach east of the Fifty Point headland (Reach 1). Other profiles are reviewed below to highlight the impacts of downcutting when shore protection is constructed along an actively eroding shoreline.

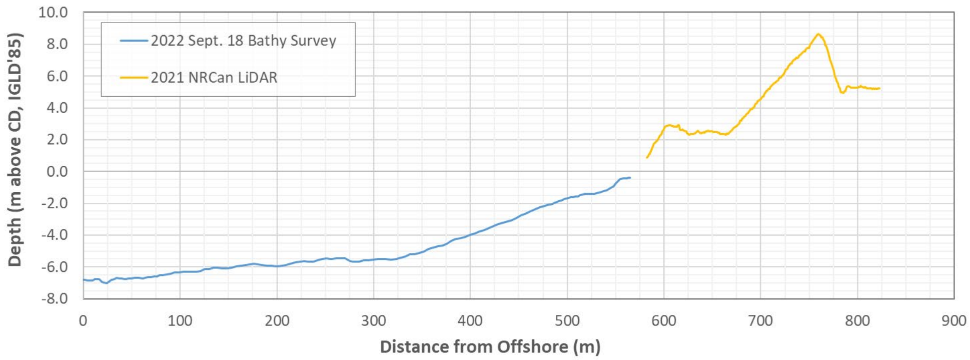

Figure 4.14 Profile 1 at Fifty Point Conservation Area Beach

An oblique photograph of the eroding bank at the foot of Lewis Road is presented in Figure 4.15. The combined lake bottom and bank profile (Profile 7) is plotted as the blue line in Figure 4.16. The profile features the classic concave shape of an eroding cohesive sediment shoreline, but one that is extremely deep in the nearshore. The Lewis Road site is compared to an eroding cohesive profile from Port Stanley on Lake Erie, which features a similar shape but with a much shallower nearshore. The deep nearshore at Lewis Road is further contrasted with Profile 8B from the Maitland Valley CA, which is a concave cobble lag protected profile. The 2 m depth contour extends almost 700 m offshore, while the 2 m contour at Lewis Road is only 10 m from the waters edge. These comparisons illustrate the relative deep water encountered near the HCA shoreline when compared to other eroding cohesive sediment shorelines throughout the Great Lakes, leading to relatively high wave exposure of the shoreline.

Figure 4.15 Eroding bank at Lewis Road

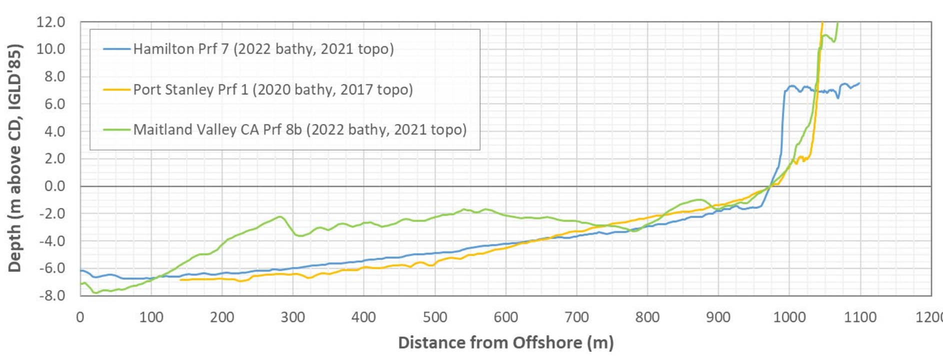

Figure 4.16 Profile 7 at Lewis Road compared to Port Stanley and Maitland Valley CA

Figure 4.17 below depicts the shoreline in the vicinity of Profile 9, fronting Watercrest Drive in Reach 2. The combined lake bottom and shoreline profile is captured in Figure 4.18 (blue line). The 4 m depth contour is only 60 m from the shoreline, after which the profile becomes quite flat (almost concave in shape). A 1:100 nearshore slope (V:H) is common for an eroding cohesive shoreline. The observed slope at the shoreline is much steeper and deeper at 1:15 (V:H). Profile9 in Reach 2 is compared to two other cobble lag profiles from the Maitland Valley CA on Lake Huron in Figure 4.18. The deeper nearshore conditions for Profile 9 will result in less wave energy dissipation as waves propagate to shore, with more wave energy reaching the shoreline.

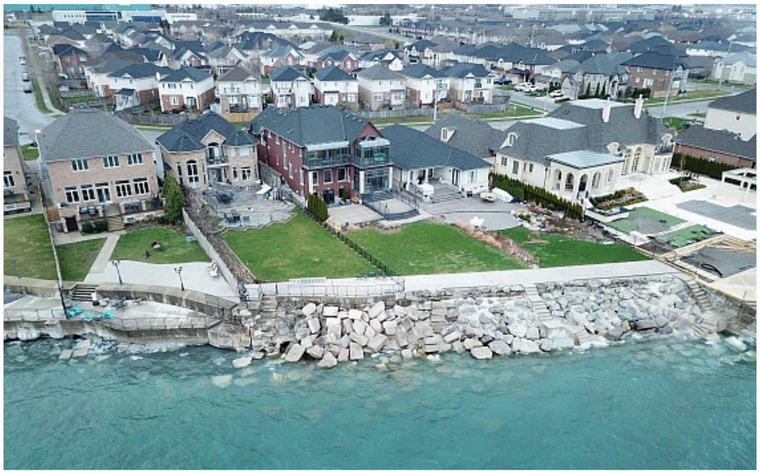

Figure 4.17 Armoured shoreline at Watercrest Drive, Reach 2

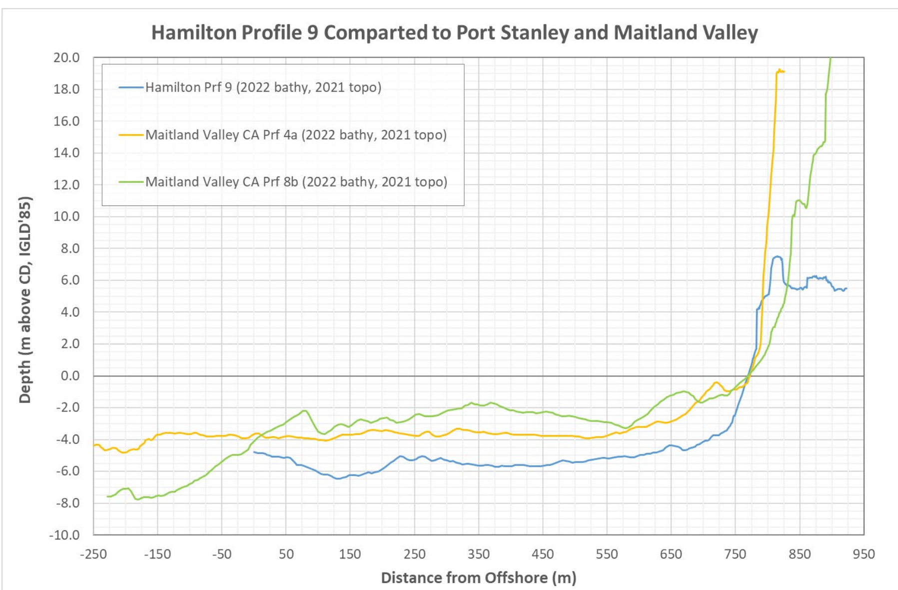

Figure 4.18 Profile 9 at Watercrest Drive compared to Maitland Valley CA Profiles

A final set of profile comparisons are provided in Figure 4.20 for Hamilton Beach, Reach 4. The location of Profiles 20, 23, 25, and 26 along Hamilton Beach are shown in Figure 4.19. Key observations include:

- Profile 20, at the southern end of the reach, is the deepest and features one well defined nearshore bar.

- Profile 23, in the central portion of the reach, is shallower than Profile 20 and features two sand bars.

- Profiles 25 and 26 are located close to the navigation channel and are the shallowest of the group. This progression suggests the net direction of longshore sand transport is from south to north. However, this observation is at odds with shoreline change comparisons, which did not show any sand accretion against the navigation channel jetty. It may be that the historical trend was a net longshore transport direction from south to north, but the alignment of the shoreline and geometry of the nearshore profiles has long-since achieved dynamic stability whereby net transport has become relatively small.

Figure 4.19 Profile Locations, Hamilton Beach

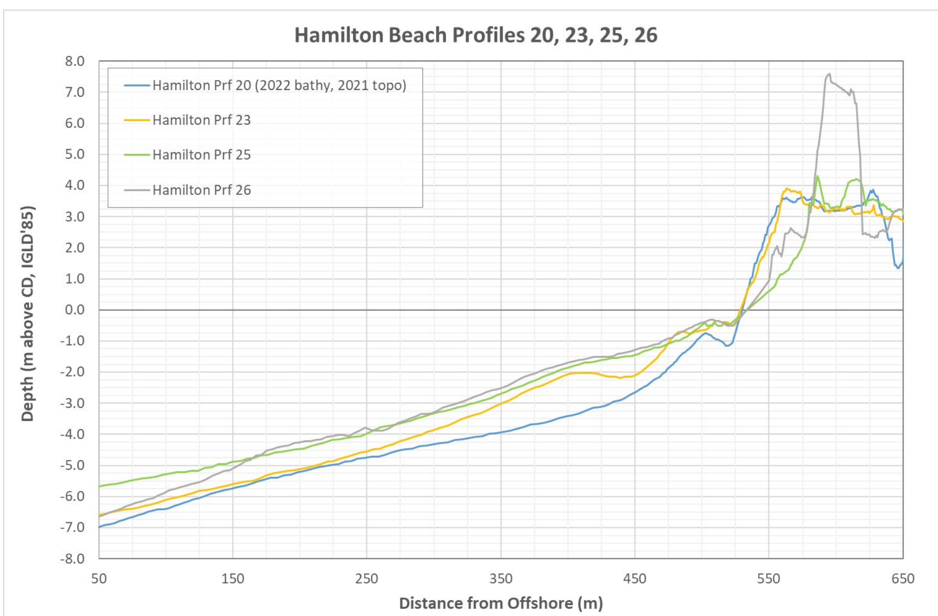

Figure 4.20 Profile comparisons at Hamilton Beach from SE to NW

4.2 Water Level Analysis

A critical component in the assessment of coastal hazards and management of 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 analysis of static lake levels and local storm surges, followed by a joint probability analysis (JPA).

Water levels on the Great Lakes fluctuate over a broad range of 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 based on historical data therefore requires statistical analyses of static lake levels and storm surges over a reasonably long period of data, accounting for seasonal variations, and using the best available statistical analyses techniques.

Historically, 100-year flood levels used in the regulation of most Great Lakes shorelines were based on work completed by the Ministry of Natural Resources (now the MNRF) 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 (at least hourly) 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 4.21 below presents monthly mean lake levels for Lake Ontario from 1900 to 2021, inclusive.

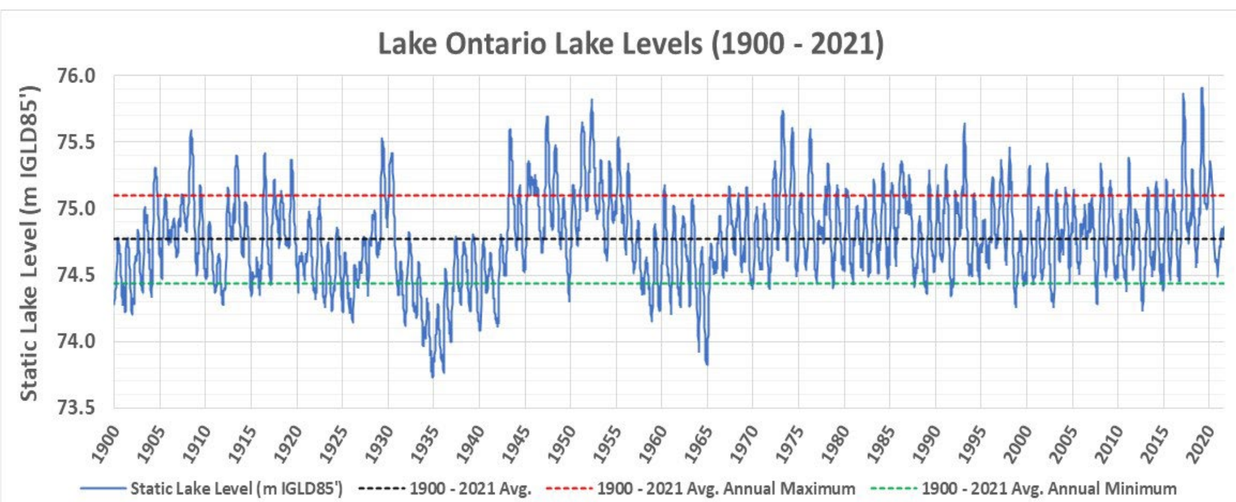

Figure 4.21 Monthly mean lake levels for Lake Ontario from 1900 – 2021, inclusive

4.2.1 Water Level Regulation

In addition to natural water level fluctuations, some influence on Lake Ontario 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. Approximately 85% of the total water supply to Lake Ontario by volume is from upstream sources (i.e. Lake Erie via the Niagara River). The remaining 15% is made up of direct contributions from the Lake Ontario drainage basin. Inflow to Lake Ontario from upstream sources is unregulated, with no control structures in place between Lake Erie and Lake Ontario. Lake Ontario outflow is influenced by the operation of the Moses-Saunders Power Dam in Cornwall, Ontario. 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-Saunders 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 operation 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 hydroelectricity. 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. Refer to Figure 4.21 which clearly shows greater variability in water levels pre-regulation (pre-early 1960s), compared to the post-regulation period.

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 the development of 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.

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 preserve 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.

4.2.2 Static Lake Levels

Modelled historical static lake level data courtesy of Environment and Climate Change Canada (ECCC) were used in the statistical analysis of static lake levels for this study. Performing the statistical analysis on measured water levels would not accurately represent 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 (2017 to present day). Moreover, upstream channel configurations have changed over the period of historical measured data, having an influence on the inflow to Lake Ontario. As such, a dataset of *modelled* static lake levels for Lake Ontario was used in the analysis, generated by routing historical recorded water supplies through ECCC's calibrated Great Lakes routing model assuming 2012 channel configurations (referred to as 'basis of comparison' conditions) and outflow control as per Plan 2014 for the entire modelled period from 1900 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 water level dataset to create a synthetic dataset containing 122 years of monthly mean lake levels for Lake Ontario, and including the record breaking period of extreme water supply from 2017 to 2019. Of the 122 years of data contained in the analyzed 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 that 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 regulations plans perform similarly. 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 122 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 (and verified visually) was selected, and static lake levels corresponding to a variety of average recurrence intervals (ARIs) were output for each month of the year. Table 4.2 provides a summary of 100-year static lake levels for Lake Ontario by month, based on water levels from 1900 – 2021 and accounting for 2012 channel configurations throughout the Great Lakes Basin and the influence of Plan 2014 on Lake Ontario outflows.

Table 4.2 Monthly static lake levels for Lake Ontario corresponding to a variety of average recurrence intervals (in metres above IGLD85')

	Monthly Static Lake Level - Lake Ontario (m IGLD85')												
Tr	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	MAX
1.5	74.54	74.55	74.66	74.86	74.96	74.98	74.96	74.89	74.78	74.65	74.56	74.53	74.98
2	74.66	74.69	74.79	74.99	75.09	75.10	75.07	74.99	74.88	74.74	74.65	74.64	75.10
5	74.91	74.94	75.02	75.24	75.36	75.36	75.30	75.19	75.05	74.89	74.82	74.83	75.36
10	75.03	75.06	75.13	75.37	75.50	75.50	75.43	75.30	75.13	74.96	74.90	74.92	75.50
20	75.13	75.16	75.22	75.48	75.62	75.63	75.54	75.39	75.19	75.02	74.96	74.99	75.63
25	75.16	75.19	75.24	75.51	75.65	75.66	75.57	75.42	75.21	75.03	74.98	75.01	75.66
50	75.24	75.27	75.31	75.60	75.75	75.77	75.67	75.49	75.25	75.07	75.02	75.06	75.77
100	75.31	75.33	75.36	75.67	75.84	75.87	75.75	75.56	75.29	75.11	75.06	75.11	75.87
200	75.38	75.39	75.41	75.74	75.92	75.95	75.83	75.62	75.33	75.14	75.10	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
Year	1973	1973	1973	1993	2017	2019	2019	2019	2019	1986	1986	1986	

As is illustrated in Table 4.2, the governing 100-year static lake level for Lake Ontario is +75.87 m IGLD85', most likely occurring during the month of June. This value is 26 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.

4.2.3 Measured Storm Surge

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. This gradient in water levels at opposite ends of the lake will typically oscillate back and forth, a process known as seiching (commonly referred to as the bathtub effect). 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 6 to 36 hours. The closest water level gauge to the project shoreline is at Burlington (Station ID 13150). The Burlington gauge is located approximately 100 m offshore on the south jetty of the federal navigation channel into Hamilton Harbour, effectively placing it within the study area. The Burlington gauge features hourly or better water level data from 1971 to present day, a period of more than 50 years. Statistical analysis of measured storm surges at the Burlington gauge were completed for the entire period of recorded data.

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 24 hours removed. The residual between a specific data point (water level) and the background static lake level is then calculated. Large, positive residuals represent potential storm surge events, with the residual representing the magnitude of the 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 4.22 presents a timeseries of water levels recorded at the Burlington water level gauge during the largest storm surge event on record, which occurred on April 10, 1973, and featured a surge magnitude of approximately 75 cm at its peak. The oscillations due to seiching near the peak of the event are clearly evident in the timeseries data. This was a highly unusual event, as it occurred outside of the part of the year in which the largest surges typically occur on Lake Ontario (late fall and winter), and its magnitude was nearly 15 cm higher than the second highest surge event on record at Burlington.

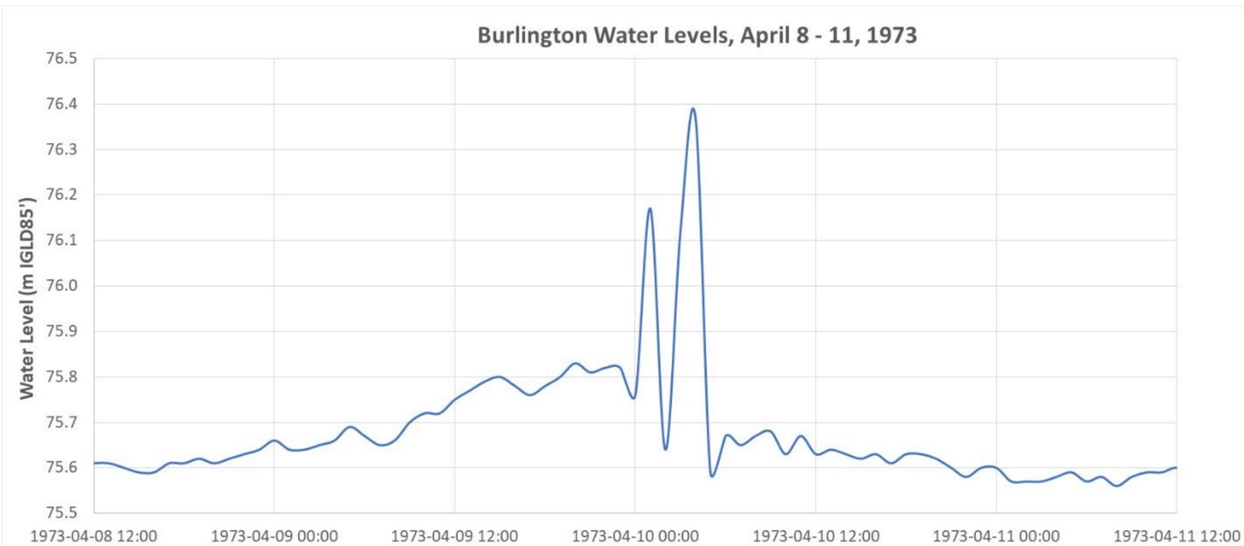

Figure 4.22 April 10, 1973, storm surge event at the Burlington water level gauge

Maximum residuals (surge magnitude) from identified surge events at the Burlington water level gauge were ranked and separated into 12 monthly datasets to capture seasonality. In general, storm surge events on Lake Ontario are more frequent and severe during the fall and winter months. However, since storm surge events 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 fit to several statistical distributions, with the best fitting distribution based on a combination of correlation coefficient and visual inspection being selected. Storm surge magnitudes corresponding to a variety of average recurrence intervals were subsequently evaluated from the selected distributions, with results provided in Table 4.3.

Table 4.3 Monthly storm surge magnitudes at Burlington for a variety of average recurrence intervals (m)

	Monthly Storm Surge - Burlington (m)												
Tr	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	MAX
1.5	0.25	0.25	0.24	0.21	0.16	0.11	0.09	0.10	0.13	0.16	0.21	0.23	0.25
2	0.28	0.26	0.25	0.23	0.18	0.12	0.10	0.11	0.15	0.18	0.22	0.26	0.28
5	0.36	0.33	0.31	0.28	0.23	0.15	0.13	0.14	0.19	0.22	0.29	0.33	0.36
10	0.42	0.37	0.36	0.33	0.29	0.18	0.15	0.16	0.22	0.25	0.35	0.39	0.42
20	0.47	0.42	0.43	0.39	0.35	0.20	0.17	0.19	0.24	0.27	0.42	0.45	0.47
25	0.49	0.43	0.45	0.41	0.38	0.21	0.18	0.19	0.25	0.28	0.44	0.47	0.49
50	0.55	0.48	0.55	0.50	0.48	0.24	0.21	0.22	0.28	0.30	0.51	0.52	0.55
100	0.60	0.53	0.67	0.61	0.60	0.26	0.24	0.24	0.30	0.33	0.59	0.58	0.67
200	0.66	0.57	0.84	0.77	0.77	0.29	0.27	0.26	0.32	0.35	0.66	0.64	0.84
MAX Obs.	0.42	0.53	0.40	0.75	0.23	0.25	0.17	0.18	0.23	0.28	0.30	0.60	0.75
Date	1999-01-02	2007-02-13	1985-03-04	1973-04-10	2000-05-13	1983-06-28	2013-07-19	1983-08-12	2006-09-02	2011-10-19	2008-11-30	2007-12-16	

As shown in Table 4.3, based on an extreme value analysis of recorded storm surges from 1971 – 2021, the predicted 100-year storm surge magnitude at the Burlington water level gauge is 67 cm. Based on the best fitting probability distribution for the month of April, the April 1973 event depicted in Figure 4.22 was an event with an expected return period on the order of 200 years.

4.2.4 100-year Flood Level

In order to assess the 100-year flood level, a seasonal joint probability analysis was performed to assess the joint probability of the full range of possible static lake level and storm surge combinations at the Burlington water level gauge. 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 documented in Sections 4.2.2 and 4.2.3. 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:

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

Assessing the above formulation for the full range of possible combined flood elevations (Z) at the Burlington water level gauge and for each month of the year results in a series of monthly cumulative joint probability distributions of *combined* flood levels. Flood levels corresponding to a variety of average recurrence intervals for each month of the year are presented in Table 4.4.

Table 4.4 Monthly flood levels at Burlington for a variety of average recurrence intervals (in metres above IGLD85')

	Monthly Combined Flood Level - Burlington (m IGLD85')												
Tr	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	MAX
1.5	74.54	74.49	74.56	74.79	74.86	74.86	74.84	74.78	74.67	74.59	74.54	74.53	74.86
2	74.94	74.94	75.03	75.20	75.26	75.20	75.15	75.08	75.00	74.90	74.88	74.88	75.26
5	75.20	75.21	75.28	75.47	75.54	75.47	75.39	75.30	75.19	75.06	75.06	75.10	75.54
10	75.33	75.34	75.41	75.61	75.70	75.61	75.53	75.41	75.28	75.15	75.15	75.20	75.70
20	75.44	75.45	75.51	75.74	75.84	75.75	75.65	75.51	75.35	75.21	75.23	75.29	75.84
25	75.48	75.48	75.54	75.77	75.88	75.78	75.69	75.54	75.37	75.23	75.26	75.31	75.88
50	75.58	75.58	75.64	75.88	76.01	75.90	75.79	75.62	75.43	75.28	75.33	75.39	76.01
100	75.68	75.67	75.75	76.00	76.15	76.03	75.90	75.71	75.49	75.33	75.42	75.47	76.15
200	75.81	75.80	76.04	76.22	76.38	76.19	76.04	75.82	75.54	75.38	75.58	75.59	76.38
MAX Obs.	75.47	75.51	75.55	76.37	76.07	76.03	75.97	75.64	75.46	75.32	75.19	75.37	76.37
Date	1978-01-26	2007-02-13	1973-03-17	1973-04-10	2019-05-29	2019-06-13	2019-07-06	2019-08-18	2019-09-01	2019-10-03	1986-11-05	2019-12-01	

As shown in Table 4.4, based on a joint probability analysis of static lake levels and measured storm surges, the predicted 100-year flood level at Burlington is +76.15 m IGLD85'. This value is 14 cm higher than that which is presented by the MNR in 1989. For the flood mapping, the level was rounded to 76.2 m IGLD'85.

Given that the HCA shoreline extends some 18 km east along the south shore of Lake Ontario from the location of the Burlington water level gauge, the water level analysis presented above was repeated for the Port Weller water level gauge, located approximately 30 km east of Fifty Point. The 100-year flood level at Port Weller was determined to be +76.16 m IGLD85', nearly identical to that predicted at the Burlington gauge. The relevance of this is discussed further in the sections that follow.

4.2.5 Numerical Modelling to Establish Storm Surge Gradients

Although the static lake level component of the joint probability analysis is consistent across the study area, it was necessary to use numerical tools to evaluate potential changes in storm surge magnitude across the Lake Ontario and Hamilton Harbour shoreline, and its influence on the 100-year flood level. To resolve surge gradients throughout the study area the following was completed:

1) The development and calibration of a lakewide high-resolution numerical model to simulate storm surge gradients across the lake and along all shoreline reaches, using spatially and temporally varying atmospheric hindcast data.

2) Selection of an ensemble of storms to simulate in the hydrodynamic model to generate spatially varying storm surge gradient maps between the long-term water level monitoring stations at Burlington and Port Weller. The objective is to model a sufficient ensemble of storms to develop an understanding governing surge gradients from all possible and consequential directions, at varying intensities and combinations of static lake level and surge residuals (i.e. joint probability).

3) Interpretation of modelled storm surge residuals along the shoreline. The extreme gradient maps, depicting relative storm surge gradient variability, can be used to better

understand, and if required, interpolate the 100-year flood level between long-term monitoring stations.

A DHI MIKE 21 flexible mesh (FM) hydrodynamic (HD) model was developed of Lake Ontario (Figure 4.23), using triangular mesh to resolve the bathymetry of the entire lake. The model bathymetry was obtained from a combination of sources, including the Canadian Hydrographic Service (CHS) non-navigational (NONNA) bathymetric data and NOAA's Great Lakes Bathymetric data collection. Colour contours representing model bathymetry are presented in Figure 4.23.

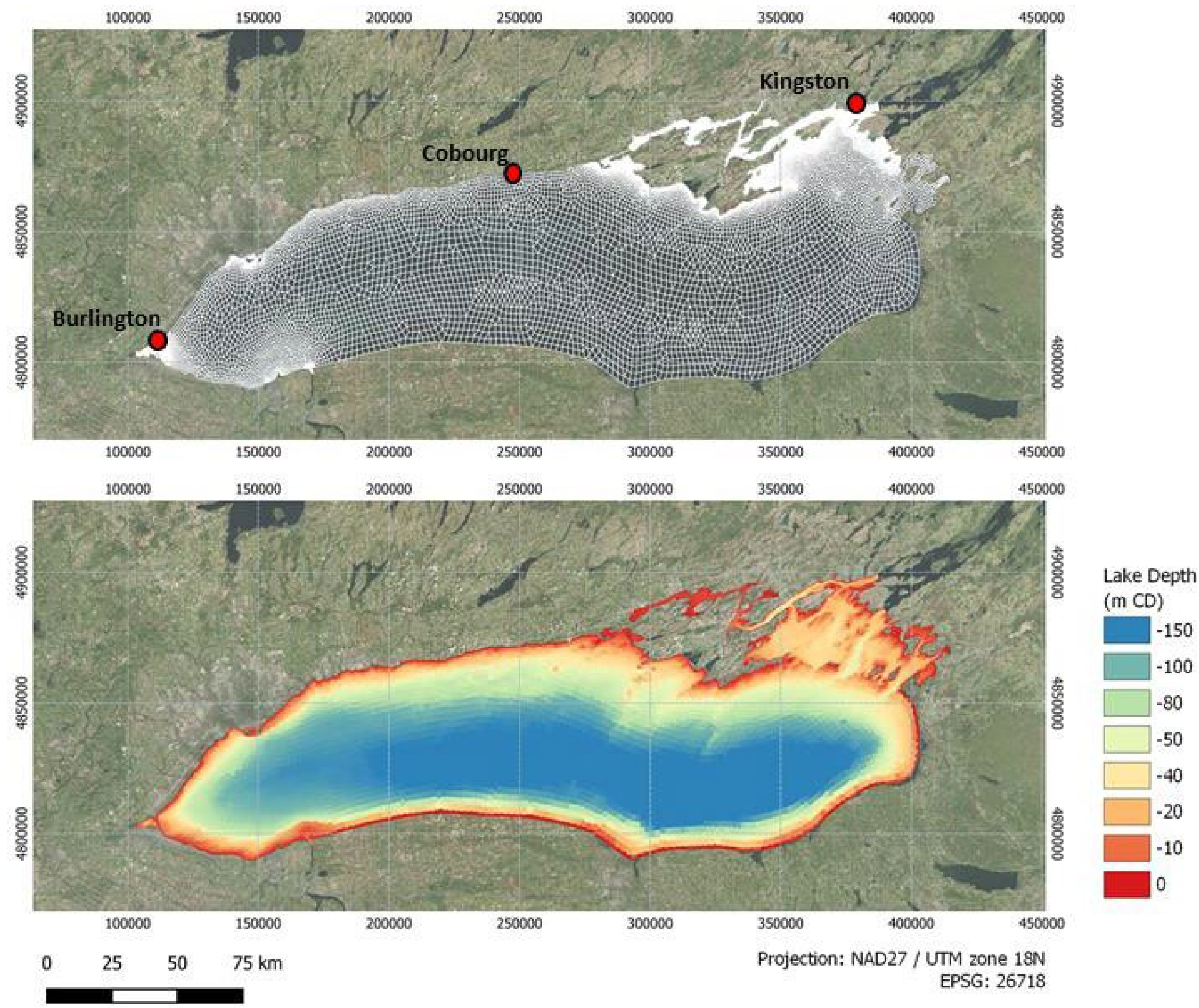

Figure 4.23 Lake Ontario surge model mesh (top) and interpolated bathymetry (bottom)

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 through the navigation channel to the harbour. The detailed mesh for Hamilton Harbour is depicted in Figure 4.24.

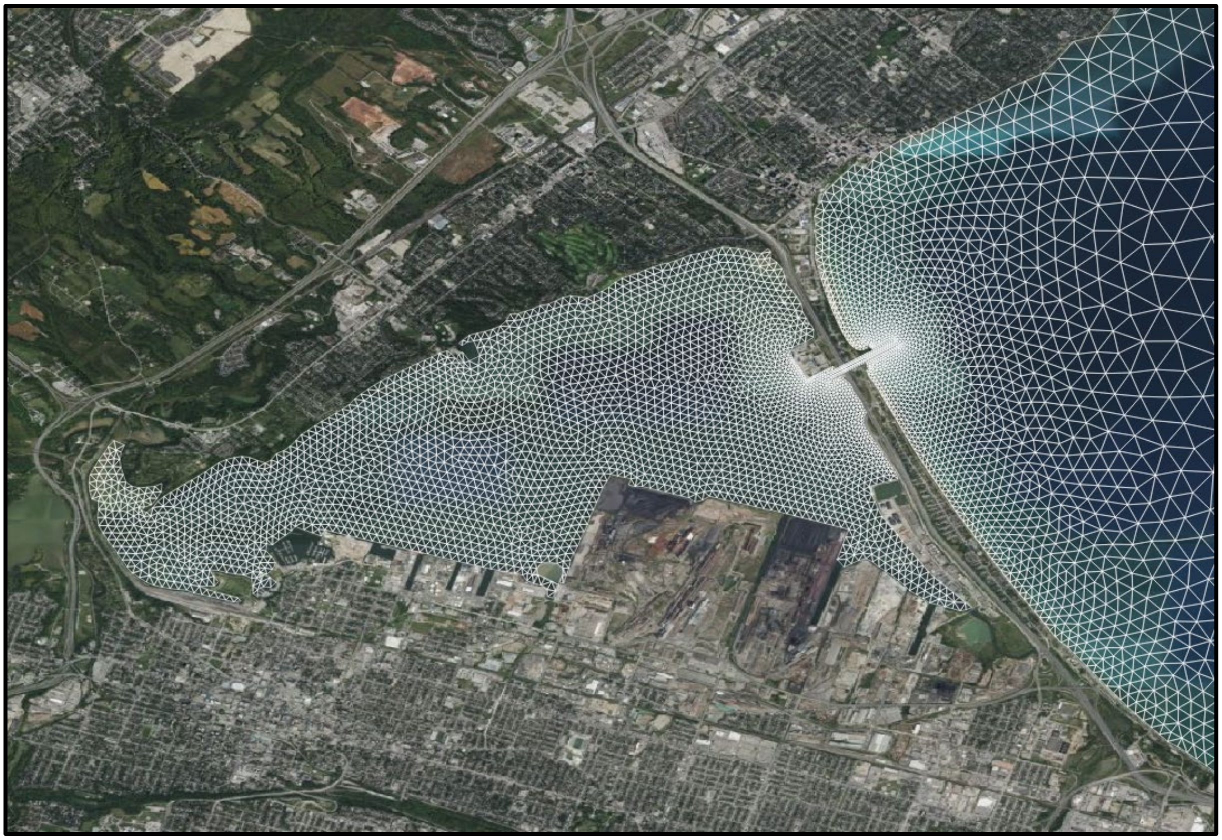

Figure 4.24 Detailed model mesh for navigation channel and Hamilton Harbour

The most important data to develop a robust regional storm surge model is a temporally and spatially varying wind and atmospheric pressure hindcast. To resolve this data requirement, DHI has selected the global CFSR hindcast model administered by NOAA NCAR. The CFSR model is a global, high resolution, coupled atmosphere-ocean-land surface-sea ice system designed to provide the best estimate of historical winds across coupled land-ocean domains.

CFSR wind speeds at 10 m above MSL and atmospheric pressures are available from 1979 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.

4.2.5.1 Selection of Simulation Events

Table 4.5 provides an overview of the ensemble of selected extreme storm events simulated as part of this assessment and their key characteristics in terms of water level, surge residual and sustained wind conditions at the peak of the surge event. The storms selected in Table 4.5 provide an understanding of governing surge gradients from all possible and consequential directions, at varying intensities and lake levels affecting Hamilton Harbour and the western shoreline of Lake Ontario.

Table 4.5 Summary of simulated storms

Storm Id	Date	Water Level		Surge Residual		Wind at Peak Water level	
		(m IGLD85')	Approx RTP (yr)	(m)	Approx RTP (yr)	Speed (km/h)	From Direction (°N)
1	December 16th, 2007	74.93	1-yr	0.60	75-yr	40	70
2	February 13th 2007	75.51	5-yr	0.53	50-yr	48	80
3	April 15th, 2018	75.44	3-yr	0.39	7.5-yr	67	60
4	December 19th, 2008	75.01	1.5-yr	0.44	15-yr	67	80

4.2.5.2 Hydrodynamic Model Calibration

The MIKE 21 hydrodynamic model was calibrated for each storm event listed in Table 4.5 using water level data collected at the Burlington water level gauge (Station 13150). A time step of 10 minutes has been selected to describe the water level evolution. For each storm, the hydrodynamic model is started 5 days before the peak of the storm to initialise regional scale circulation induced by the wind forcing across the model domain.

Model calibration for each storm is presented in Figure 4.25 as a timeseries of modelled (blue) versus observed (grey) storm surge residual (i.e. water level above the background static lake level occurring shortly before the storm event). The model demonstrates strong performance, with the peak storm surge residual for each storm being satisfactorily simulated. A summary of observed versus modelled storm surge residuals is presented in Table 4.6, where model bias for the peak of the storm surge is approximately +/- 5 centimeters.

Table 4.6 Observed versus modelled water levels at ECCC Station 13150.

Storm Id	Date	Observed Water Level at Burlington (m)	Modelled Water Level at Burlington (m)	Delta (observed – modelled, m)
1	December 16th, 2007	0.62	0.61	0.01
2	February 13th 2007	0.33	0.39	-0.06
3	April 15th, 2018	0.45	0.41	0.04
4	December 19th, 2008	0.50	0.47	0.03

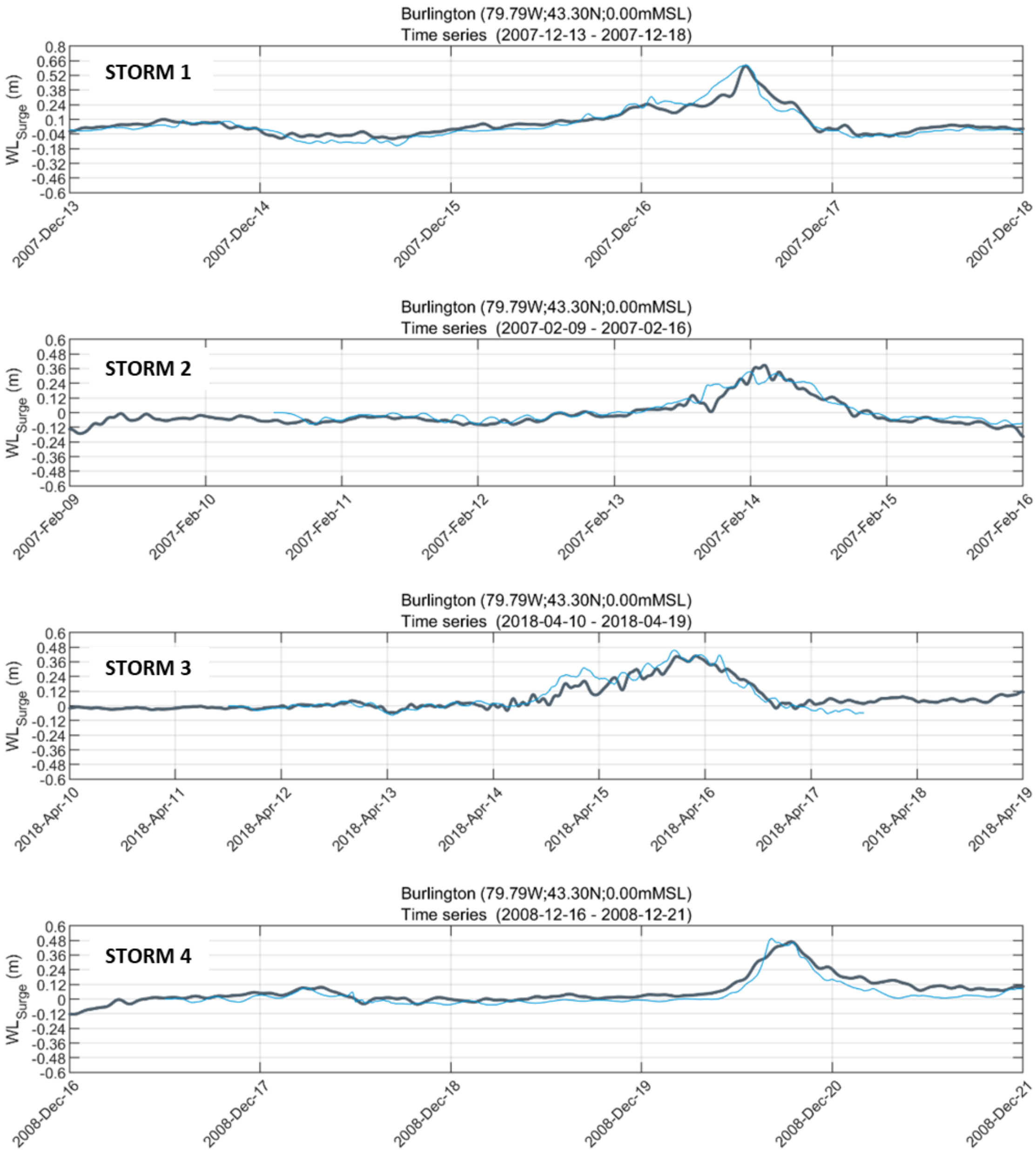

Figure 4.25 Hydrodynamic Model Calibration (blue is modelled, grey is measured)

4.2.5.3 Hydrodynamic Model Results

Maps of peak storm surge magnitudes for the events listed in Table 4.5 are presented in Figure 4.26 and Figure 4.27, respectively. The model showed there was very little change spatially in the peak storm surge condition across the HCA Lake Ontario shoreline and at the western end of Hamilton Harbour for the simulated events. Therefore, the 100-year flood level established at the Burlington Gauge, 76.15 m IGLD'85 (refer to Section 4.2.4), was rounded to 76.2 m IGLD'85 and used for the entire jurisdiction of the Hamilton Conservation Authority. This is the recommended 100-year flood level for the entire HCA shoreline and has been used as such in the shoreline hazard mapping generated for this SMP.

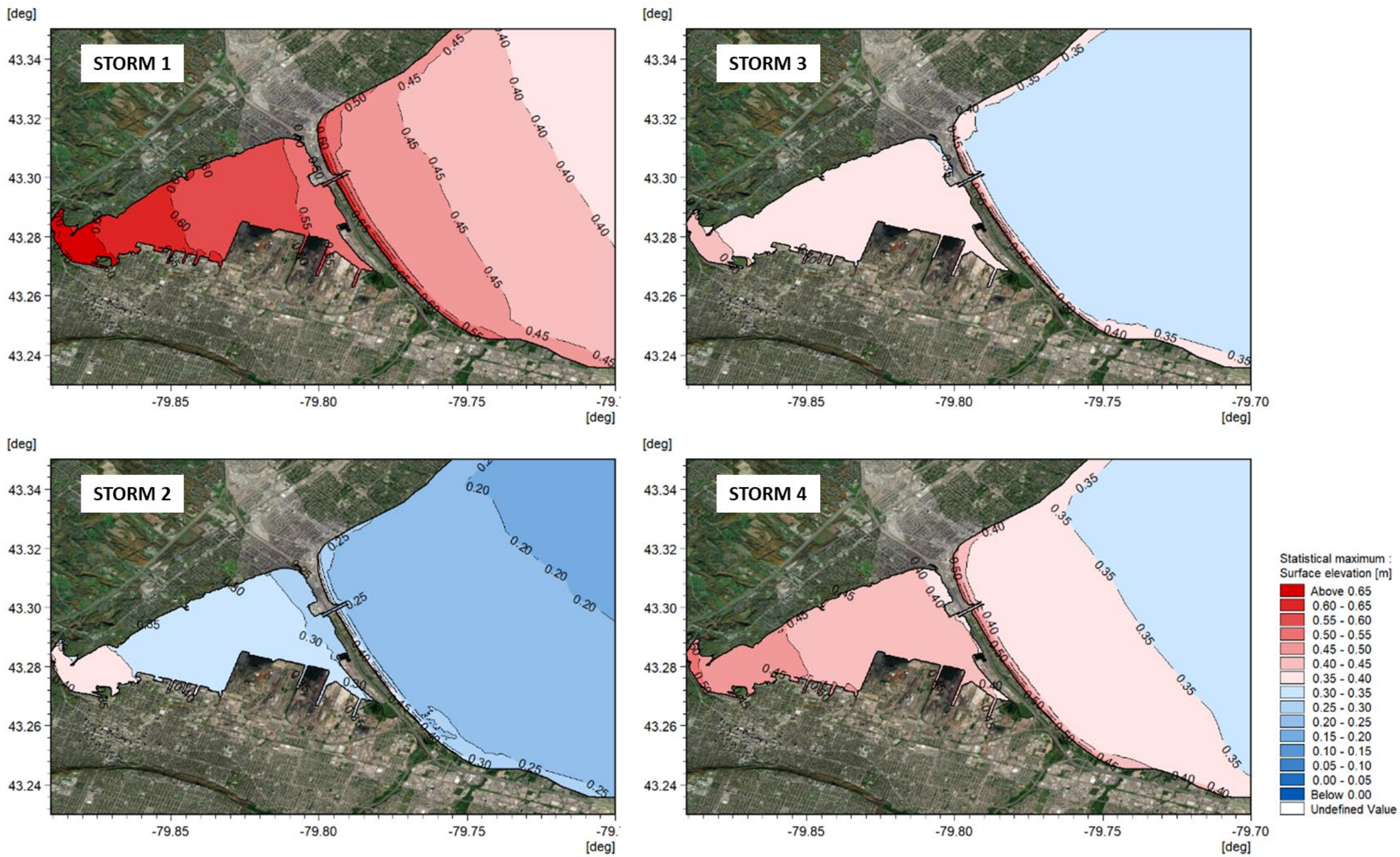

Figure 4.26 Maximum storm surge for each storm event within the Hamilton Harbour and Western Lake Ontario Shoreline

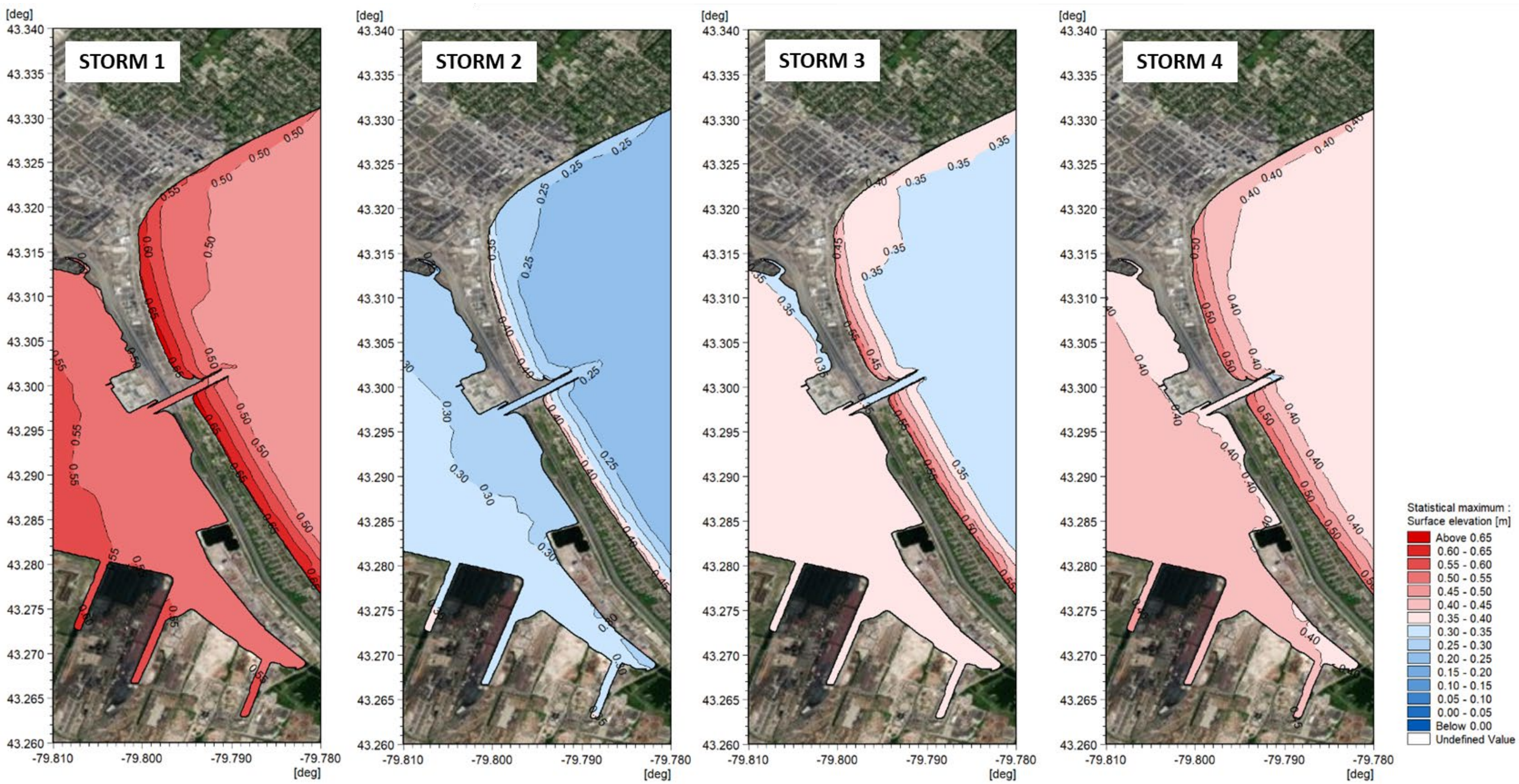

Figure 4.27 Maximum storm surge along the Burlington Beach & Burlington Canal

4.2.6 Projected Climate Change Impacts on Future Lake Levels

In a recent paper published in the Journal of Great Lakes Research (Seglenieks and Temgoua, 2022), Environment and Climate Change Canada (ECCC) research and projections of future Great Lakes water levels were presented for global temperature increases of 1.5 to 3.0 °C. 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 study found that 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 due to future wet periods across the lakes. Refer to Figure 4.28, reproduced from Seglenieks and Temgoua (2022), which plots time series of future water level projections for Lake Ontario, compared to the historical baseline period from 1918 to 2020. The 13 scenarios are sub-divided into four discrete 30-year datasets centered on global mean temperature changes of 1.5, 2.0, 2.5 and 3.5 °C of warming.

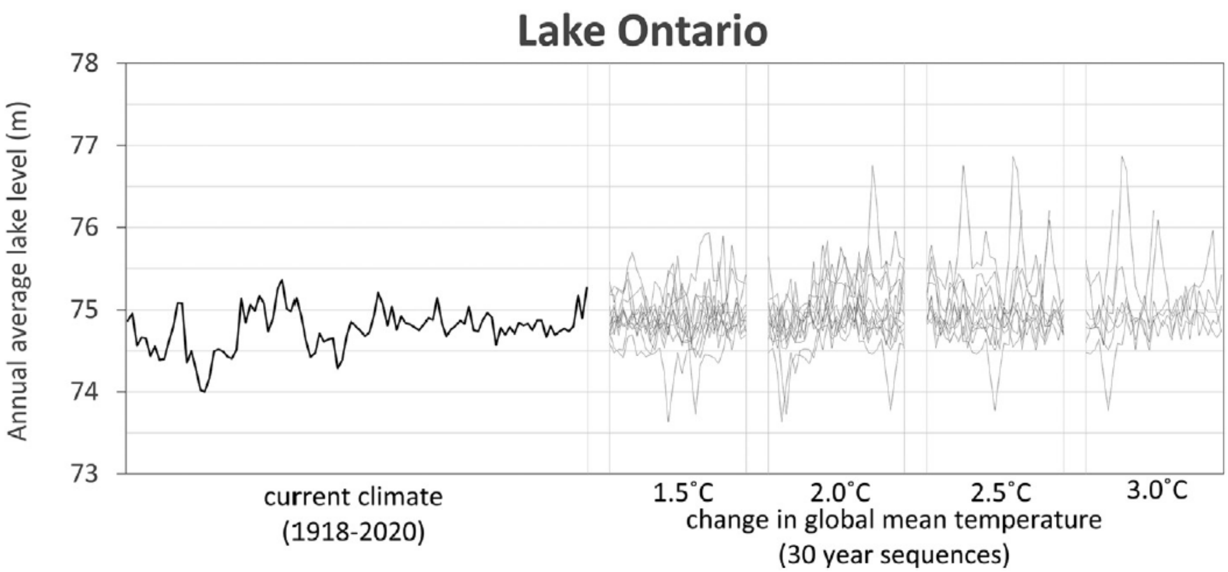

Figure 4.28 Projected future Lake Ontario levels for different global warming trends and GCM-RCM simulations (from Seglenieks and Temgoua, 2022)

Future climate change simulations have uncertainties associated with the inputs, predictive capability of the models, and outputs. The influence of the regulation plan, Plan 2014, for Lake Ontario and how the Board of Control will deal with future periods of high supplies, also adds uncertainty. Therefore, it is important to recognize that future water levels presented in Figure 4.28 are projections, not predictions. In addition, how the projected extreme water supply scenarios under 2.5 and 3.5 degrees of warming, and in particular the very wet years, would be conveyed through the Great Lakes and connecting channels given the physical conditions of the system today is not fully known. As such, the information in Figure 4.28 is considered indeterminate for the very high lake levels in the 2.5 and 3.0 °C simulations.

It is also important to note that deviations from the Plan 2014 rules controlling the operation of the Moses-Saunders Dam during periods of extreme water supply are not represented in the routing model outputs and subsequent water level projections in Figure 4.28. During the record high water supplies experienced in 2019 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 additional uncertainty in the extreme high water level projections shown in Figure 4.28 for the future warming scenarios due to uncertainty surrounding deviations from the regulation plan during periods of extreme water supply (i.e., lake levels greater than 76.0 m).

The projected future lake levels from the ECCC study are also summarized as probability of exceedance for each global warming scenario, 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 °C are summarized in Table 4.7. These data indicate that as temperatures in the Great Lakes Basin continue to increase, mean lake levels may increase slowly over time (refer to the 50% exceedance results in Table 4.7). The 1% exceedance, which is indicative of the 100-year static lake level, is projected to increase 0.39 m with 1.5 °C 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 4.7 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 the 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 °C of warming between 2030 and 2052 if CO_2 emissions continue to increase at the current rate (refer to Figure 4.29). In a 2021 publication by Hébert et al., it was stated that warming of 1.5 °C by 2038 was extremely likely (>95%).

In summary, climate change may have a significant impact on future water levels on Lake Ontario and the hazard mapping generated for this study. It is recommended that the hazard mapping and in particular the 100-year flood level used in this study be revisited in the future pending additional research into the projected impacts of climate change on Great Lakes water levels, the future operation of the Moses-Saunders Dam, and changes to the Technical Guidelines for the determination of shoreline hazards in Ontario that are likely to include provisions for the inclusion of the projected impacts of climate change.

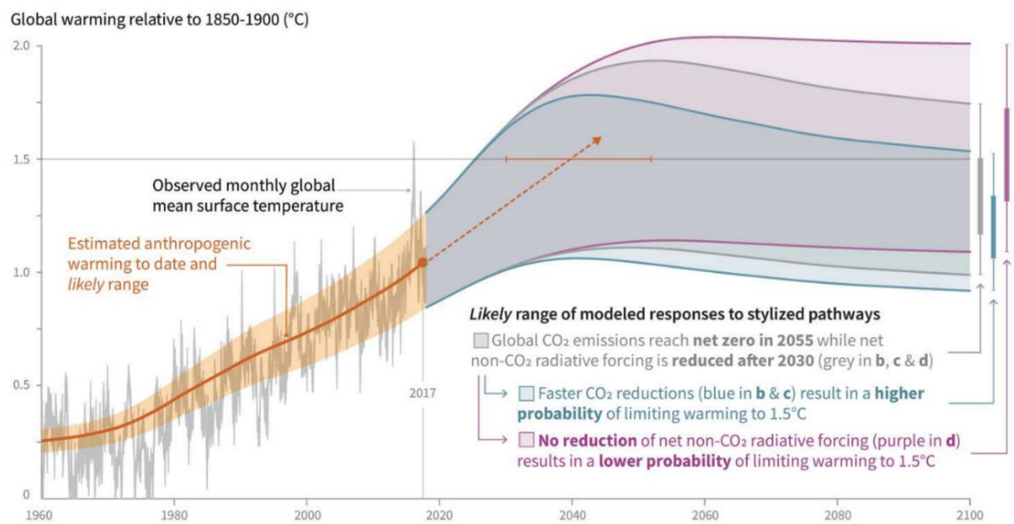

Figure 4.29 Observed global temperature change and projected increases for different CO2 emission scenarios (IPCC, 2018)

4.3 Wave Climate and Influence on Hazard Mapping

At present, there are no long-term nearshore measured wave records to describe the wave climate along the HCA shoreline. The closest wave observations are over 20 km to the east (Environment and Climate Change Canada Buoy 45139, 43.250N 79.53W). The data record is both incomplete, too far from the area of interest, and too short, for use in this project.

In the absence of measured wave data, a historical wave climate for Lake Ontario known as the Wave Information Study (WIS) has been developed by the United States Army Corps of Engineers (USACE) Coastal and Hydraulics Laboratory Engineering Research and Development Center. This study was a 45-year wave hindcast for Lake Ontario covering the period from 1970 to 2014. Although widely applied, there are several limitations to the WIS study affecting the wave climate at the HCA shoreline. These include:

- The WIS dataset only provides wave conditions offshore, at discrete locations, at distances of approximately 3.0 to 6.0 km from the shoreline and is therefore representative of deep-water wave conditions only. Wave conditions in nearshore shallow regions where effects such as shoaling, refraction and wave breaking occur, are not captured by the WIS model. The data cannot be reliably used to describe and quantify wave effects along the complex HCA shoreline.

- The WIS dataset does not include the period from 2014 to present day, which is a period of interest due to the high lake levels experienced in 2017 and 2019 which have direct influence on wave energy exposure along the shoreline. These periods should be captured and considered in the wave climate used to inform the SMP.

To characterize the nearshore wave climate along the HCA shoreline, DHI used its industry standard MIKE21 numerical modelling suite to simulate a long-term, high-resolution continuous wave hindcast for the area of interest. A continuous hourly simulation period from 1980 to 2020 was selected to enable statistical interpretation of wave records at any location of interest.

It is often necessary to extrapolate hindcast data to probabilities beyond the record length (USACE, 2006) to determine the annual exceedance probability (AEP). To determine the AEP for waves typically found during a 1- to 100-year event, an extreme value analysis (EVA) of long-term observations must be completed. Extreme values with associated long return periods are estimated by fitting a probability distribution to a dataset of observed or modelled wave conditions. There are uncertainties associated with extreme value analyses, and the uncertainties generally increase for higher return periods. Ideally, time series that are long compared to the desired return periods should be available to reliably extract return period values. In practice, however, the opposite is true and values corresponding to return periods much longer than the length of recorded data are needed. Intuitively, the further away from the period of data one has to extrapolate, the larger the uncertainties of the resulting estimates will be. As a rule of thumb, for example, the ISO standard ISO 19901-1 (ISO, 2005) recommends to not use return periods more than a factor of three beyond the length of the data set when deriving return period values for design (Vanem, 2015). Therefore, for the assessment of a 100-year event, one would need continuous timeseries that is over 34 years. The hindcast completed for this study includes 40-years of data, suggesting that sufficient confidence can be placed in the results of the extreme value analysis for up to 100-year wave conditions along the HCA shoreline.

4.3.1 Spectral Wave Model Development

The continuous 40-year spectral wave modelling was performed using DHI's state-of-the-art numerical model flexible mesh (FM) MIKE 21 spectral wave (SW) model. The MIKE21 FM SW simulates the growth, decay and transformation of wind-generated waves and swell in offshore and coastal areas. MIKE 21 SW includes the following physical phenomena:

- Wave growth by action of wind
- Non-linear wave-wave interaction
- Dissipation due to white capping
- Dissipation due to bottom friction
- Dissipation due to depth-induced wave breaking
- Refraction and shoaling due to depth variations

The spectral wave model was developed using the MIKE21 flexible unstructured mesh to allow for higher resolution in nearshore regions of interest, and lower resolution in middle of the Lake, thereby enhancing the computational efficiency of the model. The modelling was completed in two (2) stages. First, a continuous 40-year lake wide simulation with a static water level was completed across a relatively coarse model domain (mesh). The results from the regional lake wide model were then used to drive the boundary conditions of a local, high-resolution model along the HCA shoreline. The local model mesh is resolved at a very high level of detail along the shoreline (< 5 meters), and uses varying water levels at each step, corresponding to measured water levels at the Burlington water level gauge (Station 13150).

Model bathymetry was interpreted using the same bathymetric data used in the MIKE21 HD model for the storm surge modelling (Section 4.2.5). The most important data to develop a robust regional and local wave climate is a temporally and spatially varying wind hindcast. In this instance, the same NOAA CFSR hindcast that was used to force the storm surge model (as described in Section 4.2.5) was also used to force the wave model.

Periods of lake ice were included in the model when simulating the long-term wave climate affecting the HCA shoreline. Shore-fast and lake ice play an important role in developing winter wave dynamics and replicating wave energy experienced along the shoreline. DHI has used daily Lake Ontario ice cover data from 1973 to present day, as described by Yang et. al. (2020). To record the ice changes during the winter season, Great Lakes ice cover data has been collected and maintained since 1973 by Canadian Ice Service, U.S. National Ice Center, and National Oceanic and Atmospheric Administration's Great Lakes Environmental Research Laboratory. To make these long-term data consistent and accessible, Yang et. al. (2020) reprocessed the Great Lakes ice cover database to generate daily gridded data (1.8 km resolution) using a re-project method with Nearest Neighbor Search for spatial interpolation, and linear interpolation with categorization for temporal interpolation. DHI has found that this dataset of ice cover provides a strong basis for modelling winter wave conditions throughout the Great Lakes. The grided data was extracted from the NOAA/GLERL database from 1980 – 2020 and processed for use in the MIKE21 SW model, where ice is interpreted as a percentage of coverage across a uniform grid.

4.3.2 Model Calibration to Wave Observations

The DHI MIKE21 SW model was calibrated to wave observations at ECCC buoy 45139. As shown in Figure 4.30, modelled wave conditions (grey line) and observed wave conditions (green line) indicate a strong correlation with respect to significant wave height (top), peak wave period (middle), and mean wave direction (bottom). Model performance and results are satisfactory for the intended applications of this investigation. There is no USACE WIS data available directly at the ECCC buoy location, and therefore the closest WIS data point (< 2km) is also plotted in Figure 4.30 (blue line) and compared to the DHI modelled waves at the same location (orange line). It can be observed that generally all data sets demonstrate similar characteristics, with the exception of the peak wave event on September 20, 2003, where the USACE WIS data significantly underestimates the observed peak wave height during the storm. The DHI MIKE21 SW model is able to capture these peak wave conditions.

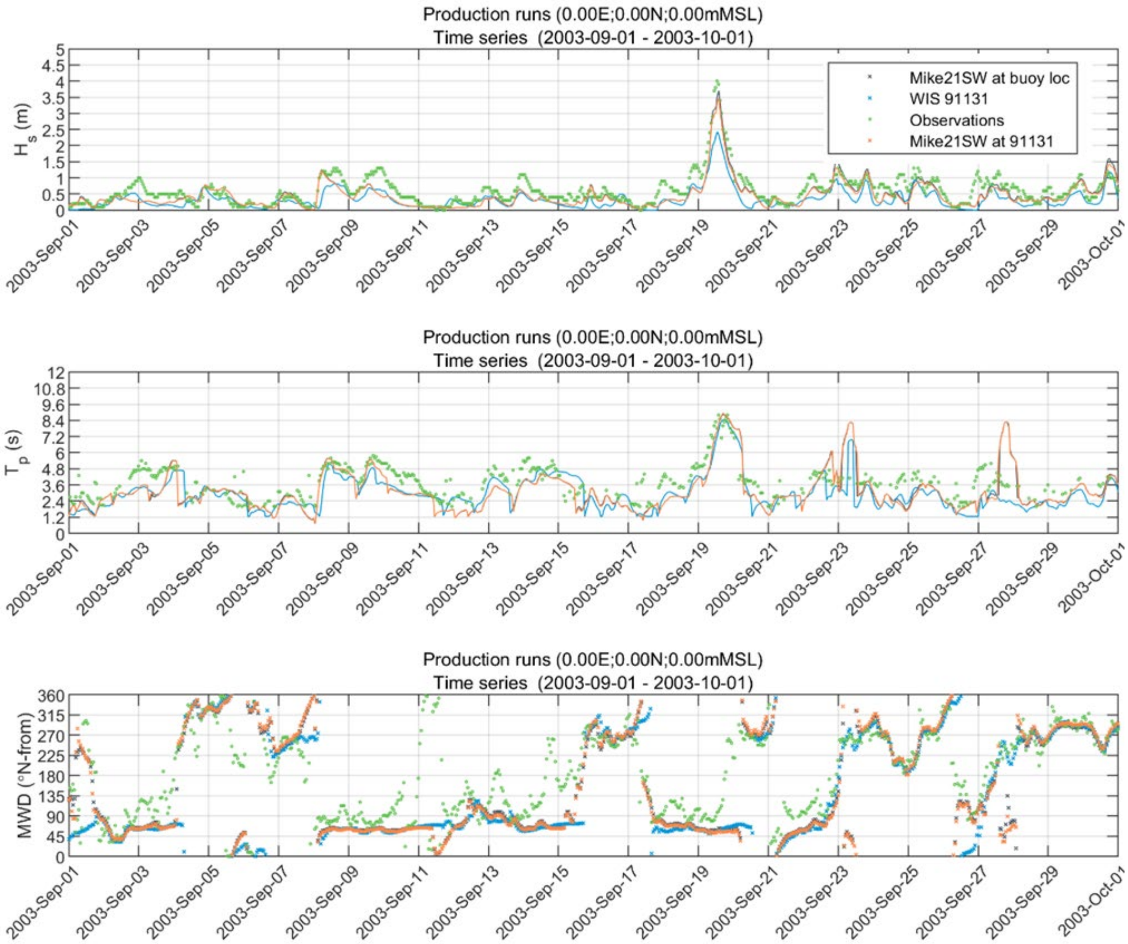

Figure 4.30 Comparison of observation at ECCC buoy 45139 (green) to DHI modelled (grey) wave parameters (Hs – top, Tp – middle, MWD – bottom), and closest USACE WIS station (91131) to the ECCC buoy 45139 (blue), and DHI model results at station (91131)

4.3.3 Model Validation to USACE WIS Model

As described previously, no long-term wave observation record is available along the HCA shoreline. In the absence of such data, the DHI MIKE21 SW model results are compared to the industry-benchmark USACE WIS model which has been extensively applied throughout the Great Lakes, including Lake Ontario for engineering design and planning activities. For the analysis, WIS data at station 91137, which is directly in front of Burlington Beach, was selected. The wave characteristics (significant wave height, peak period, and mean wave direction) during the most severe storm event in the USACE WIS hindcast are shown in Figure 4.31 (blue line), observed on January 28, 2011. The DHI MIKE21 SW results for the same time period are also shown on Figure 4.31 (grey line). These results indicate strong correlation between the models offshore of Burlington Beach during the extreme event, with a difference in Hs < 0.05m, Tp < 0.50s, and a MWD < 5° during the peak of the storm.

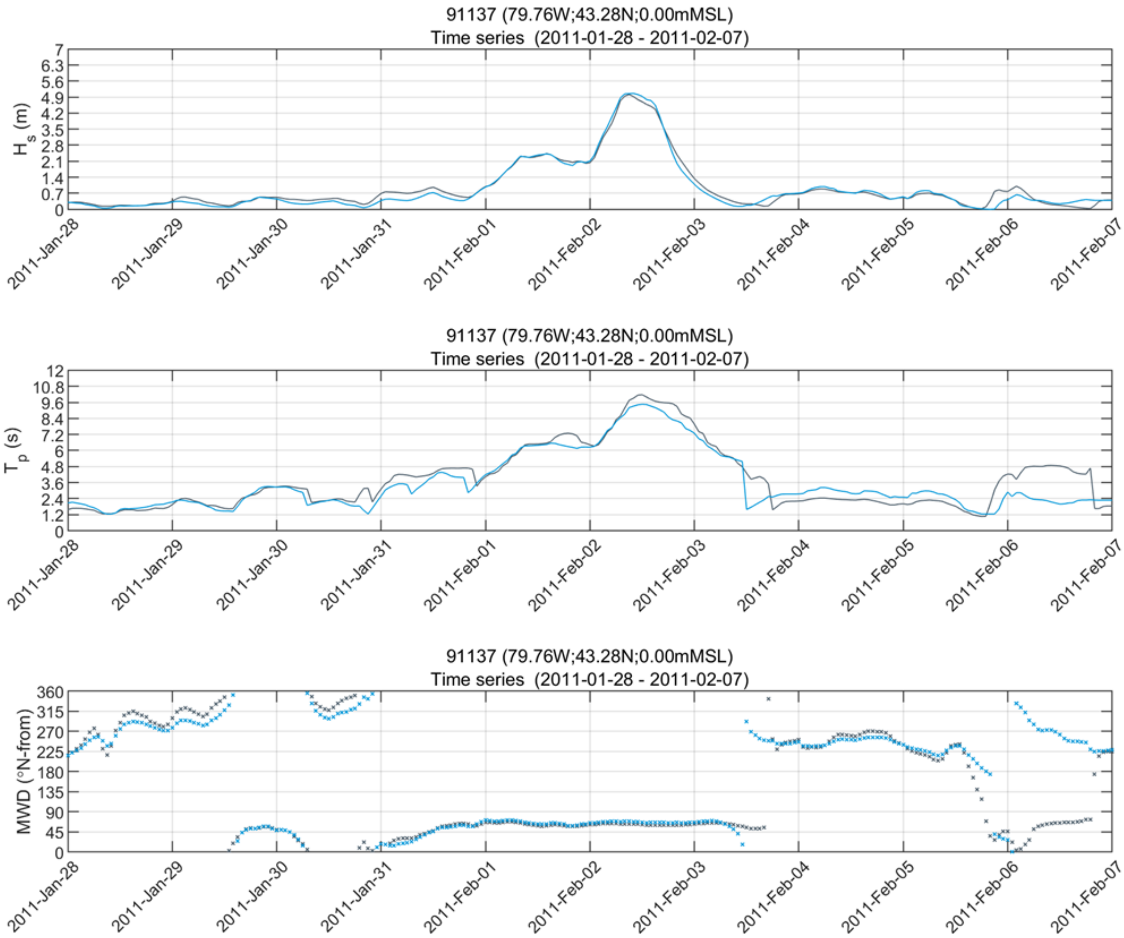

Figure 4.31 Time series comparing key wave parameters (significant wave height – top, peak wave period – middle, and mean wave direction – bottom) USACE WIS data at station 91137 to DHI MIKE21 SW modelled data

A statistical analysis can be used to better assess USACE WIS performance relative to the DHI MIKE21 SW hindcast performance, for the entire period of data overlap from 1981 to 2014. Model quality indices can be used to describe model performance. Most of the quality indices are based on the entire data set, and hence the quality indices should be considered averaged measures and may not be representative of the accuracy during extreme conditions. The relevant quality indices to consider are presented in the legend of Figure 4.32. This figure compares significant wave height of all modelled USACE WIS data (x-axis) to DHI MIKE21 SW data (y-axis).

The correlation coefficient (CC) is a non-dimensional measure reflecting the degree to which the variation of the first variable is reflected linearly in the variation of the second variable. A value close to 0 indicates very limited or no (linear) correlation between the two data sets, while a value close to 1 indicates a very high or perfect correlation. In this instance, the comparison between the DHI model and WIS data achieves a CC of 0.89 for the significant wave height. These results indicate a strong correlation. In essence, the output from the DHI model is comparable to the output from the WIS model. The peak ratio (PR) is the average of the N_{peak}

highest model values divided by the average of the N_{peak} highest observations. The peaks are found individually for each data set through the peak-over-threshold (POT) method applying an average annual number of exceedances of 4 and an inter-event time of 36 hours. A general over-estimation of the modelled peak events results in PR above 1, while an under-estimation results in a PR below 1. In this instance, the DHI model achieves a PR of 1.09 for the significant wave height when compared to the WIS data. This indicates that wave heights are slightly larger in the DHI model relative to the WIS model. In general, a slightly more conservative DHI MIKE21 SW wave hindcast (i.e. greater extreme wave heights), relative to the USACE WIS hindcast, is preferred to a less-conservative wave hindcast when developing a flood risk product.

In conclusion, the DHI model performs statistically comparable to the widely applied industry standard USACE WIS model and is therefore a reliable and robust tool to simulate continuous nearshore wave conditions along the Hamilton Conservation boundary for a 40-year period from 1980 to 2020, where data from 2014 onwards represents an entirely new dataset not presently available through the USACE WIS product.

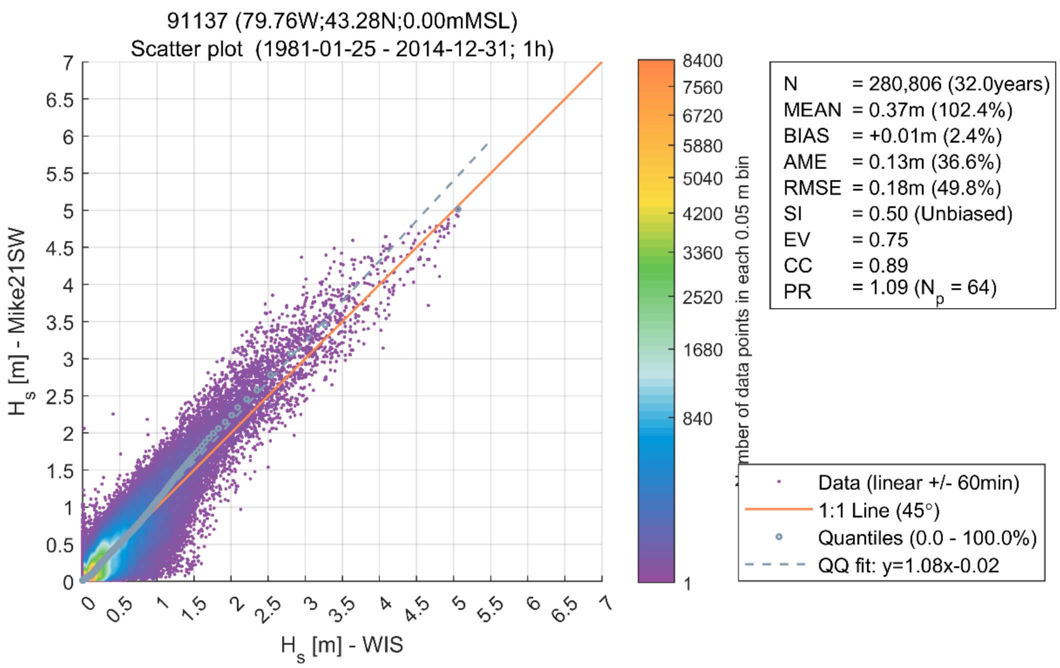

Figure 4.32 Scatter Plot comparing Significant Wave Height of modelled WIS (x-axis) versus DHI MIKE21 SW (y-axis) data

4.3.4 Extreme Wave Conditions in the Nearshore

Time series data from the DHI wave hindcast was analyzed statistically to establish 25- and 100-year wave heights at the WIS station locations, as outlined in Table 4.8. For each location, the depth below chart datum, wave height and wave period for a 25- and 100-year event, and the frequency of events for different wave height thresholds, is summarized.

Table 4.8 Wave statistics at WIS stations

DHI 40 Year Hindcast (1980 - 2020)

Station ID	Depth CD (m)	25-year Hs (m)	25-year Tp (s)	25-year DIR (deg)	100-year Hs (m)	100-year Tp (s)	100-year DIR (deg)	No. Events (Hs > 3 m)	No. Events (Hs > 4 m)	No. Events (Hs > 5 m)
91134	17	5.63	10.5	30 - 60	6.14	11.0	30 - 60	134	37	6
91135	12	4.70	10.5	20 - 50	4.95	11.0	20 - 50	101	25	0
91136	19	5.63	10.5	40 - 70	6.16	11.0	40 - 70	117	34	6
91137	13	5.03	10.5	50 - 70	5.32	11.0	50 - 70	101	25	2
91138	16	5.39	10.5	60 - 70	5.83	11.0	60 - 70	106	28	3
91139	30	5.69	10.5	70 - 90	6.17	11.0	70 - 90	120	37	7
91140	31	5.81	10.5	70 - 90	6.30	11.0	70 - 90	127	39	9
91141	31	5.87	10.5	80 - 90	6.35	11.0	80 - 90	132	41	11
91142	32	6.01	10.5	80 - 90	6.51	11.0	80 - 90	147	46	13
	AVG =	**5.53**	**10.5**		**5.97**	**11.0**		**120.56**	**34.7**	**6.3**

The final step in the wave analysis was to transform the offshore waves to the shoreline to establish shallow water wave conditions along the Lake Ontario and Hamilton Harbour shorelines for the 25- and 100-year wave heights. The following conditions were considered:

- 25-year wave event (Table 4.8) with 25-year onshore winds and 100-year flood level (+76.2 m IGLD85')
- 100-year wave event (Table 4.8) with 100-year onshore winds and 100-year flood level (+76.2 m IGLD85')

Significant wave heights simulated using the nearshore wave model for the 25-year and 100-year events are depicted regionally in Figure 4.33 and locally in Figure 4.34.

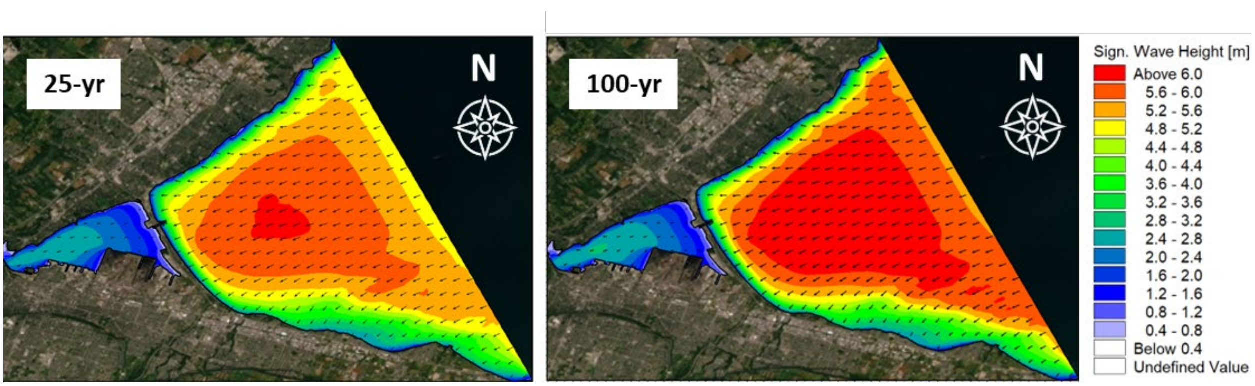

Figure 4.33 Regional 25-yr (left) and 100-yr (right) significant wave height conditions

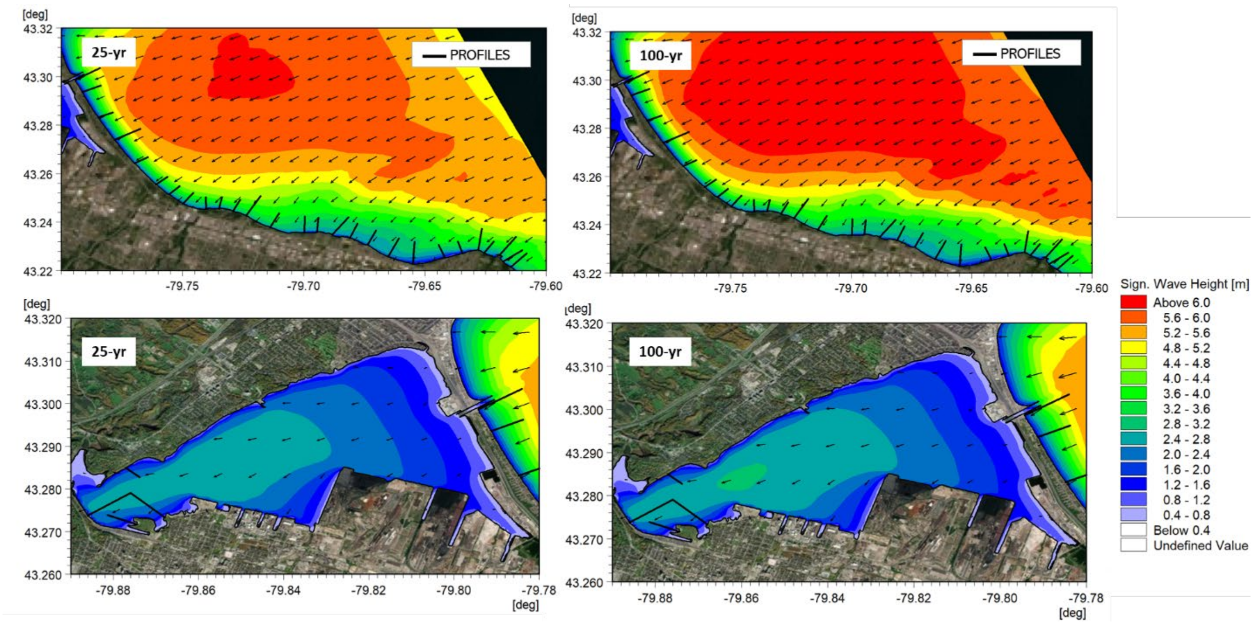

Figure 4.34 Local 25-yr (left) and 100-yr (right) significant wave height conditions

4.3.5 Wave Uprush and Overtopping

A critical component of the *flooding hazard* for Great Lakes shorelines is the effect that waves will have on the shoreline. More specifically, the *flooding hazard* limit must account for the horizontal distance landward from the waterline (i.e. the setback) that may be impacted by wave uprush and other water related hazards. Wave uprush is the process by which waves impact the shoreline and surge up the shoreline to an elevation higher than the still water level. A definition sketch of wave uprush is provided in Figure 4.35 below.

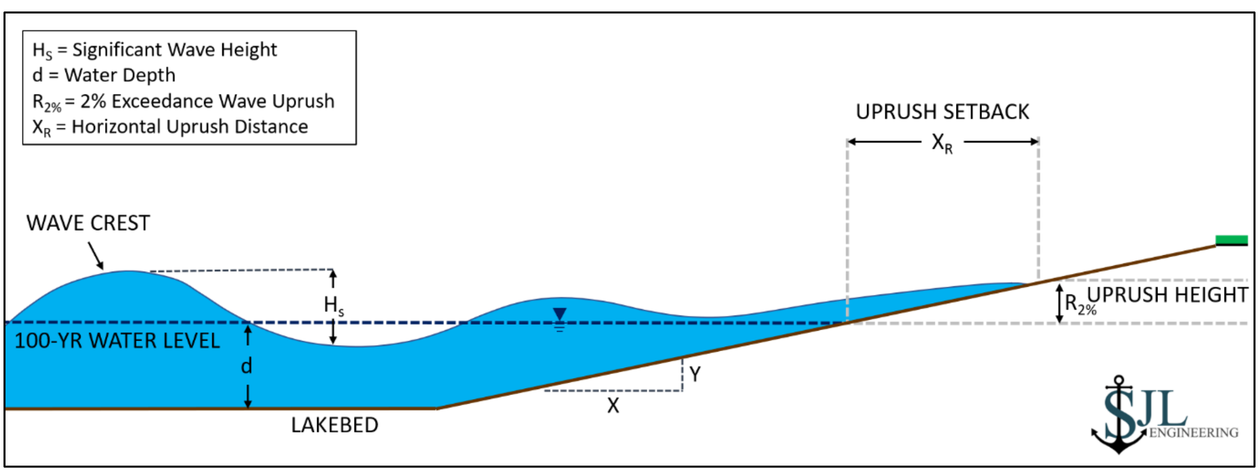

Figure 4.35 Wave uprush on a gentle sloping shoreline – definition sketch

To determine appropriate horizontal setbacks to account for wave uprush along the HCA shoreline, uprush calculations were completed at 30 locations where bathymetry was collected. Refer to Figure 3.8 for the locations of each bathymetric profile collected for the study. The water level used in the wave uprush analysis was the 100-year flood level (+76.2 m IGLD85'), while wave conditions corresponded to the 25-year event. Wave conditions used in the analysis of wave uprush were output at multiple locations along the nearshore profile at each of the 30 locations from the MIKE21 nearshore wave model described in Section 4.3.4 above.

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 this study, the uprush formulas and methodology presented in the EurOtop Manual (2018) were selected. The EurOtop Manual is the industry leading guidance document for the evaluation of wave uprush and overtopping, particularly on steep shorelines and coastal structures.

In the composite slope uprush calculation, the 2% exceedance uprush elevation is first calculated at the lakeward end of the bathymetric/topographic profile using the equations published in the EurOtop Manual. The tool then calculates the uprush resulting from progressively smaller wave heights moving landward across the profile. 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 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 or setback from the waterline can also be determined. The location along the profile producing the furthest landward excursion of uprush (X_R) is the governing result for that profile. Results of the uprush calculations at each of the 30 nearshore profiles are presented in Table 4.9 below.

For shorelines featuring a low bank or shoreline protection structure with a well defined crest, wave uprush may exceed the crest elevation of the bank or structure and generate wave overtopping. This scenario is depicted graphically in Figure 4.36. Although the composite slope approach does provide a horizontal distance estimate for overtopped shorelines, it is likely less accurate due to the overtopping processes that occur as wave action surpasses the bank crest (no longer strictly wave uprush). 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 shoreline (X_R in Figure 4.36). Inputs to the equation include the wave period, runup elevation on the bank (assuming an infinite bank height) and freeboard (elevation of the bank crest above the static water level). Where overtopped banks or coastal structures were encountered across the HCA shoreline, the Cox-Machemehl equation was evaluated, with the results presented in Table 4.9 below.

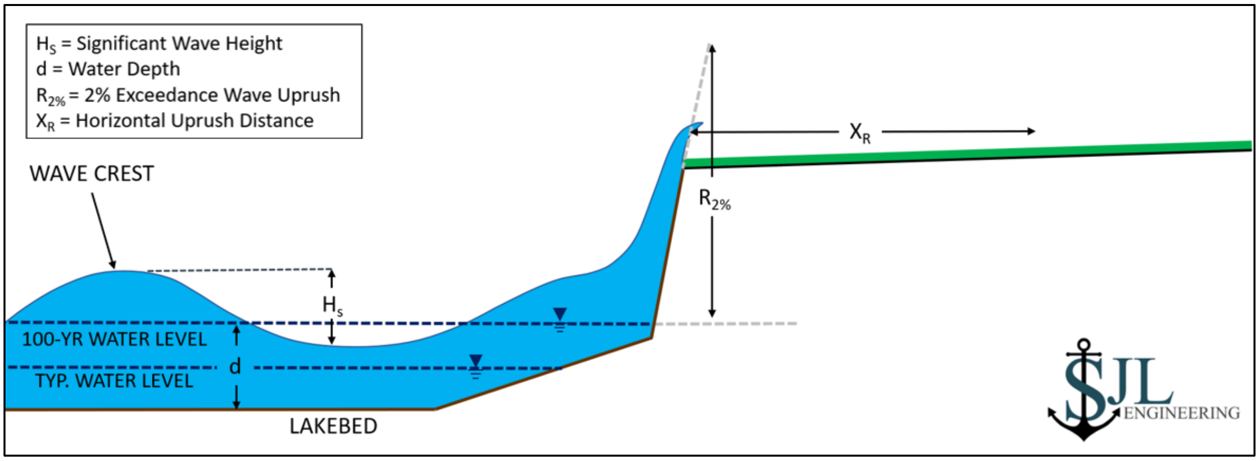

Figure 4.36 Wave uprush on a steep bank or structure resulting in overtopping of the bank or structure crest

A final consideration in the evaluation of wave effects on the shoreline for shorelines featuring shoreline protection is the rate of wave overtopping that would be expected during the 100-year flood level event. High wave overtopping rates (typically measured in litres per second, per metre of shoreline) can result in significant ponding of water and potentially erosion of the bank or table lands behind the crest of the structure. For densely developed shorelines such as the majority of the HCA Lake Ontario shoreline, it is therefore important to categorize the rate of expected overtopping and compare it to acceptable overtopping rates for various structure types and land-uses, to get a sense of which areas along the shoreline may be especially prone to flooding and damage during major wave events.

Wave overtopping was evaluated at each of the 30 nearshore profiles for both a vertical seawall and sloping, armour stone revetment using the methods published in the EurOtop Manual (2018). Three crest elevations were evaluated at each profile, the first being the actual elevation from the topographic data, and the others being 0.5 m lower, and 0.5 m higher. Table 4.9 below presents the results of overtopping calculations for each profile location, provided as a range for each structure type across the three evaluated crest elevations.

Table 4.9 Results of wave uprush and overtopping analysis at 30 locations on HCA shoreline

Profile ID	Reach	Shoreline Type	$R_{2\%}$ (m IGLD85')	X_R (m) (composite-slope)	XR (m) (Cox-Machemehl)	Seawall Overtopping (l/s/m)	Revetment Overtopping (l/s/m)
1	1	Beach	77.51	86.0	-	-	-
2	1	Structure	81.45	-	17.2	-	< 10
3	2	Structure	78.54	-	24.0	540 – 980	1370 – 3540
4	2	Structure	78.02	-	25.0	740 – 1230	2280 – 6620
5	2	Structure	77.70	-	9.9	100 – 370	230 – 1420
6	2	Structure	80.74	-	21.6	10 – 60	30 – 110
7	2	Low Bank	81.58	-	11.6	< 10	-
8	2	Structure	80.77	-	26.6	20 – 40	20 – 70
9	2	Structure	81.68	-	17.3	100 – 240	200 – 670
10	2	Structure	79.37	-	16.7	40 – 130	80 – 330
11	2	Beach	78.32	67.0	-	-	-
12	3	Structure	78.71	-	33.7	71 – 210	110 – 420
13	3	Structure	78.62	-	26.8	150 – 390	270 – 1000
14	3	Structure	79.48	-	22.6	70 – 220	160 – 620
15	3	Structure	77.82	-	22.9	390 – 790	910 – 2760
16	3	Beach	77.80	93.0	-	-	-
17	3	Structure	78.00	-	14.1	40 – 200	130 – 700
18	4	Beach	77.76	101.0	-	-	-
19	4	Low Bank	80.03	-	24.2	10 – 30	20 – 110
20	4	Beach	77.84	-	29.4	-	-
21	4	Beach	78.05	-	20.2	-	-
22	4	Beach	78.01	-	21.0	-	-
23	4	Beach	78.07	-	21.3	-	-
24	4	Beach	78.01	-	22.5	-	-
25	4	Beach	78.24	35.0	-	-	-
26	5	Structure	81.61	-	22.7	180 – 520	580 – 2900
27	7	Structure	77.20	-	7.6	30 – 120	50 – 360
28	7	Beach	77.83	3.0	-	< 10	100 – 280
29	8	Structure	78.55	-	6.6	350 – 550	930 – 2430
30	8	Low Bank	77.57	-	5.5	-	-

To provide additional context to Table 4.9, for safe vehicle or pedestrian use of the area behind the shoreline protection structure, or to mitigate damage to buildings in very close proximity to the structure, overtopping rates should generally be limited to 0.02 – 0.05 l/s/m (CIRIA, 1991). To mitigate damage to landscaping and erosion of the backshore in lee of the structure, for revetments and seawalls, overtopping rates should be limited to ~50 l/s/m (CIRIA, 1991). If the backshore features a stone or concrete splashpad or is otherwise protected against erosion and damage, the acceptable overtopping rate increases to ~200 l/s/m. It is noted that overtopping rates of between 1 – 10 l/s/m are typically adopted for design.

For information on how the wave uprush and overtopping analyses presented above were incorporated into the *flooding hazard* and *dynamic beach hazard* limit for the HCA shoreline, refer to Section 5.2 and 5.3.

5.0 MAPPING HAZARDOUS LANDS

Section 5.0 summarizes the approach to mapping hazardous lands and future considerations for updating the mapping generated for this SMP. In some locations lot specific analysis of hazards may be warranted. The hazard maps are provided in Appendix C.

5.1 Erosion Hazard Limit

The *erosion hazard* limit 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. Similarly, the updated Great Lakes Technical Guide (MNRF, 2023), currently under review by the MNRF, recommends mapping the 100-year recession rate then the stable slope allowance.

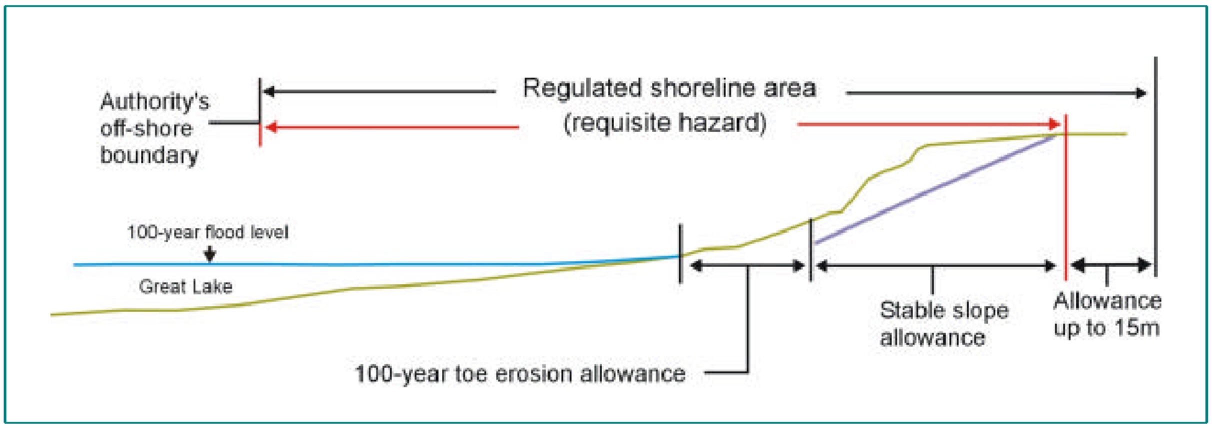

Figure 5.1 Erosion hazard setback approach (Conservation Ontario and MNR, 2005)

5.1.1 Mapping Approach

For this study, the erosion hazard limit was mapped for the eroding bank and bluff shorelines on Lake Ontario and Hamilton Harbour. Within the GIS mapping environment, the following steps were taken to map the erosion hazard limit:

- **Lake Ontario banks and bluffs:** The 2021 topographic LiDAR was used to map an appropriate toe of slope, which is the transition from the beach to steeper bank/bluff face. For sections of shoreline featuring shoreline protection structures, the toe was delineated as the waters edge. A long-term recession rate for Reaches 1 to 4 of 0.5 m/yr was then applied as a horizontal setback from the existing toe of slope (0.5 m/yr * 100 years = 50 m). Then, the land elevation at the hypothetical toe of slope in 100-years was extracted from the LiDAR grid. The toe of slope elevation was subtracted from the land elevation at 5 m increments along the shore, then multiplied by three (3) to establish the 3:1 (H:V) stable slope allowance. Finally, the horizontal setback points for the *erosion hazard* limit were joined to create a continuous line segment in GIS.

- **Hamilton Harbour banks and bluffs:** Since the majority of the Hamilton Harbour shoreline is protected, often with a vertical structure, a toe elevation of 74.2 m IGLD'85 was selected. This contour was offset by the standard 10 m recession distance (0.1 m/yr * 100 years = 10 m) for the 100-year planning horizon to account for future toe erosion. The methodology described above to establish the elevation difference from the toe position in 100-years versus the land elevation was applied. This bank or bluff height was then converted to a horizontal setback for the stable slope using the standard 3:1 (H:V) ratio. With further site specific analysis in the future, there may be sites were a submerged toe associated with shore protection in deep water is encountered (i.e., the toe elevation is lower than 74.2 m IGLD'85). If this site condition is encountered, the stable slope would be applied to an elevation lower than 74.2 m IGLD'85 in a site specific analysis.

5.2 Flooding 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, resulting in a Regulated Area that is 30 m landward from the 100-year flood level. A definition schematic of the *flooding hazard* is provided in Figure 5.2.

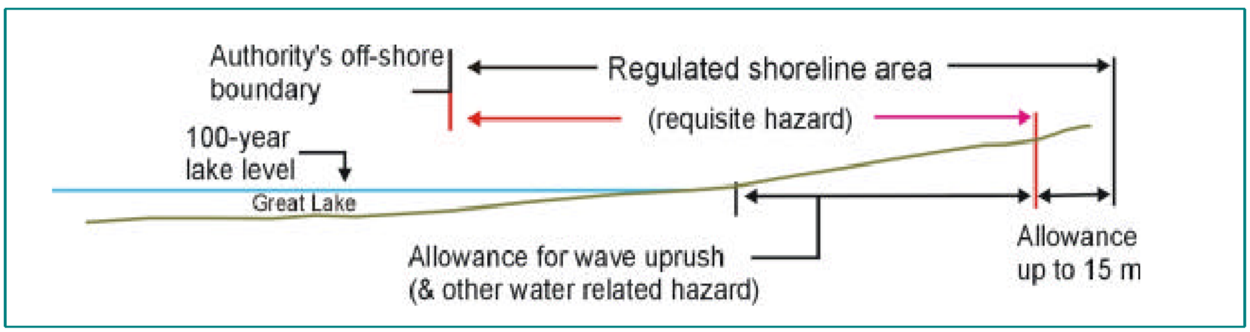

Figure 5.2 Flooding hazard definition (Conservation Ontario and MNR, 2005)

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 4.3.5, wave uprush was evaluated at 30 locations around the project geography to determine whether or not the standard 15 m setback was appropriate. In general, it was found that due to the significant wave exposure, deep nearshore, and prevalence of steep shorelines featuring shoreline protection structures prone to wave overtopping, the standard 15 m setback was insufficient for the Lake Ontario portions of the HCA shoreline (refer to Table 4.9). The results of the wave uprush and overtopping analysis were used to inform appropriate *flooding hazard* limits within each project reach, as discussed below.

5.2.1 Mapping Approach

To map the shoreline flooding hazard, the 100-year flood level of 76.2 m IGLD'85 was first mapped for the entire Lake Ontario and Hamilton Harbour shoreline. The one exception is the northern portion of Reach 8, which was not captured with the 2021 topographic LiDAR. In this area, the 2018 topographic LiDAR collected by the Region of Halton was used to establish the 76.2 m contour.

The *flooding hazard* limit was subsequently mapped landward of this line using the following rules:

A. For beaches with gentle sloping, homogeneous beach profiles, the *flooding hazard* limit is mapped as the furthest landward extent of the topographic contour corresponding to the $R_{2\%}$ uprush elevation during the 25-year wave event or the 15 m standard setback measured from the 100-year flood level, which ever is greater.

B. For beaches with well defined beach crests or beaches backed by a continuous dune or paved path which is overtopped during the 25-year wave event, the *flooding hazard* limit is mapped as the furthest landward of the average horizontal uprush setback (X_R) determined using the Cox-Machemehl equation from all evaluated uprush profiles along the beach, or the 15 m standard setback measured from the 100-year flood level, which ever is greater.

    a. Where significant wave overtopping in excess of 200 l/s/m is shown to occur during the 25-year wave event, or where there is significant variability in the horizontal uprush setback in adjacent profiles, one standard deviation is added to the average horizontal uprush setback (X_R) calculated at the uprush profiles within the reach when mapping the *flooding hazard* limit.

C. For natural banks and shoreline protection structures that <u>are not</u> overtopped during the 25-year wave event, the *flooding hazard* limit is mapped as the topographic contour corresponding to the calculated $R_{2\%}$ uprush elevation.

D. For natural banks and shoreline protection structures that <u>are</u> overtopped during the 25-year wave event, the *flooding hazard* limit is mapped as the furthest landward extent of the average horizontal uprush excursion (X_R) determined using the Cox-Machemehl equation from adjacent profiles with similar shoreline characteristics (slope, exposure, crest elevation), or the 15 m standard setback measured from the 100-year flood level, which ever is greater.

    a. Where significant wave overtopping in excess of 200 l/s/m is shown to occur during the 25-year wave event, or where there is significant variability in the horizontal uprush setback in adjacent profiles, one standard deviation is added to the average horizontal uprush setback (X_R) from the relevant uprush profiles when mapping the *flooding hazard* limit.

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 can be added (refer to Figure 5.3).

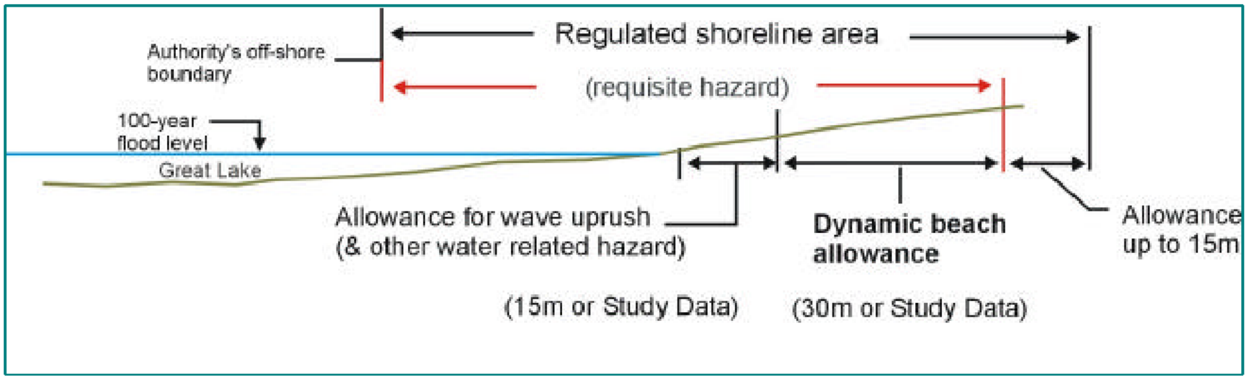

Figure 5.3 Dynamic beach hazard limit (Conservation Ontario and MNR, 2005)

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 or 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

The *dynamic beach hazard* is typically mapped as a standard 30 metre setback from the *flooding hazard* (MNR, 2001a & 2001b). This was the general approach followed for the HCA shoreline, unless the beach material extent was less than 30 m due to an engineered walkway or road with sub-grade, for example, or a transition to non-beach material (e.g., residential backyard, parking lot). In these cases, the dynamic beach allowance was mapped as the lakeward edge of the engineered walkway or road with an engineered sub-grade.

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 the approximate limit of wave action on the lakebed (MNR, 2001a). This approach recognizes 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 defined by the transition from sandy substrate to cobble lag lake bottom interpreted from the sonar imaging and land-based onshore limit defined by the dynamic beach allowance.

5.4 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 periods of higher lake levels are experienced in the future. This is particularly important for the *erosion hazard limit* since an eroding shoreline will make the static hazard lines from 2023 outdated in the future.

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 there is no published 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 updating the Technical Guide to consider 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*.
- Future periods of high or extreme lake levels are realized that would increase the 100-year flood level used for this study.
- Ice cover reductions and increased storm activity lead to recession rates higher than the standards adopted for this study.
- Dynamic beach response to fluctuating water levels and erosion occurs beyond the range of the *dynamic beach hazard* limit mapped for this study (i.e., more than 30 m inland from the *flooding hazard* limit).
- Changes to the management of discharges at the Moses-Saunders Power Dam in Cornwall, Ontario that could lead to higher lake levels.

6.0 PUBLIC ENGAGEMENT

Public engagement on the Shoreline Management Plan and updated hazard mapping is planned in the future.

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 HCA shoreline. The shore protection standard and access standard are also discussed, and guidance is provided as it relates to future upgrades and maintenance to shoreline protection structures within the HCA watershed.

7.1 Framing Management Options

When evaluating coastal hazard mitigation strategies, climate change adaptation, and strategies to increase coastal resilience for Great Lakes shorelines, the **PARAP** framework provides a logical and progressive way of grouping options. The framework is based on the PARA approach to shoreline risk mitigation (Doberstein et al, 2018), with the addition of a new option 'preserve'. A hierarchy has also been introduced, with the five broad categories considered in the following order of priority: **P**reserve natural shorelines, **A**void further development on hazardous lands, **R**etreat from and **R**e-align hazardous lands, **A**ccommodate coastal hazards, and **P**rotect infrastructure and other assets with nature-based solutions and engineered structures. Each category is described in the sections that follow, with some of the concepts in the **PARAP** framework requiring engineering support and approvals/permits from regulatory agencies prior to implementation.

7.1.1 Preserve Natural Shorelines

The principal objective of the preserve strategy is to maintain natural shorelines since they are resilient to hazards, protect infrastructure and development, and deliver social and ecological benefits. This category recognizes that in addition to the critical ecological and environmental benefits of maintaining natural shorelines, preserving nature is often the most cost effective means to mitigate risk associated with the shoreline hazards. An oblique photograph of natural beach shoreline in Reach 4 is provided in Figure 7.1.

Figure 7.1 Natural beach shoreline in Reach 4

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 natural 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, construction on lots of record, or re-development (tear down and rebuild). Avoid is a very cost effective hazard mitigation strategy since future problems are not created by present-day land use decisions. Figure 7.2 presents an example of the avoid strategy for an eroding shoreline on the north shore of Lake Ontario where a large natural buffer was incorporated into the residential subdivisions.

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

7.1.3 Retreat and Re-align

Retreating from and re-aligning land uses on hazardous lands is a broad coastal risk mitigation strategy that requires municipal involvement in planning and extensive community engagement to co-develop solutions to change land use(s) and move assets away from natural hazards. Retreat and re-align strategies represent the third approach to mitigate coastal hazards, adapt to climate change, and increase coastal resilience. With the existing density of shoreline development along much of the Hamilton Conservation Authority jurisdiction, there may be limited opportunities for this PARAP strategy.

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 to be successful, 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 7.3 presents an example of the retreat concept on Lake Erie that includes extending an existing road through farmland (New Scotland Line) and relocating buildings presently on the edge of an actively eroding bluff to a location landward of the new road (white boxes). This strategy requires undeveloped lands behind existing development, which is uncommon in the study area, leading to limited locations for its application. However, at risk buildings could be re-located to new locations inland.

Figure 7.3 Road and home re-alignment further inland to reduce erosion threats

7.1.4 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, lowest 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 urban stormwater management systems, upgrading emergency plans and emergency vehicle fleets for first responders, and completing emergency preparedness planning. Figure 7.4 presents some examples of how existing buildings can be floodproofed (left) and a specialized emergency access vehicle capable of using roads inundated by floodwaters (right).

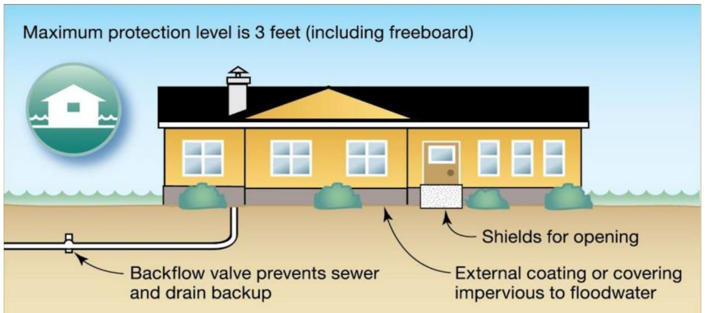

Figure 7.4 Examples of measures for floodproofing an existing building (left) and a specialized emergency vehicle with the ability to navigate through floodwaters (right)

7.1.5 Protect

The protect strategy is focused on safeguarding people, property, and infrastructure from exposure to shoreline hazards, with the use of nature-based solutions (first priority) and traditional engineered structures (second priority). Beach nourishment and dune restoration strategies are examples of nature-based protection options, as depicted in Figure 7.5 at nearby Burlington Beach. For shorelines with relatively low wave exposure, such as those within Hamilton Harbour, hybrid grey-green (traditional–nature based) protection structures can also be implemented, such as stone revetments fronted by vegetated buffers, rock shoals, or habitat islands with vegetation. Figure 7.6 provides an example of the existing use of habitat islands and rock shoals as shoreline protection within Hamilton Harbour.

Figure 7.5 Foredune restoration at Burlington Beach with beachgrass

Figure 7.6 Existing habitat islands and shoals in Reach 8, Hamilton Harbour

Historically, traditional engineering structures have been the most common approach deployed to address coastal hazards in Ontario for existing shoreline development and at-risk infrastructure. Where nature-based solutions and hybrid grey-green protection strategies are not feasible, a variety of engineered shoreline protection structure types can be considered to reduce flooding or erosion risk, including conventional, shore-parallel shoreline protection structures such as revetments, seawalls, and breakwaters. These types of structures are already prevalent along the HCA shoreline. Refer to Figure 7.7 which depicts a conventional, multi-layer armour stone revetment on the HCA Lake Ontario shoreline.

Figure 7.7 Conventional, multi-layer armour stone revetment on the HCA Lake Ontario shoreline

Before implementing a traditional, engineered shoreline protection structure however, the short and long-term impacts of the proposed structure on coastal processes such as sediment transport and lakebed downcutting must be well understood and mitigated through design. As such, coastal structures should always be designed by qualified professionals following accepted, industry standard design guidelines, and be permitted through the HCA and where necessary, other governmental organizations such as the Ministry of Natural Resources and Forestry (MNRF) and the Department of Fisheries and Oceans (DFO). Additional guidance on shoreline protection structures and their application along HCA shorelines is provided in the following sections.

7.2 Protection Works Standard

The protection works standard is defined in Section 6.0 of the PPS (2020) as the combination of non-structural or structural works and allowances for slope stability and flooding/erosion to reduce the damage caused by *flooding hazards, erosion hazards,* and *other water-related hazards*, and to allow access for their maintenance and repair.

It is acknowledged that the term "protection works" is somewhat misleading, in the sense that total protection from shoreline hazards cannot always be assured (i.e. structural integrity cannot be assured for the long term). However, if designed by a qualified professional and there are no adverse environmental impacts, it may be possible to use the protection works standard to reduce the 100-year planning horizon for the *erosion hazard* limit, as outlined in this section.

In general, where actions intended to address shoreline hazards involve the installation of protection works, emphasis should be placed on non-structural, and nature-based approaches, as outlined in Section 7.1. Protection works using traditional, structural approaches should only be considered where such actions are required to protect existing developments that are at high risk, where non-structural or nature-based solutions are not feasible, and where environmental and downdrift impacts have been appropriately addressed and incorporated into the design of the protection works.

To meet the requirements of the protection works standard, all three criteria must be met:

1. Protection works must be of sound, durable construction, appropriate for the conditions of exposure, and be designed by a qualified coastal engineer according to acceptable, industry standards, including the production of engineering drawings, construction specifications and a design brief, at minimum. Limited guidance on shoreline protection structures suitable for the HCA shoreline is provided in 7.2.1.

2. Protection works must be designed based on conditions commensurate with a 100-year design event, at minimum, and account for potential flanking at the alongshore limits of the structure (i.e., the property boundary), and/or appropriate transitions to neighbouring infrastructure and lots.

3. The design and installation of protection works must be such that access to the protection works by heavy machinery, for regular maintenance purposes and/or to repair the protection works should failure occur, is accommodated through the application of the access standard (refer to Section 7.3).

Designing a shore protection structure based on conditions commensurate with the 100-year design event, does not suggest that the structure will have a design life of 100-years. Estimates of structure design life are based, to a large degree, on past experiences which have shown that the shoreline environment around the Great Lakes is very harsh, and that necessary maintenance of shoreline structures is often neglected. There is no mechanism to ensure that regular monitoring and maintenance is carried out by current or subsequent owners of shoreline properties. Moreover, ongoing lakebed downcutting (vertical erosion), erosion of adjacent shorelines that remain unprotected or feature failed or ineffective shore protection structures, and uncertainties about future water level and storm exposure will ultimately impact the effective design life of a structure. In a study of the historical changes and durability of structures in Stoney Creek, between 1934 and 1979, Keizer (1981) found that, on average, 71% of shoreline structures are damaged or destroyed within 10 years of construction, and 87% within 20 years. Although these percentages have likely decreased since the implementation of more stringent policies on shoreline armouring and advances in coastal engineering, based on recent experience on the Great Lakes, they are likely still reasonably high.

For new shoreline protection structures, provided the structure meets the three criteria listed above, the following guidelines are recommended as general limits to the accepted effective design life of shore protection structures (MNR, 2001):

- For shorelines with low recession rates (i.e., ≤ 0.3 m/yr), maximum effective design life = 25 – 35 years.
- For shorelines with moderate recession rates (i.e., 0.3 m/yr to 0.7 m/yr), maximum effective design life = 15 – 25 years.
- For shorelines with high to severe recession rates (i.e., ≥ 0.7 m/yr), maximum effective design life = 10 – 15 years.

The recession rates used to categorize effective design life should be those associated with natural, unprotected shorelines, as is the case when evaluating the average annual recession rate for mapping the *erosion hazard*. As was presented in Section 5.1, a long-term average annual erosion rate of 0.5 m/yr has been assumed for the HCA Lake Ontario shoreline in the delineation of the *erosion hazard*. Based on the review of past erosion rates and the comparison of historical photographs completed as a component of this work and presented in Section 4.1, the actual and future erosion rates for the HCA shoreline in the absence of shoreline protection may be even higher. As such, at minimum, the HCA shoreline falls into the “moderate recession” category described above (i.e. AARR = 0.3 m/yr to 0.7 m/yr). It is therefore recommended that the maximum effective design life accepted for coastal structures as a component of the protection works standard be 25 years within the HCA watershed.

Where the criteria laid out herein has been met and the protection works standard is justified, the protection works standard may be used as a means to reduce the 100-year planning horizon for the *erosion hazard* limit, at the discretion of the HCA. The equation to calculate the erosion allowance component of the *erosion hazard* where the protection works standard is applied is provided as follows:

$$Erosion\ Allowance = \left[\frac{(100 - n)}{100}\right] \times 100\ year\ Recession\ Rate$$

where n = the effective design life for the protection works, recommended herein as 25 years or less.

The application of the protection works standard for the reduction of the planning horizon in the evaluation of the *erosion hazard* is illustrated graphically in Figure 7.8 below. Figure 7.9 presents a graphical depiction of the same shoreline at the end of the 100-year planning horizon, at which point the structure has failed, shoreline recession has resumed over the remainder of the planning horizon, and the stable slope allowance is now replicated by the actual position of the receding shoreline.

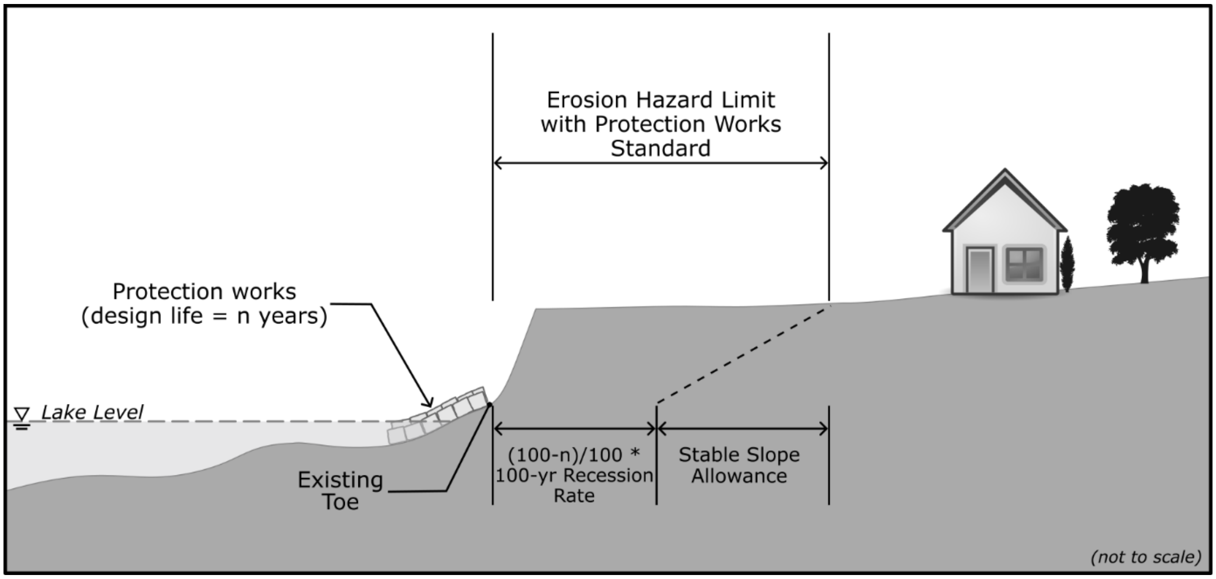

Figure 7.8 Protection Works Standard application

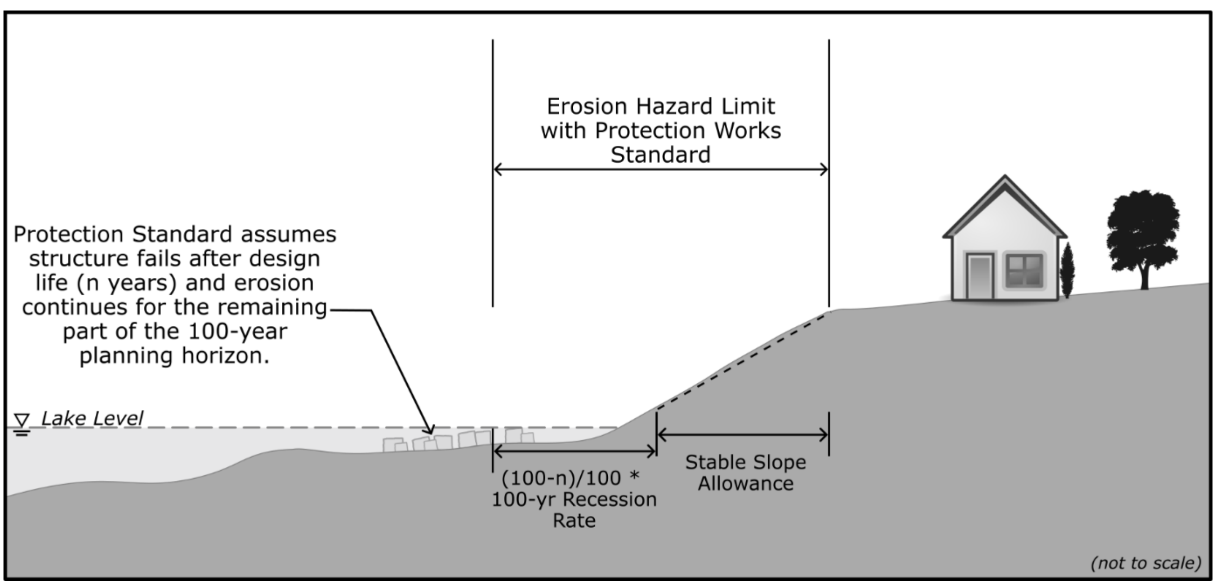

Figure 7.9 Protection Works Standard at the end of the 100-year planning horizon

The application of the protection works standard is generally intended for new shoreline protection structures. The standard may, at the discretion of the HCA, be applicable to existing shoreline protection works, provided the structure is inspected and assessed by a qualified coastal engineer. In this case, a structural assessment report should generally be provided affirming that the structure, in its present state, is suitably constructed for the shoreline type, natural recession rate, and conditions to which it is exposed. The remaining effective design life of the structure should be evaluated by the engineer, accounting for its condition but also its age. It is recommended that the maximum effective design life to be accepted through such an assessment be 25 years, consistent with the recommendations made above.

7.2.1 Traditional Shore Protection Guidance

As stated above, in general, where actions intended to address shoreline hazards involve the installation of protections works, emphasis should be placed on nature-based or hybrid grey-green approaches. Protection works using conventional, structural approaches should only be considered where such actions are required to protect existing developments that are at high-risk, where nature-based or hybrid solutions are shown to not be feasible, and where environmental impacts have been appropriately addressed and incorporated into the design of the protection works.

Protection structures should generally be shore-parallel and placed against the existing bank or bluff with minimal lakeward projection to mitigate potential impacts to longshore sediment transport and other nearshore coastal processes. Shore protection structures should preferably 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.

7.2.1.1 Lake Ontario Shoreline

For exposed, high-wave energy shorelines such as the Lake Ontario portion of the HCA shoreline, 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 (downcutting) directly in front of the structure. This increases wave exposure due to the increased depth and can lead to failures if the structure toe is not founded deep enough or designed properly. Sloping structures are also less likely to fail due to ground or hydrostatic pressures compared to vertical structures, particularly when vertical structures are comprised of impermeable materials (e.g., concrete, sheet pile). Figure 7.10 provides an example of a vertical concrete block seawall failure on Lake Ontario during the high water period in 2017 and 2019. The failure was likely caused by a combination of erosion at the toe of the structure and hydrostatic pressure buildup behind the wall due to wave overtopping and groundwater.

Figure 7.10 Failed vertical stacked concrete block seawall on Lake Ontario

A significant advantage to sloping structures, particularly those comprised of multiple layers of stone, is that when properly designed, they tend to have gradual failure mechanisms such as displacement of structure elements (stones) or settlement over relatively long periods of time. As such, sloping structures can generally have their design life extended through monitoring and relatively straightforward maintenance. By contrast, vertical structures tend to fail abruptly and catastrophically during a major storm event. As such, maintenance of vertical structures is less straightforward, with pending failures often not being readily predictable.

A typical design for a sloping stone revetment suitable for Great Lakes shorelines would include an outer “primary” stone course, with underlaying courses of smaller ‘filter’ stone. The primary stone layer(s) can be comprised of a single layer of very large, tightly packed, blocky armour stone (quarried stone), or more conventionally of multiple layers of randomly placed irregular armour stone or field stone. Single-layer armour stone structures require a smaller volume of material; however, individual stone sizes must be larger, and the cost associated with blocky armour stone is typically higher per tonne than irregular armour stone. Both revetment types are prevalent throughout western Lake Ontario including on the HCA shoreline, with the selection between the two often being based on the availability of materials and cost, as both structure types can be designed to effectively resist wave loading and mitigate erosion for exposed Lake Ontario shorelines. Figure 7.11 presents examples of single-layer, blocky armour stone revetments, while Figure 7.12 presents examples of conventional, randomly placed, multi-layer armour stone revetments. Concept-level cross sections for both structure types are provided in Figure 7.16 and Figure 7.17.

Figure 7.11 Examples of single-layer, blocky armour stone revetments on the Great Lakes

Figure 7.12 Examples of conventional, randomly placed, multi-layer armour stone revetments on the Great Lakes constructed with irregular armour stone (left) and field stone (right)

When designing a sloping structure, special attention must be given to the toe and crest details. 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. The depth of embedment should be higher where vertical downcutting of the lakebed is ongoing, such as is the case for the exposed HCA shoreline. This toe detail is a critical component of the design with significant impacts on the longevity of the structure. The crest of the structure must be carefully designed to either be sufficiently high to limit wave overtopping to acceptable levels, or where the elevation of the table lands prevents this, the crest should feature oversized stone backed by a stone or concrete splashpad or secondary seawall to absorb wave impacts and provide drainage pathways for overtopped water to return back to the lake. The stone gradation used for each layer of a revetment must be carefully selected based on the wave conditions to which the structure will be exposed. Finally, termination details at the ends of the structure including protection against flanking and transitions to adjacent infrastructure must be carefully considered by the designer. These are all examples of design elements that need to be evaluated on a site-specific basis by a qualified professional.

In some cases, due to space limitations or specific shoreline characteristics, vertical, or near-vertical structures may be necessary. In these cases, the structure can be comprised of stacked armour stone, cast-in-pace concrete, or steel sheet piles. Figure 7.18 provides a concept-level cross section of a stacked armour stone seawall. The design of vertical structures requires that the toe is founded deep enough to resist overturning throughout its design life, accounting for ongoing lakebed downcutting at the structure toe, a process that will likely accelerate due to the presence of the vertical wall. A stone scour mat or stone berm placed against the vertical structure may be effective in mitigating or slowing erosion of the lakebed at the toe, and will provide additional wave dissipation and stability to the overall structure (refer to Figure 7.13). Another critical design consideration for vertical structures, particularly those comprised of mostly impermeable materials (e.g., concrete or steel sheet pile), is the crest protection and drainage provisions to ensure that overtopped water does not erode behind the structure and has a pathway to return to the lake, thereby mitigating landside flooding and the buildup of hydrostatic pressure behind the wall. Any vertical structure proposed for the exposed Lake Ontario shoreline should be designed on a site-specific basis by a qualified professional with experience in the design of coastal structures in similar environments.

Figure 7.13 Examples of stone berms placed in front of vertical structures to reduce erosion at the toe, reduce wave reflection and overtopping, and provide added stability to the structure

7.2.1.2 Sheltered, Low-Energy Shorelines & Beach Environments

For shorelines with relatively low-wave exposure such as those within parts of Hamilton Harbour, preserving natural shoreline buffers and vegetated banks should generally be prioritized where erosion risks are low. Where shoreline protection is warranted, nature-based or hybrid grey-green shore protection structures are preferred over traditional revetments and seawalls. 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 supplementing cobble or shingle shorelines with additional, oversized cobbles interspersed with riparian vegetation. Beach nourishment and dune restoration are also important forms of nature-based shoreline protection for dynamic beach environments, such as those within Reach 4. These approaches can assist in restoring a natural beach-dune system whereby dune vegetation is able to establish and trap sand, thereby rebuilding the dune system and increasing the overall resilience of the beach to erosion during periods of high lake levels and major storms. Figure 7.14 presents an example of a successful dune restoration program at Port Stanley on Lake Erie.

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

Hybrid grey-green shoreline protection structures may be suitable for low-energy shorelines at some locations within Hamilton Harbour. Hybrid solutions may 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. Concept-level cross sections of two such approaches suitable for shallow, low-energy shorelines are provided in Figure 7.19 and Figure 7.20. Artificial habitat island and rock shoals are examples of hybrid grey-green infrastructure that can provide erosion protection to shorelines and have already been implemented at locations within Hamilton Harbour (refer to Figure 7.6). In some cases, existing shoreline protection structures can be supplement with nature-based elements to improve their overall stability, performance and longevity while restoring a more natural shoreline.

Traditional shoreline protection structures are generally not recommended for dynamic beach environments. However, where structural protection is required to protect existing development or infrastructure such as pedestrian pathways or buildings, as is the case at multiple locations within Reach 4, an armour stone beach curb or partially buried revetment may be appropriate. A beach curb is a low-crested wall placed at the back of the beach, preferably well behind the beach crest that develops throughout the typical range of beach profiles. A partially buried revetment is a sloping stone structure placed in a similar location and largely buried below grade. These structures must be founded sufficiently deep to resist settlement or undermining through the entire range of anticipated beach profile adjustments. Figure 7.15 presents an example of an armour stone beach curb on the HCA shoreline.

Figure 7.15 Example of a stacked armour stone beach curb at Confederation Park, Hamilton

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.

It is noted that the guidance provided in this section is for general use only. The design of shoreline protection is site-specific, as local shoreline conditions and wave exposure can vary significantly over short distances of shoreline. The design of shore protection should always be completed by a qualified coastal engineer, based on local design conditions, including (but not limited to) wave exposure, bathymetry and topography, shoreline geometry, background recession and downcutting rates, geology, availability of materials, and considerations related to land-use and the proximity of development.

7.2.1.3 Monitoring, Maintenance and Structure Upgrades

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 qualified professional. Regular monitoring should include photographs and visual observations documenting any apparent movement of displacement of structural elements such as stones, settlement, or loss of material. For vertical walls, the observer should regularly check for signs of bending, tipping, leaning, cracking, or bulging. For structures which transition to unprotected shorelines at property boundaries, flanking of the structure (ongoing erosion adjacent to or behind the end of a structure) should be carefully monitored. A qualified professional engineer should be contacted immediately 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 timeline fashion by a contractor with experience in the construction of coastal structures. Appropriate maintenance measures should be determined by a qualified professional. It is recommended that long-term monitoring and maintenance plans be a requirement of regulatory approvals for new shoreline protection structures.

For much of the HCA shoreline which features existing coastal structures in varying conditions, property owners may wish to proactively upgrade the structures. For existing sloping stone structures, this may include the placement of additional, properly sized stone on the structure slope, at the structure toe or on the structure crest. For existing vertical walls this may include placing a stone berm against the structure or raising the structure crest through the addition of a concrete cap or layer of blocky armour stone. A common upgrade to shoreline protection structures is the addition of overtopping protection through the placement of a rip rap or concrete splash pad with appropriate drainage provisions behind the crest of an existing structure. Suitable upgrades for existing shoreline protection structures will be site-specific and dependent on the nature and condition of the existing shore protection. As such, upgrades to shoreline protection should be assessed and designed by a qualified professional based on site-specific conditions.

7.2.1.4 Shore Protection Concepts and Costs

Construction cost estimates are provided in Table 7.1 for armour stone revetments and armour stone seawalls on Great Lakes shorelines. Costs are provided per metre of armoured shoreline (measured in a shore-parallel direction). Concept-level cross sections are provided in the figures that follow. Costs and concept-level cross sections are not provided for vertical concrete or steel sheet pile structures, as these structures are generally not recommended for new, private shoreline protection.

In general, structures designed and constructed for high-energy, exposed shorelines are much more expensive than hybrid grey/green, nature-based, or traditional structures for low-energy environments. Provided cost estimates are based on unit rates and construction quotations for projects on similar shorelines throughout Ontario, and are indexed to 2023 dollars. Costs may vary from the provided ranges depending on site-specific considerations, material availability, location, contractor availability and site access, among other things. Costs listed in Table 7.1 do not include any applicable taxes, contingencies, costs associated with project permitting, engineering design fees or other professional costs associated with the implementation of shoreline protection. A minimum contingency of 25% should be added to the costs provided when considering the affordability of implementing shoreline protection.

Table 7.1 Estimated ranges of probable construction costs for shoreline protection concepts suitable for portions of the HCA shoreline

Shoreline Exposure to Waves	Shoreline Protection Type	Typical Construction Costs, per metre (in 2023 CAD)
High	Armour Stone Revetment	$3,200 - $5,500 /m
High	Stacked Armour Stone Seawall	$3,000 - $5,000 /m
Low	Stone Revetment/Berm (armour or rip rap)	$1,200 - $2,400 /m
Low	Stacked Armour Stone Wall or Beach Curb	$1,300 - $2,600 /m

The information provided in this section including estimated ranges of probable construction costs and the conceptual cross-sections presented below are provided 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 should meet the criteria laid out in Section 7.2, and will require site-specific work permits from the HCA, with additional permits or approvals required from the Ministry of Natural Resources and Forestry (MNRF) and the Department of Fisheries and Oceans (DFO) should any portion of the structure be situated lakeward of the seasonal high water line or be located on crown land. For permits and approvals to be issued, the proposed shoreline protection structures must adhere to the specific policies of the regulatory bodies listed above, and potentially others, depending on the location and purpose of the structure.

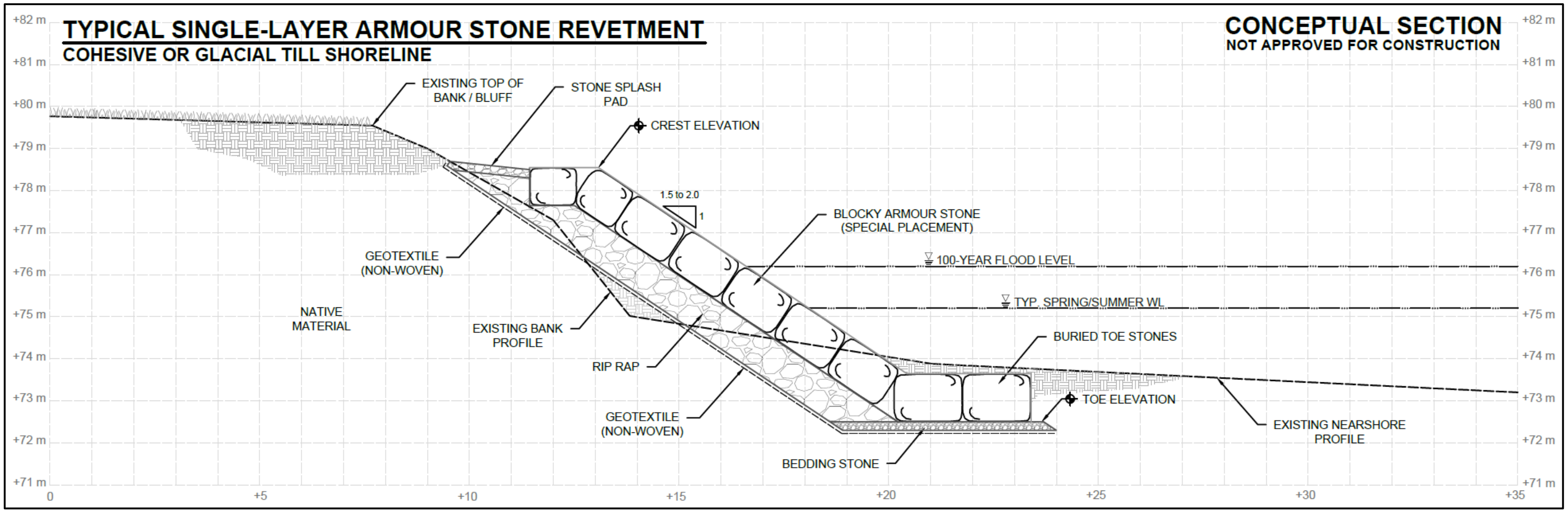

Figure 7.16 Typical single-layer armour stone revetment for cohesive or glacial till shoreline (concept only)

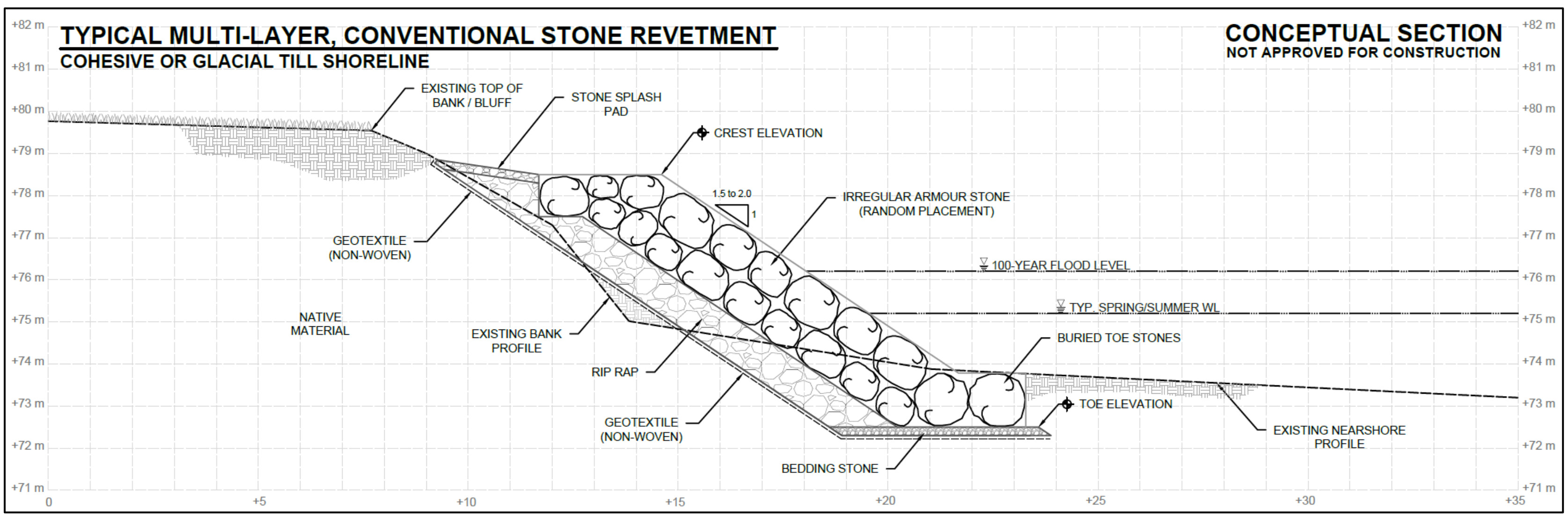

Figure 7.17 Conventional, multi-layer, randomly placed armour stone revetment for cohesive of glacial till shoreline (concept only)

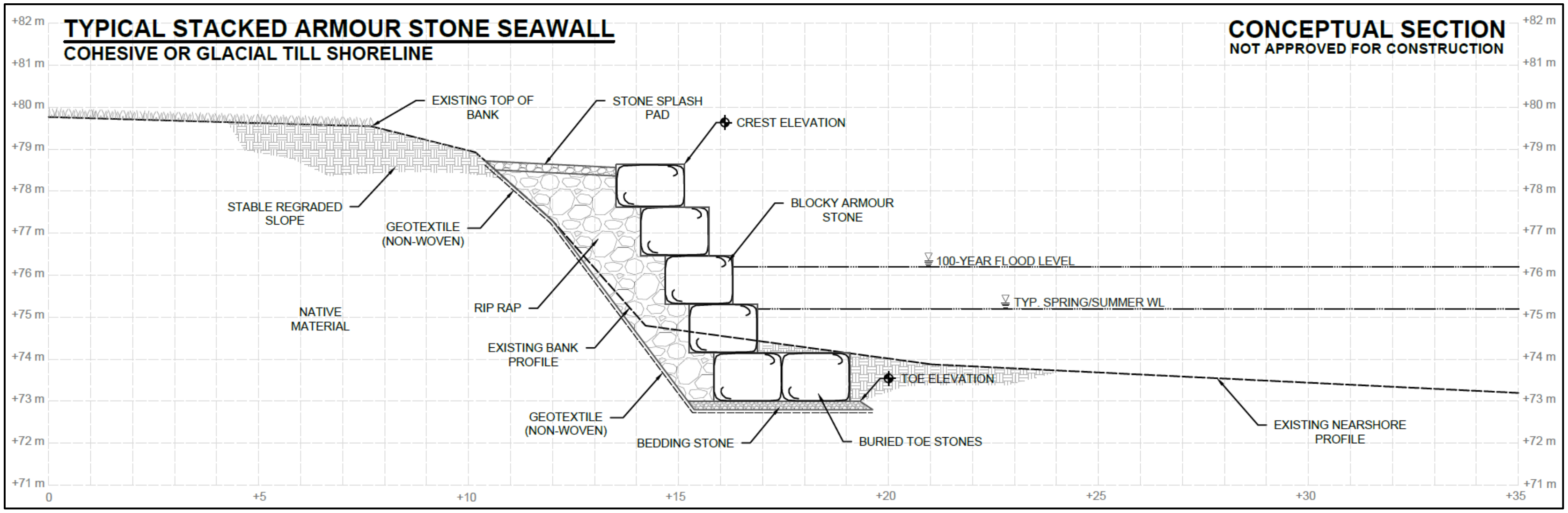

Figure 7.18 Typical stacked armour stone seawall for a cohesive or glacial till shoreline (concept only)

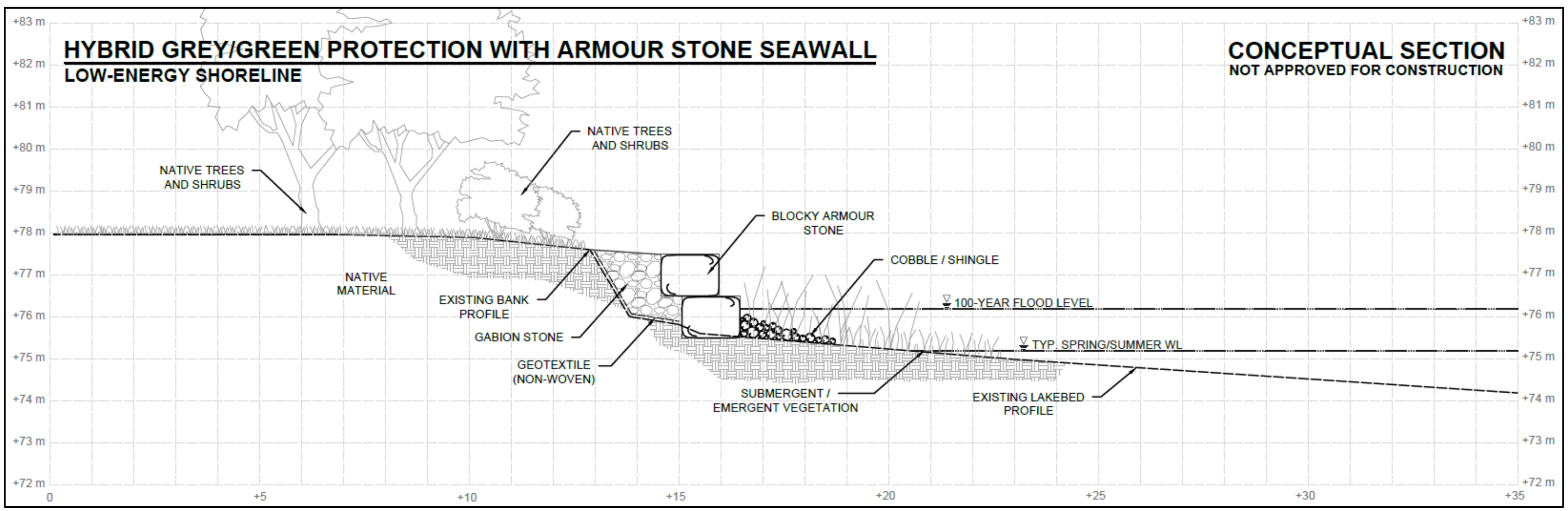

Figure 7.19 Aspects of a hybrid grey-green shoreline protection scheme with a stacked armour stone seawall for low-energy shorelines

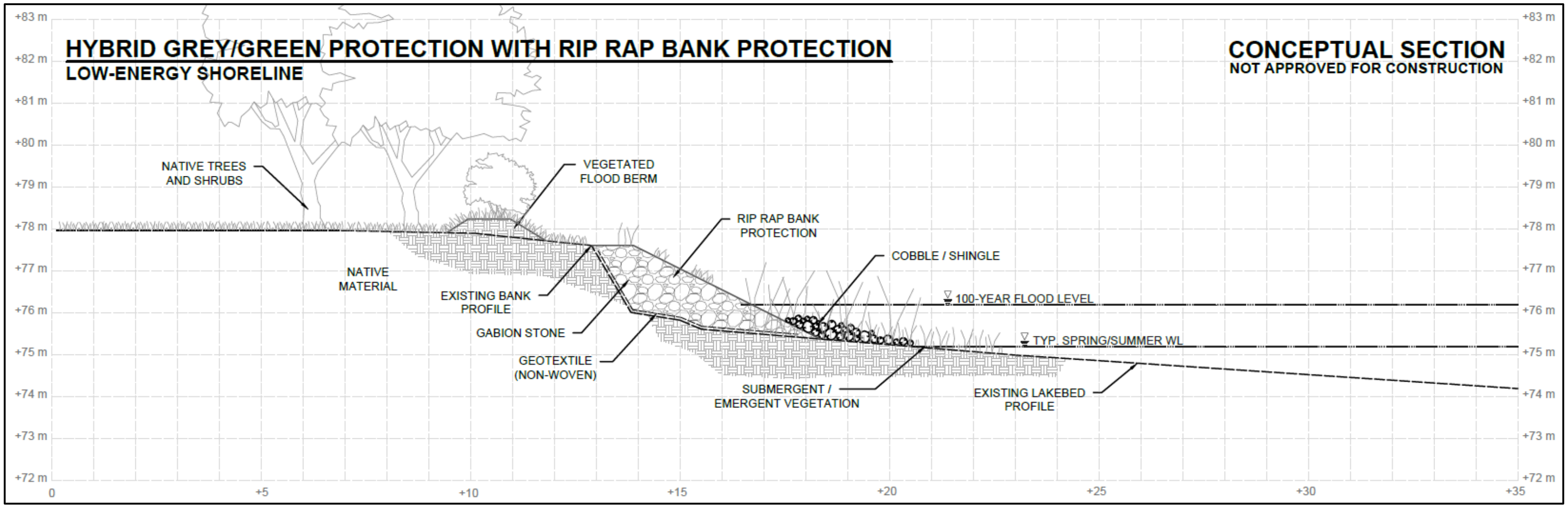

Figure 7.20 Aspects of a hybrid grey-green shoreline protection scheme with rip rap bank protection for low-energy shorelines

7.3 Access Standard for Erosion and Flooding

The access standard is defined in Section 6.0 of the PPS (2020) as methods or procedures to ensure safe vehicular and pedestrian movement, and access for the maintenance and repair of protection works, during times of *flooding hazards*, *erosion hazards,* and/or *other water related hazards.* To this effect the application of the access standard is discussed separately below as it pertains to the *flooding hazard,* and the *erosion hazard.*

7.3.1 Flooding Hazard

Access is an important consideration during flooding events with the primary concern being the ability to ensure that building occupants can safely evacuate, and that police, fire protection, ambulance and other essential services can continue to be provided. In general, development and site alteration applications should be directed to areas away from hazardous lands, as per the PPS (2020). If development is not possible outside of the hazardous lands due to lot constraints or other reasonable factors, then development on the least hazardous portion of the lot may be considered (pending review by the HCA) as presented in Figure 7.21. If the development is located in such a location that it is surrounded by floodwaters and inaccessible by people or emergency vehicles, then it is not consistent with Section 3.1.7 (b) of the PPS (2020), which states that vehicles and people must have a way of safely entering and exiting the area during times of flooding, erosion, and other emergencies. As a general rule, for an access route to be accessible during the 100-year flooding event (i.e., the conditions associated with the *flooding hazard*), the depth of flooding must be less than 0.3 m, consistent with the approximate elevation of the exhaust on most vehicles.

Access requirements for development and site-alteration are, however, not limited to lot-level flooding. If the only ingress and egress route to the area in which the lot is located does not have safe access during the 100-year flooding event due to inundation of the roadway by more than 0.3 m, than the area in which the lot is located does not meet the access standard. In turn, development on any portion of the lot would not meet the access standard, as is required by Sections 3.1.2 (c) and 3.1.7 (b) of the PPS (2020).

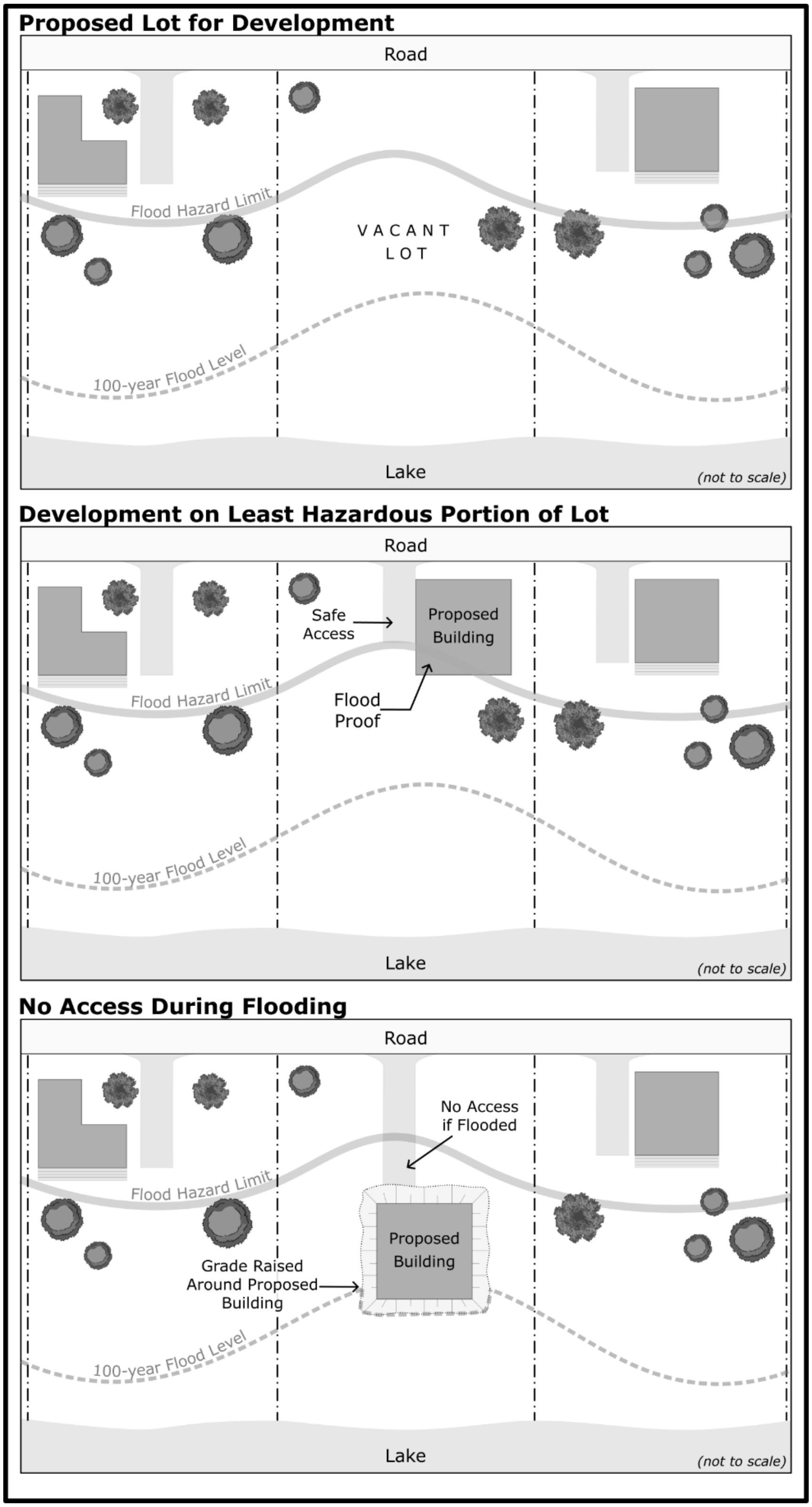

Figure 7.21 Access requirements for development near the flooding hazard (middle panel meets access standard, bottom panel does not meet the standard)

7.3.2 Erosion Hazard

During its design life, a shoreline protection structure will generally require routine maintenance to continue to provide its intended protection and maximize its design life. Eventually, a structure may need to be replaced or extensively refurbished with heavy construction equipment to ensure that the appropriate level of protection is being provided. Therefore, to provide construction access, a minimum 5 m corridor from the property boundary to any buildings should be provided, plus another 5 m corridor from the inland extent of the *erosion hazard* limit to any buildings or other permanent infrastructure. Refer to Figure 7.22. These access corridors should be integrated into the proposed development plan for sites subjected to the *erosion hazard*.

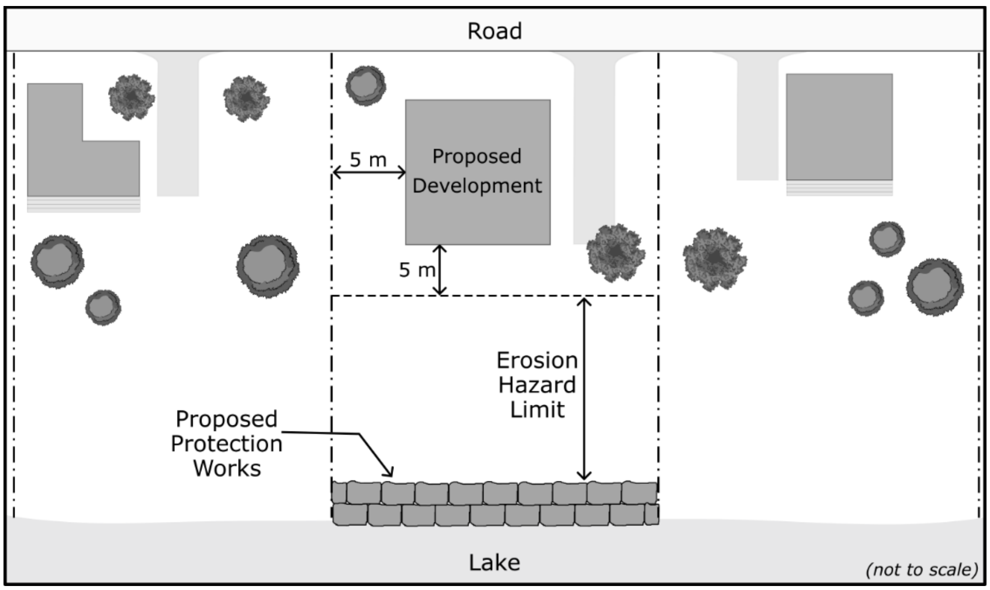

Figure 7.22 5 m Access Standard for the Erosion Hazard

7.4 Technical Summaries and Reach Recommendations

Shoreline management recommendations for the individual reaches are provided in Appendix A following the PARAP framework hierarchy. The recommendations are provided for each reach in a standardized reach summary template. Each template includes a map with the reach boundaries, a reach overview, sample photographs from the oblique aerial photo database, the Great Lakes shoreline ecosystem classification, shoreline conditions and structure types encountered within the reach, specific challenges related to the mapped shoreline hazards, the technical basis for shoreline hazard mapping, and the reach-specific management recommendations to address shoreline hazards. Each reach summary also includes a disclaimer for use by others. Refer to Table 7.2 for a copy of the blank reach summary template. Completed reach summaries for each project reach are provided in Appendix A.

Table 7.2 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">Reach Overview</td></tr>
<tr><td colspan="2">• Physical description of reach and typical site photographs</td></tr>
<tr><td>Typical Photo</td><td>Location of Interest Photo</td></tr>
<tr><td colspan="2">Great Lakes Shoreline Ecosystem Classification</td></tr>
<tr><td colspan="2">• Overview of ecosystem classification with shoreline reach</td></tr>
<tr><td colspan="2">Shoreline Conditions and Structure Type</td></tr>
<tr><td colspan="2">• Information on natural versus hardened shoreline, statistics on shore protection types</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">• Reach specific management actions using the PARAP framework</td></tr>
<tr><td colspan="2">Use Disclaimer</td></tr>
<tr><td colspan="2">The information in this reach summary was prepared for Hamilton 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>

8.0 STUDY CONCLUSIONS AND RECOMMENDATIONS

The overall study conclusions and recommendations are provided in Section 8.0. Detailed descriptions of study findings, conclusions and recommendations at a reach scale are provided in Appendix A.

8.1 Key Study Findings

The key study findings from the Hamilton Conservation Authority SMP include:

- Reaches 1 to 3 on Lake Ontario are characterized as eroding cohesive sediment shorelines. These shorelines have been extensively developed and feature almost complete armouring (i.e., 85%).
- While the rate of shoreline erosion has been reduced with shoreline protection in Reach 1 to 3, the lake bottom continues to erode and the nearshore is very deep and steep, especially when compared to naturally eroding banks and bluffs at other cohesive shoreline sites in the Great Lakes.
- The deep and steep nearshore conditions allow large storm waves to propagate close to shore and break on the existing shoreline protection structures. This wave exposure, combined with the erosive nature of the soils, substrate, and low landside elevations susceptible to wave overtopping, are the principal reasons frequent shoreline protection maintenance is required for the shoreline protection along the lake.
- As erosion continues in Reaches 1 to 3, both on the lake bottom and shore, some lots may ultimately be too small to facilitate development or re-development. In such situations, re-aligning the land use to something more compatible to the severity of the hazards should be pursued.
- Shoreline armouring has significantly reduced the rate of sediment supply in the littoral cell from Jordon Harbour to the federal navigation channel, which in turn negatively impacts the availability of sediment to build and maintain local beaches. This reduction in sediment supply combined with the deep nearshore conditions for most of Reach 1 to 3, limits the occurrence of beaches within this portion of the HCA shoreline to a small number of fillet beaches.
- The combination of shoreline armouring in the littoral cell and the longshore barriers at the Fifty Point Headland and Newport Yacht Club jetty have reduced the supply of sand and gravel to the beaches in Reach 4 below historical rates (i.e., current supply is significantly less than 1800s).
- The federal navigation channel to Hamilton Harbour was first stabilized in 1826. Sediment that would have historically been transported north to Burlington Beach is now trapped on Hamilton Beach or deflected offshore. Similarly, sediment that would have been transported south to Hamilton Beach is now trapped north of the jetties or deflected offshore.

- Further sediment transport modelling and analysis is required to understand rates and patterns of sediment transport in Reach 4 and around the federal navigation channel jetties. It is possible that structural modifications to the southern jetty could trap the sand that is currently being deposited (and ultimately dredged) in the navigation channel. Increasing sediment accumulation in the fillet beach south of the navigation channel in Reach 4 would also provide natural protection for the shoreline, which has historically eroded and recently experienced a significant revetment failure.

- Erosion mitigation in Reach 4 has historically focused on hard engineering structures. Nature-based solutions, including beach nourishment, foredune restoration, and re-aligning the trail further inland should be considered in the future.

- Significant enhancements could be made to the public boat launch at the Reach 5/6 boundary in Hamilton Harbour by re-aligning the stone breakwater, which is presently open to the longest fetch within the harbour. This exposure leads to significant wave agitation for the floating docks during wind events from the west and southwest.

- Reaches 5 to 7 within Hamilton Harbour are almost 100% armoured and future management activities should be focused on maintaining and upgrading existing shoreline protection structures. Opportunities to integrate habitat enhancement features should be explored, where possible.

- The bluffs in Reach 8 should be monitored, as signs of toe erosion and slope instability were observed at the Woodland Cemetery. Nature-based or hybrid grey-green erosion protection could be considered for this portion of shoreline in the future.

- The coastal hazard mapping completed for this SMP was generated based on technical analyses of historical lake levels, shoreline recession, and wave climate, as is outlined in the Technical Guide (MNR, 2001). It may be necessary to update the hazard mapping in the future to account for the impacts of a changing climate based on revised or updated guidance from the Province of Ontario.

8.2 Next Steps to Reduce Exposure to Coastal Hazards and Increase 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 incorporated in the City of Hamilton Official Plan through appropriate updates, policies, mapping, and zoning.

- 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 PPS (2020) requirements provide minimum thresholds, while planning authorities can adopt higher standards.

- The regulatory hazard mapping generated for this study is the minimum requirement to evaluate applications for development and site alteration, 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.

- A hierarchy of options to address natural hazards and existing coastal management challenges along the lake were provided based on the PARAP framework, including; **P**reserve natural shorelines, **A**void further development on hazardous lands, **R**etreat and **R**e-align hazardous lands, **A**ccommodate natural hazards, and **P**rotect with nature-based solutions and engineered structures. Adopting this framework will reduce exposure to coastal hazards in the future and increase resilience with nature-based solutions.

- Nature-based solutions and hybrid grey-green shore protection solutions should be the first 'Protect' approach considered to address coastal hazards, such as erosion and flooding, particularly in areas of low-wave energy such as Hamilton Harbour or the sandy beaches in Reach 4. In Reaches 1 to 3, where traditional engineering solutions are likely the only remaining option (other than retreating and re-aligning), shoreline protection maintenance plans and the design of new shore parallel protection structures should be completed by a qualified professionals with experience in the design of coastal structures in similar environments. If designed following the principles outlined in Section 7.2, the shore protection standard may be applied to development proposals, at the discretion of the HCA.

- Any proposed development within the HCA *regulated area* or construction of a new shoreline protection structure should meet the tests for development outlined in the PPS (2020), the Conservation Authorities Act (1990) and Hamilton Conservation's Ontario Regulation 161/06, as discussed in Section 2.0 of this SMP.

- The HCA regulations and planning policies should be reviewed to identify any inconsistencies with this SMP and updated hazard mapping, then modified accordingly.

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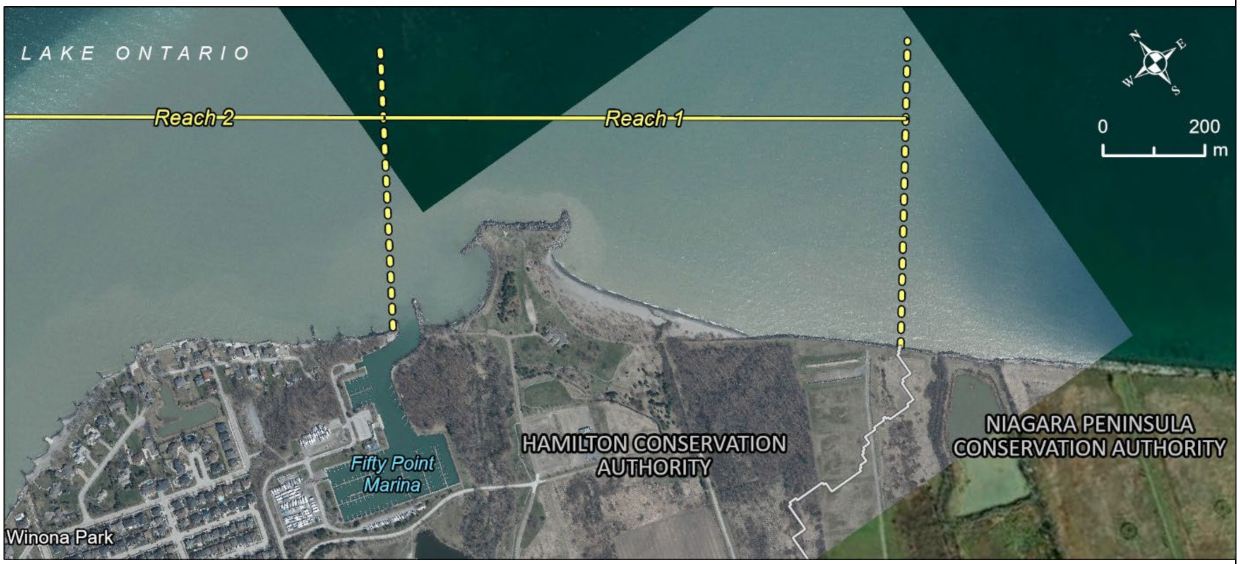
APPENDIX A – Reach Summaries

Reach 1 – Fifty Point Conservation Area

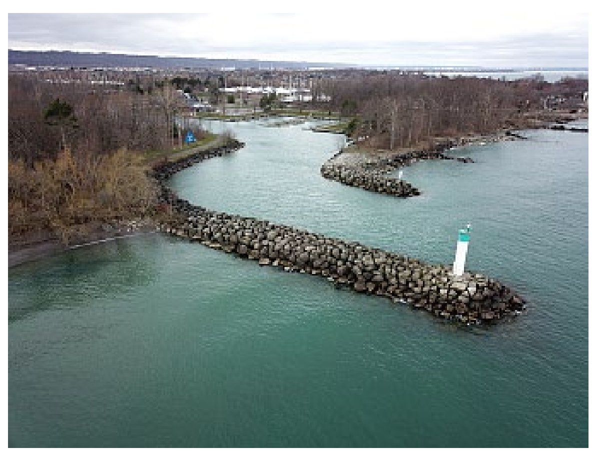


Reach Overview

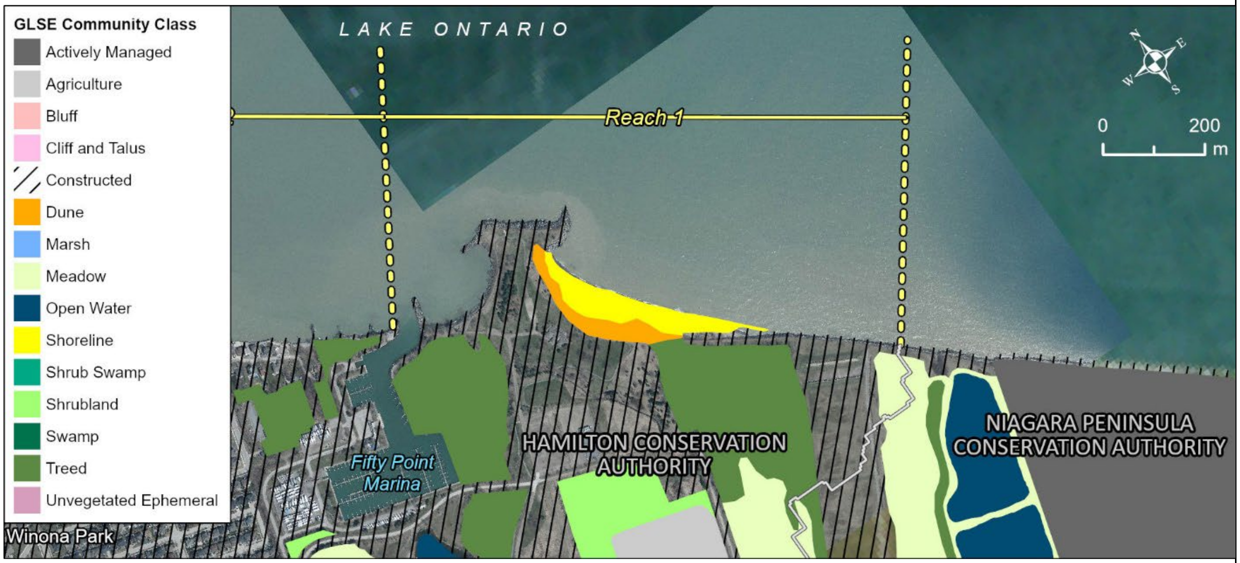
- Reach Length: approximately 1.0 km in length along the shoreline (not including marina basin).
- The Fifty Point Headland is a large lakefill project that extends roughly 200 m lakeward of the natural shoreline.
- The headland has trapped between 106,000 and 124,000 cubic metres of sand and gravel on the east side, given the net direction of sediment transport is east to west.
- Fifty Point Conservation Area is a popular recreational area that features a large swimming beach, picnic areas, and a marina.
- The eastern limit of the Conservation Authority is bordered by a military firing range that limits boat traffic along the shoreline.

Fifty Point Headland

Entrance to Fifty Point Marina



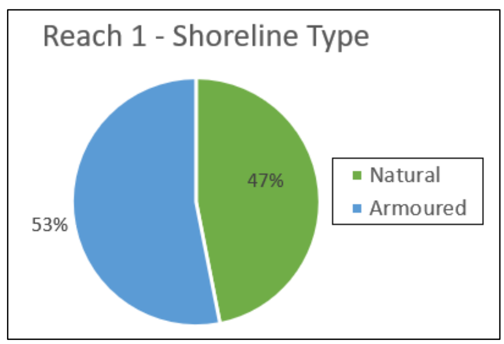
Great Lakes Shoreline Ecosystem Classification

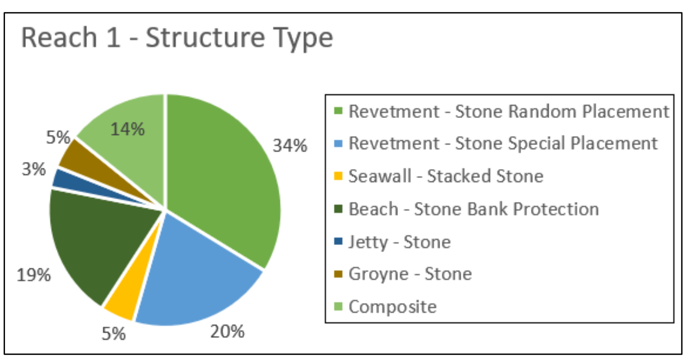


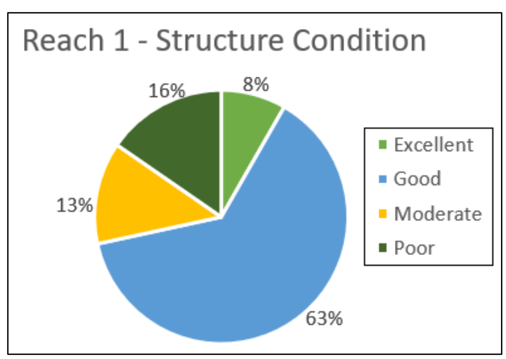
- Reach 1 features a high percentage of constructed land associated with the Fifty Point lakefill, including parking lots, buildings, and landscaped recreational spaces. The exception is a large fillet beach on the east side of the Fifty Point Headland, which is classified as shoreline and dune habitat.
- There are several large treed areas inland from the shoreline.

Shoreline Conditions and Structure Type

- Reach 1 features 47% natural shoreline and 53% armoured.
- Of the armoured shoreline, 34 % is conventional, multi-layer revetments featuring randomly placed armour stone. A further 21% is single-layer armour stone revetment.
- Most shoreline infrastructure is on public lands at Fifty Point, or adjacent to marina entrance.
- 71% of shore protection is in good or excellent condition. Only 15% is in poor condition, and 0% failed.







Challenges Associated with Natural Hazards
• The Fifty Point lakefill and headland are located in deep water and now more than 30 years old. Upgrades to the armour stone revetment were recently completed for the western half of the lake-facing shore and to the bank protection within the embayment adjacent to the marina basin entrance (see image below). As the main headland structure continues to age, additional upgrades will likely be required. Monitoring should be completely regularly and after major storm events.  • The east fillet beach at Fifty Point is low crested and in some locations the Flood Hazard Limit extends further inland than the Dynamic Beach Hazard limit. See below. 

Technical Basis for Natural Hazard Mapping

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

Geographic Area	Recession Rate (m/year)
Entire Reach	0.5

- 100-year Flood Level and Wave Uprush Limit:

Sub-Reach	100-year Flood Level (m IGLD'85)	Horizontal Uprush Allowance (m)	Calculated Wave Uprush Elevation (m IGLD85')
Fifty Point Headland	76.2	20 m	-
Fifty Point Fillet Beach	76.2	15 m (min)	77.5
Inland creeks west and east of headland	76.2	10 m	-

- Dynamic Beach(es): Coordinates in UTM Zone 17N, NAD 1983

Start	End	Recession Rate (m/year) or Stable	Dynamic Beach Name
612582, 4786273	612155, 4786797	Stable	Fifty Point Conservation Area

- Offshore Wave Climate:

WIS Station	ARI (years)	Depth (m)	Hs (m)	Tp (s)	DIR (deg)
91134	25	17	5.6	10.5	30 – 60
	100	17	6.1	11.0	20 – 50

Shoreline Management Recommendations

- **Preserve:** maintain beach at Fifty Point and consider foredune restoration projects to create a natural flood barrier.
- **Avoid:** ensure new development occurs outside of hazardous lands, and prohibit development/re-development in areas that are inaccessible during major floods.
- **Retreat and Realign:** not applicable for Reach 1.
- **Accommodate:** given Reach 1 is a conservation area, there is limited development on hazardous lands. The accommodate strategy is therefore not relevant at this time.
- **Protect:** complete regular monitoring of the armour stone revetment protecting the Fifty Point headland and complete maintenance or upgrades as required.

  Pursue opportunities to bypass sediment at littoral barriers and/or artificially nourish local beaches with sediment trucked to the shoreline from upland sources.

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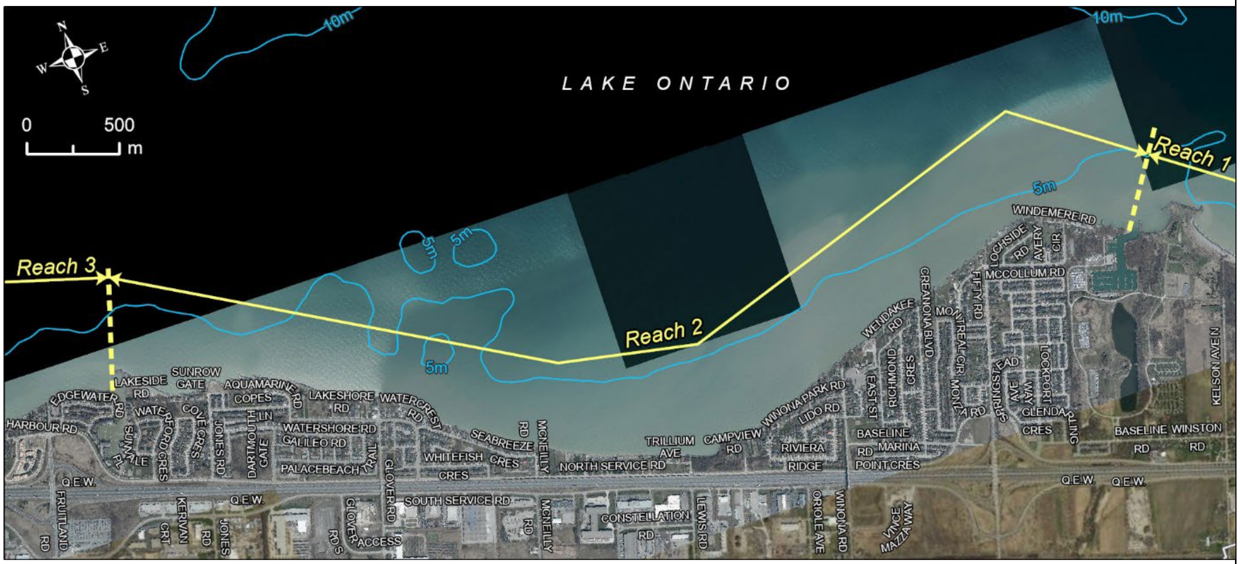
Reach 2 – Fifty Point to Newport Yacht Club



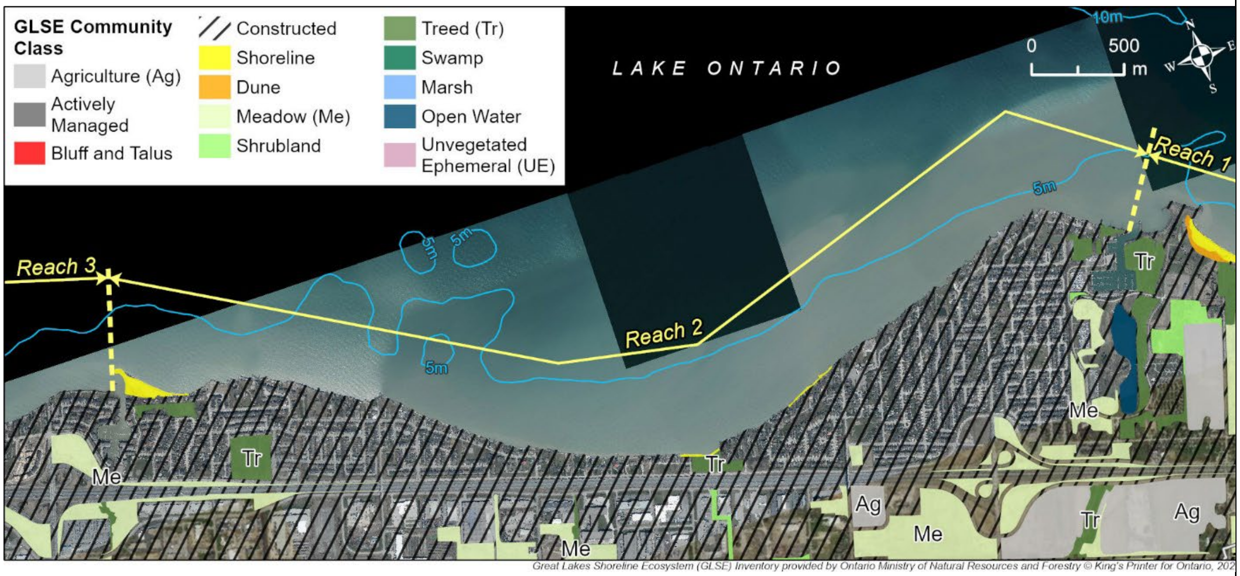
Reach Overview

- Reach Length: approximately 6.0 km in length along the shoreline.
- Reach 2 features extensive and dense single-lot residential development and a wide range of shoreline protection structures, many of which are in poor condition.
- Evidence of failed shoreline protection structures are visible throughout the reach along the shoreline and in many locations in the shallow waters lakeward of new structures.
- The eroding banks at the foot of Lewis Road is one of the last remaining sections of eroding shoreline with the Hamilton Conservation jurisdiction.

Armoured shoreline east of Fifty Point

Newport Yacht Club Jetty

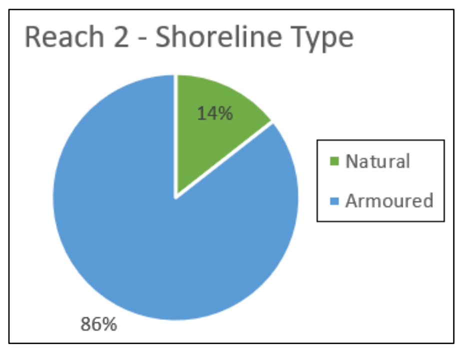
Great Lakes Shoreline Ecosystem Classification

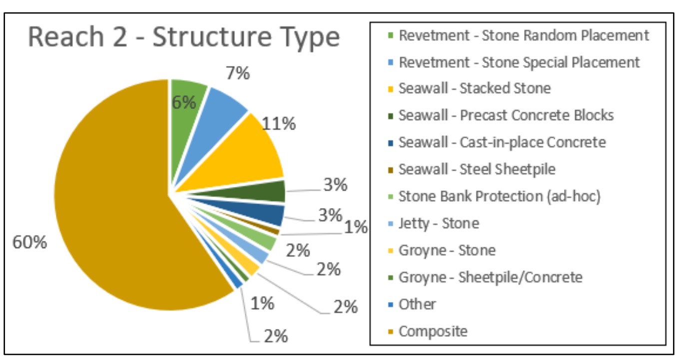


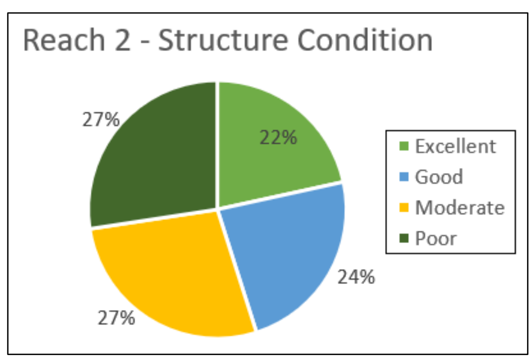
- The majority of the shoreline in Reach 2 is classified as constructed (artificial), due to the high density of residential development, roads, and shoreline hardening.
- The fillet beach at the Newport Yacht Club is classified as natural shoreline habitat.

Shoreline Condition and Structure Type

- Reach 2 features 14% natural shoreline and 86% armoured.
- Of the armoured shoreline, 59 % is comprised of composite structures that do not fit into a single category. Of these, the majority (71%) include some form of vertical seawall comprised of concrete, steel sheet pile, or stacked armour stone.
- Only 30% of the infrastructure appears to be appropriately "engineered".
- The majority of the shoreline infrastructure (58%) can be describe as being in moderate, poor, or failed condition.



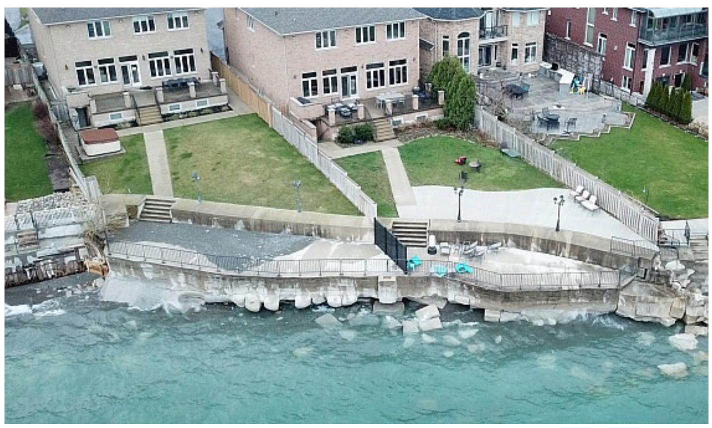




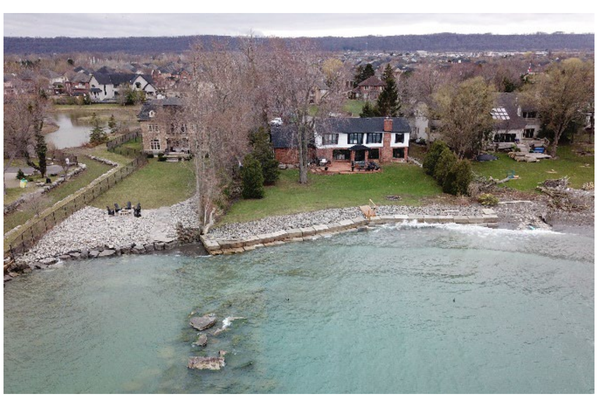
Challenges Associated with Natural Hazards

- Bank erosion at the foot of Lewis Road is threatening a hardened creek/stormwater outfall. See oblique image below.

- Vertical downcutting of the lakebed leads to undermining (see below) and failure of shoreline protection structures and increased wave exposure due to increased water depths. Relics of failed structures and structures in poor condition make structural upgrades challenging.



- Due to the high wave exposure, deep nearshore and low elevation of table lands, large portions of shoreline within Reach 2 are highly susceptible to wave overtopping and associated flooding and damage/erosion. This is particularly true for the shoreline from the Fifty Point Marina to East St.



Technical Basis for Natural Hazard Mapping

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

Geographic Area	Recession Rate (m/year)
Entire Reach	0.5

- 100-year Flood Level and Wave Uprush Limit:

Sub-Reach	100-year Flood Level (m IGLD'85)	Horizontal Uprush Allowance (m)	Calculated Wave Uprush Elevation (m IGLD85')
Fifty Point Marina to Campview Road	76.2	27 m	-
Campview Road to Glover Road	76.2	19 m	-
Glover Road to Newport Y.C. Fillet Beach	76.2	17 m	-
Newport Yacht Club Fillet Beach	76.2	15 m (min)	78.3 m
Inland creeks	76.2	10 m	-

- Dynamic Beach(es): Coordinates in UTM Zone 17N, NAD 1983

Start	End	Recession Rate (m/year) or Stable	Dynamic Beach Name
606613, 4787647	606416, 4787859	Stable	Newport Yacht Club Fillet Beach

- Offshore Wave Climate:

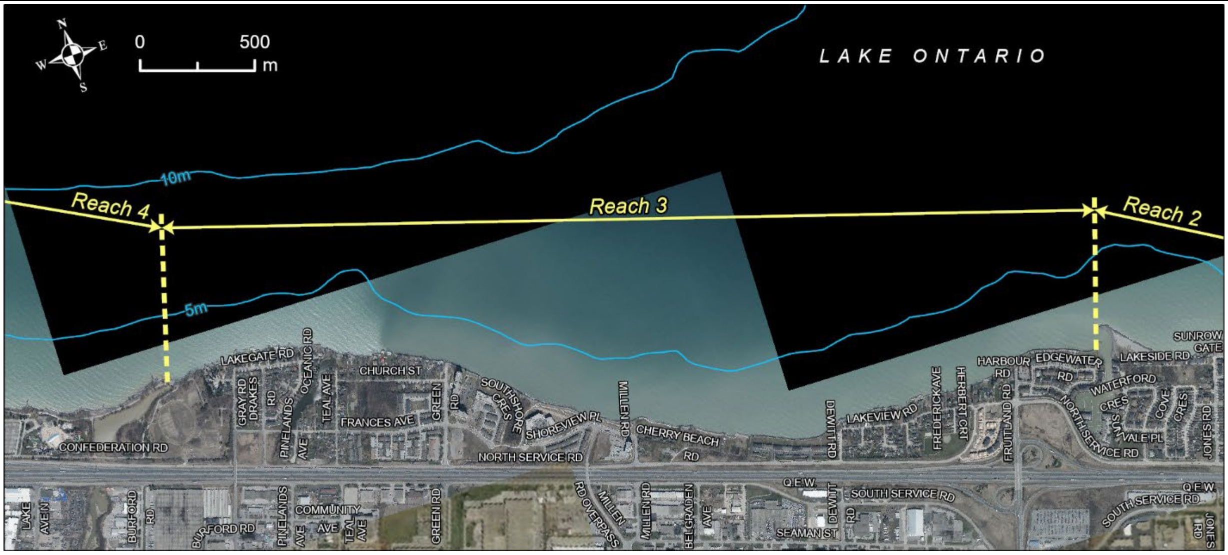
WIS Station	ARI (years)	Depth (m)	Hs (m)	Tp (s)	DIR (deg)
91134	25	17	5.6	10.5	30 – 60
	100	17	6.1	11.0	20 – 50
91135	25	12	4.7	10.5	20 – 50
	100	12	5.0	11.0	20 – 50

Shoreline Management Recommendations

- **Preserve:** the beach shoreline at the Newport Yacht Club should be preserved and even enhanced with foredune restoration to provide additional nature-based flood protection.
- **Avoid:** the avoid strategy will be primarily related to re-development of existing lots of record, as the shoreline is almost entirely armoured. If proposed re-builds or structure additions can not satisfy the various tests for development, including locating away from hazardous lands, then new development may not be possible in the future.
- **Retreat and Realign:** if coastal hazards become severe and limit the development envelope on a lot of record, it may be necessary to re-locate existing buildings further inland on deep lots or to new lots where possible.
- **Accommodate:** accommodate strategies are primarily related to floodproofing existing buildings, including raising foundations, closing lowest openings, and ensuring access during a flooding event. This is relevant for communities between Fifty Point and East St., and those immediately east of the Newport Yacht Club and fillet beach.
- **Protect:** upgrades to existing shoreline protection structures should follow standard engineering design principles and account for ongoing downcutting (deepening) at the structure toe. Overtopping protection will be a critical design consideration for low-lying properties in Reach 2. Future structure upgrades should strive for more consistency between lots.

Use Disclaimer

Reach 3 – Edgewater Drive to Confederation Park

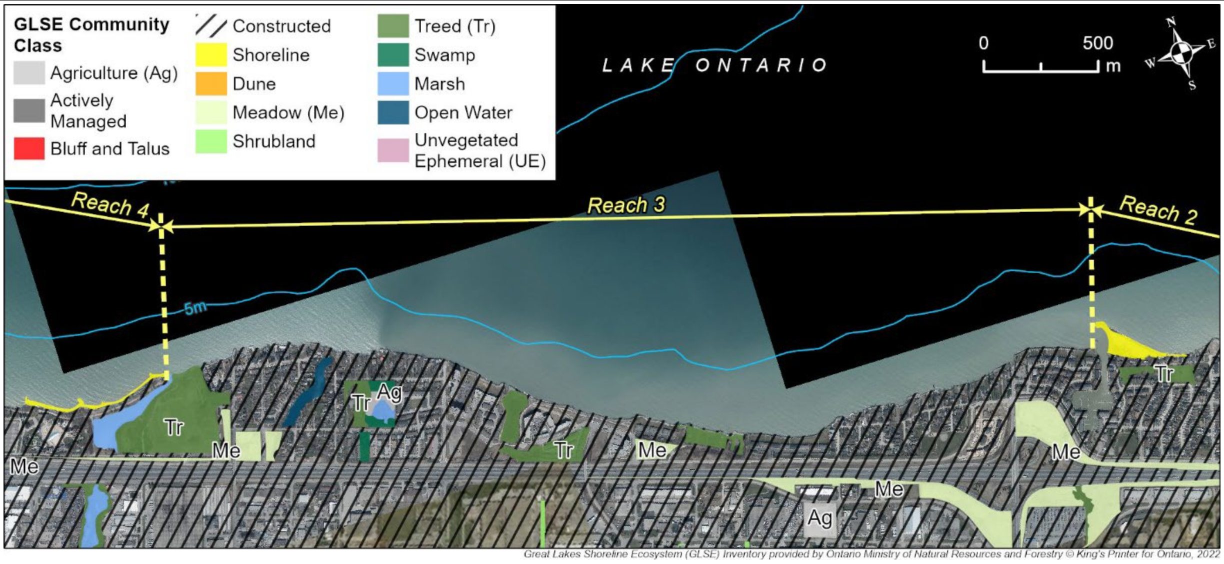


Reach Overview

- Reach Length: approximately 4.2 km in length along the shoreline.
- The reach features a mixture of high density single family residential lots and multi-unit lots.
- The shoreline is extensively armoured, often with a variety of structures from different periods due to past repairs following failures, maintenance, and upgrades.
- Failed shore perpendicular structures (e.g. jetties, groynes, wharves) are numerous and suggest significant lakebed downcutting in the nearshore.
- Public access is available at road allowances, parkettes, and walking trails.

Continuous Shoreline Armouring at Edgewater Drive	*Public Access Adjacent to Stormwater Outfall*
	

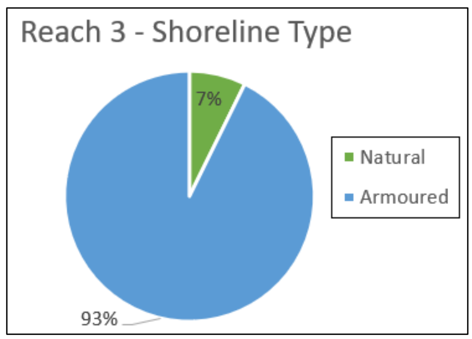
Great Lakes Shoreline Ecosystem Classification

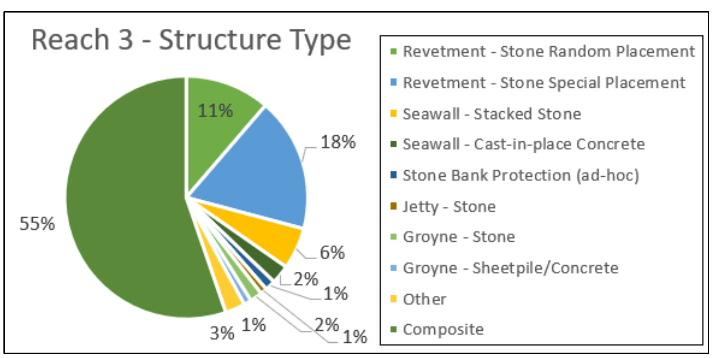


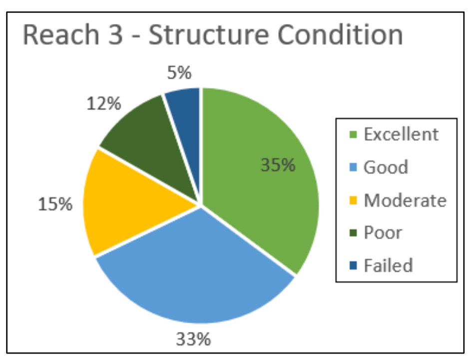
- Reach 3 is predominantly a constructed landscape due to the residential development, as seen in the map above.
- Some isolated treed patches exist, with limited connectivity to the lake via tributaries.

Shoreline Condition and Structure Type

- Reach 3 features 7% natural shoreline and 93% armoured.
- Of the armoured shoreline, 55% is comprised of composite structures that do not fit into a single category. Of these, the majority (62%) include some form of vertical seawall comprised of concrete, steel sheet pile, or stacked armour stone. A further 29% of the armoured shoreline is comprised of stone revetments.
- The majority (59%) of the infrastructure appears to be appropriately "engineered".
- The majority of the shoreline infrastructure (68%) can be describe as being good or excellent condition. 12% is in poor condition and 5% is in a state of failure.







Challenges Associated with Natural Hazards

- The Reach 3 shoreline features eroding glacial sediment. Downcutting of the glacial sediment is evident due to the number of failed structures in the nearshore and scattered debris (e.g., concrete and armour stone) found in the nearshore. See the example below.

- The Erosion Hazard Limit is the greatest challenge for new development or re-development in Reach 3, as seen by the updated mapping below. In many cases, development would only be possible provided a new or substantially upgraded shoreline protection structure is in place with a 25-year design life, as specified by the Shore Protection Standard.

- The highly variable shoreline due to the prevalence of lot-level shoreline protection and the relics of failed structures and structures in poor condition make structural upgrades challenging, but in many cases necessary.
- Due to the high wave exposure, deep nearshore and low elevation of table lands, large portions of shoreline within Reach 3 are highly susceptible to wave overtopping and associated flooding and damage/erosion.

Technical Basis for Natural Hazard Mapping

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

Geographic Area	Recession Rate (m/year)
Entire Reach	0.5

- 100-year Flood Level and Wave Uprush Limit:

Sub-Reach	100-year Flood Level (m IGLD'85)	Horizontal Uprush Allowance (m)	Calculated Wave Uprush Elevation (m IGLD85')
Newport Y.C. to Dewitt Road	76.2	30 m	-
Dewitt Road to Reach western boundary	76.2	25 m	-
Inland creeks	76.2	10 m	-

- Dynamic Beach(es): not applicable
- Offshore Wave Climate:

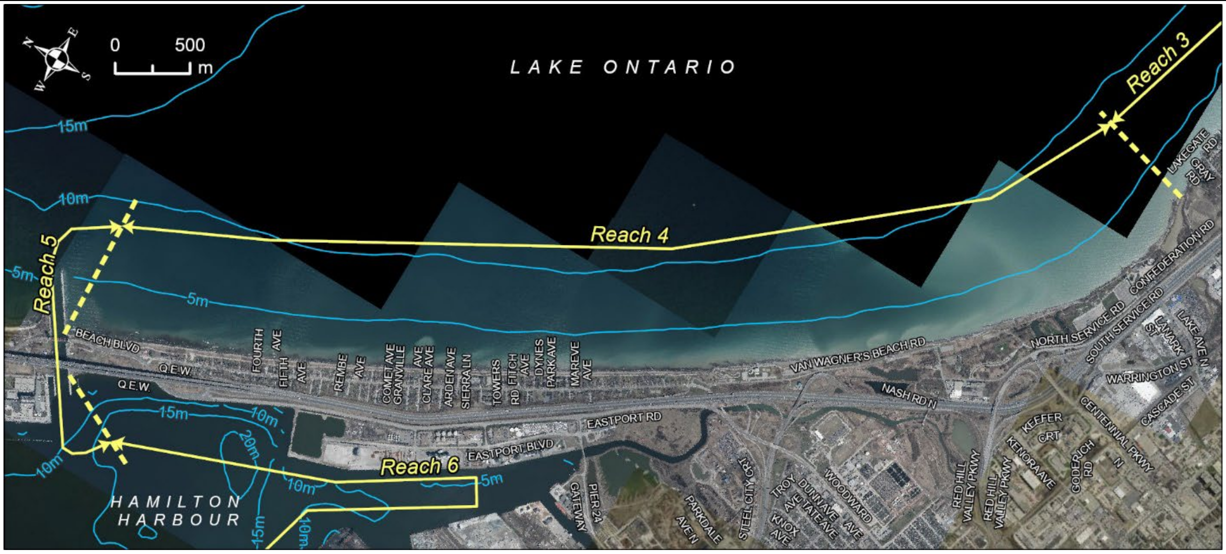
WIS Station	ARI (years)	Depth (m)	Hs (m)	Tp (s)	DIR (deg)
91135	25	12	4.7	10.5	20 – 50
	100	12	5.0	11.0	20 – 50
91136	25	19	5.6	10.5	40 – 70
	100	19	6.2	11.0	40 – 70

Shoreline Management Recommendations

- **Preserve:** there is very little natural shoreline remaining in Reach 3 but where it is present maintain buffer zones around tributaries and river mouths to protect wetland habitat and species. This will create secondary benefits of providing public access to the lake.
- **Avoid:** the avoid strategy will be primarily related to re-development of existing lots of record, as the shoreline is almost entirely developed and armoured. If proposed re-builds or structure additions can not satisfy the various tests for development, including locating away from hazardous lands, then new development may not be possible in the future.
- **Retreat and Realign:** if coastal hazards become severe and limit the development envelope on a lot of record, it may be necessary to re-locate existing buildings further inland on deep lots or to new lots where possible.
- **Accommodate:** accommodate strategies are primarily related to floodproofing existing buildings, including raising foundations, closing lowest openings, and ensuring access during a flooding event.
- **Protect:** upgrades to existing shoreline protection structures should follow standard engineering design principles and account for ongoing downcutting (deepening) of the nearshore at the structure toe. Overtopping protection will be a critical design consideration for low-lying properties in Reach 3. Future structure upgrades should strive for more consistency between lots.

Use Disclaimer

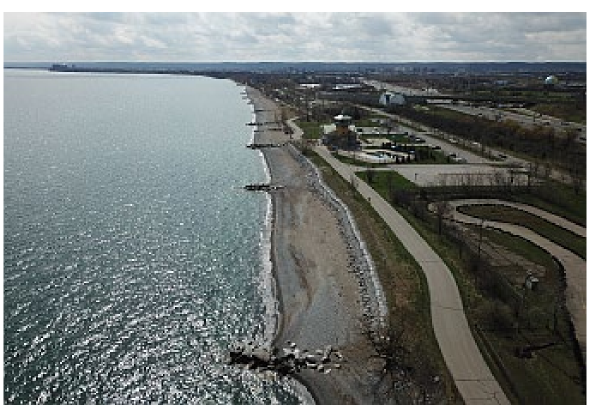
Reach 4 – Confederation Park to Navigation Channel



Reach Overview

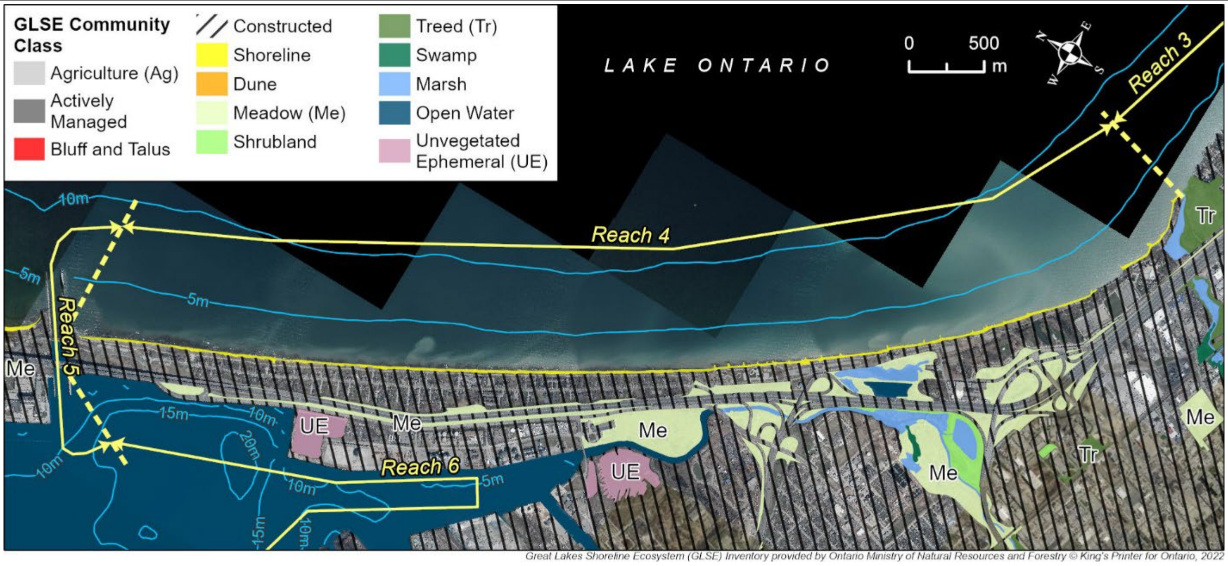
- Reach Length: approximately 7.8 km in length.
- The entire reach has been classified as a Dynamic Beach due to a near-continuous ribbon of sand that defines Hamilton Beach. It also features a continuous waterfront trail that provides public access to Lake Ontario.
- The southern half of the reach features numerous armour stone groins and some of the backshore is protected by armour stone beach curbs or ad-hoc bank protection.
- The northern half of the reach features a natural beach with foredunes. Engineered structures are not required at the back of the beach.
- The very northern limit of the reach was protected with an armour stone revetment that recently failed (early 2023).

Groynes, Sand Beach, and Waterfront Trail



Sand Beach, Dunes, and Waterfront Trail

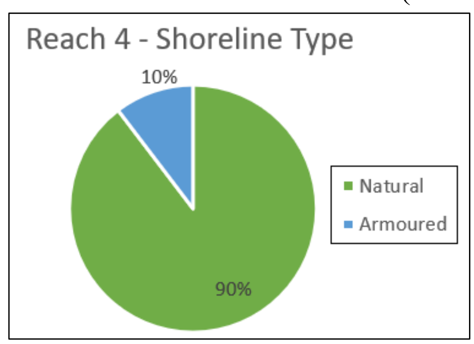
Great Lakes Shoreline Ecosystem Classification

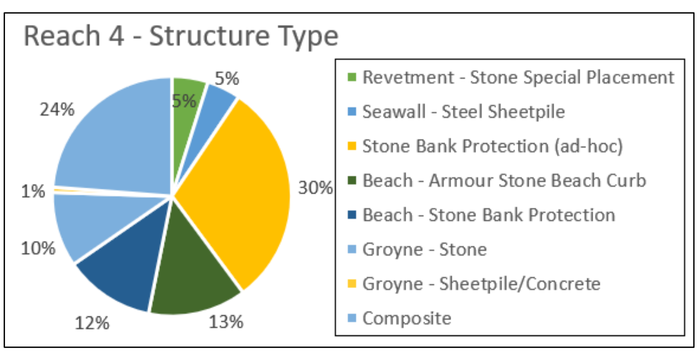


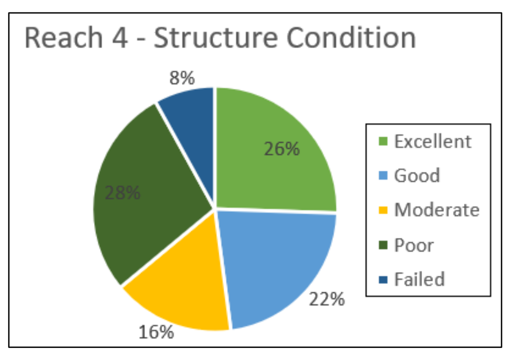
- The majority of the reach is classified as a natural shoreline ecosystem due to the presence of a sand beach and foredunes in the northern half.
- Inshore of the lake, there is some meadow and marsh habitat associated with Redhill Creek.

Shoreline Condition and Structure Type

- Reach 4 features 90% natural shoreline and 10% armoured.
- Of the armoured shoreline, 30% is comprised of ad-hoc stone bank protection, and a further 25% is armour stone beach curb or bank protection at the back of the beach (13% and 12% respectively). The reach also features a number of groyne structures (groyne footprints represent ~10% of the shoreline length).
- Roughly half of the infrastructure appears to be moderately or well engineered, and half is ad-hoc.
- The reach features structures of every condition, including 48% in excellent or good condition, 44% in moderate or poor condition, and 8% in a state of failure.





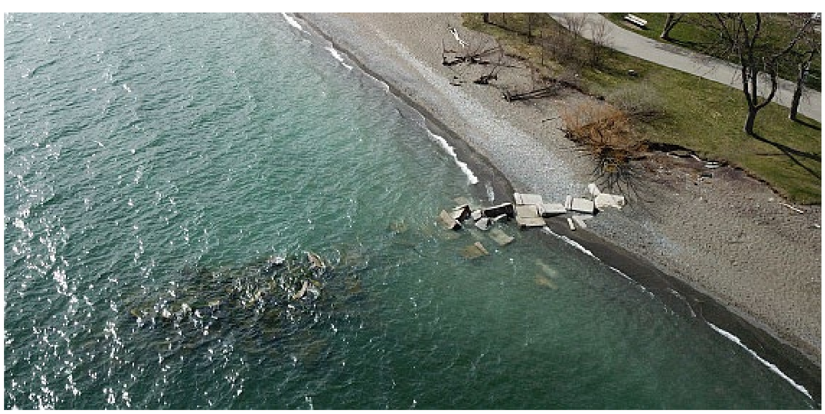


Challenges Associated with Natural Hazards

- The southern half of Reach 4 is low-lying and vulnerable to flooding and erosion, especially during periods of high lake levels such as 2017 and 2019. See erosion scarp at the back of the beach in the photograph below.

- Due to the low-lying backshore, in some cases the flood hazard limit extends further inland than the dynamic beach hazard, which is limited to the inland extent of beach sand and beach profile adjustments, which is often marked by the waterfront trail. See below.

- Some of the armour stone groins are in dis-repair (see below), leading to erosion at the back of the beach.



- Due to low-lying nature of backshore, communities and lands within Reach 4 will be at risk of flooding should future lake levels exceed historical records.

Technical Basis for Natural Hazard Mapping

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

Geographic Area	Recession Rate (m/year)
Reach 4	Dynamically Stable

- 100-year Flood Level and Wave Uprush Limit:

Sub-Reach	100-year Flood Level (m IGLD'85)	Horizontal Uprush Allowance (m)	Calculated Wave Uprush Elevation (m IGLD85')
Confederation Park	76.2	15 m	-
Van Wagners Beach	76.2	26 m*	-

*limited to toe of slope on landward side of engineered pedestrian/bike path

- Dynamic Beach(es): Coordinates in UTM Zone 17N, NAD 1983

Start	End	Recession Rate (m/year) or Stable	Dynamic Beach Name
602422, 4788853	597796, 4794716	Dynamically Stable	Hamilton Beach

- Offshore Wave Climate:

WIS Station	ARI (years)	Depth (m)	Hs (m)	Tp (s)	DIR (deg)
91136	25	19	5.6	10.5	40 – 70
	100	19	6.2	11.0	40 – 70
91137	25	13	5.0	10.5	50 – 70
	100	13	5.3	11.0	50 – 70
91138	25	16	5.4	10.5	60 – 70
	100	16	5.8	11.0	60 – 70

Shoreline Management Recommendations

- **Preserve:** in the central and southern parts of Reach 4, foredunes and beachgrass are patchy to non-existent, leading to engineered structures at the back of the beach. In the future, nature-based solutions should be pursued, where possible, with the trail aligned further inland.
- **Avoid:** ensure new development occurs outside of hazardous lands, and prohibit development/re-development in areas that are inaccessible during flooding.
- **Retreat and Realign:** if sections of the waterfront trail are threatened by erosion in the future, consider re-aligning the trail further inland (where possible) and restore natural beach and dune conditions lakeward of the trail.
- **Accommodate:** approaches to mitigate flood risk for infrastructure in Reach 4 should be considered, such as floodproofing buildings, or raising the grade across flood pathways (e.g. paved pathways and road allowances), as required.
- **Protect:** restoring foredunes is a nature-based solution that will increase the resilience of beaches to high lake levels and provide enhanced flood protection. Beach nourishment from upland sources is also an under-utilized option. When infrastructure such as buildings are threatened by flooding and erosion, engineered shore protection should be considered if retreat is not feasible, and after nature-based solutions have been investigated thoroughly.

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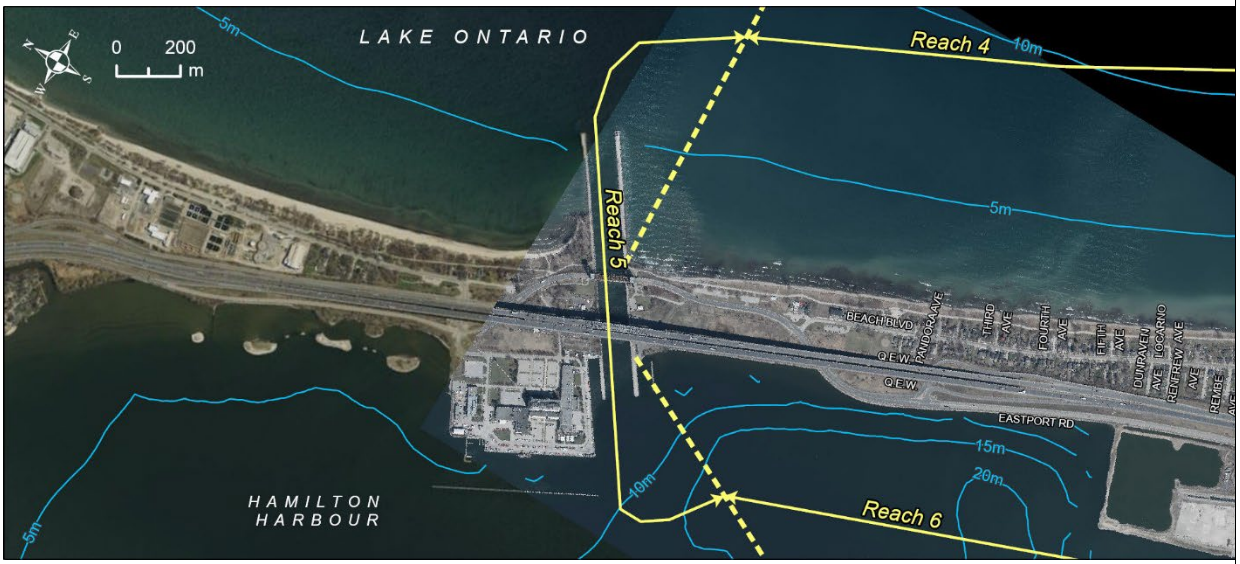
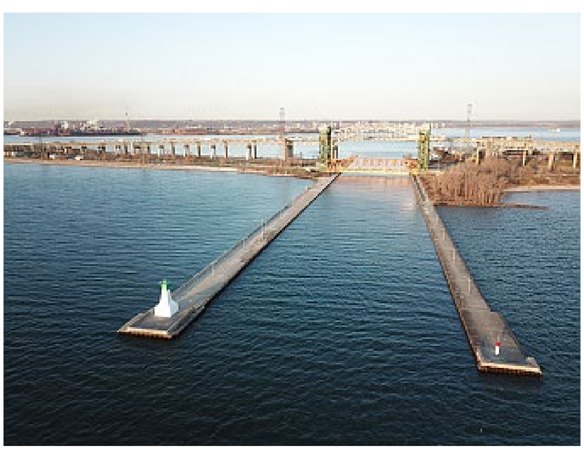
Reach 5 – Federal Navigation Channel



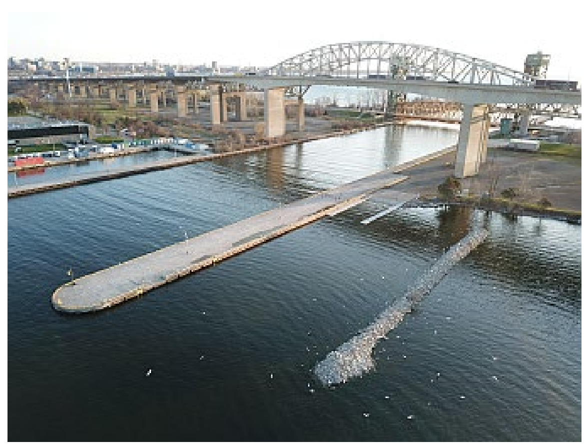
Reach Overview

- Reach Length: approximately 0.84 km in length.
- The federal navigation channel connects the lake to Hamilton Harbour.
- The Conservation Authority has limited jurisdiction in Reach 5.
- A public boat launch is located adjacent to the south jetty in the harbour.
- Pedestrian access on the jetty has recently been limited.
- The approach channel at the lakeward tip of the jetties will be dredged in the summer of 2023 to address sedimentation. Approximately 20,000 m^3 of sand will be dredged and disposed of in a nearshore location adjacent to Burlington Beach. The dredging is required roughly every 10 years (pers. comm., HOPA).

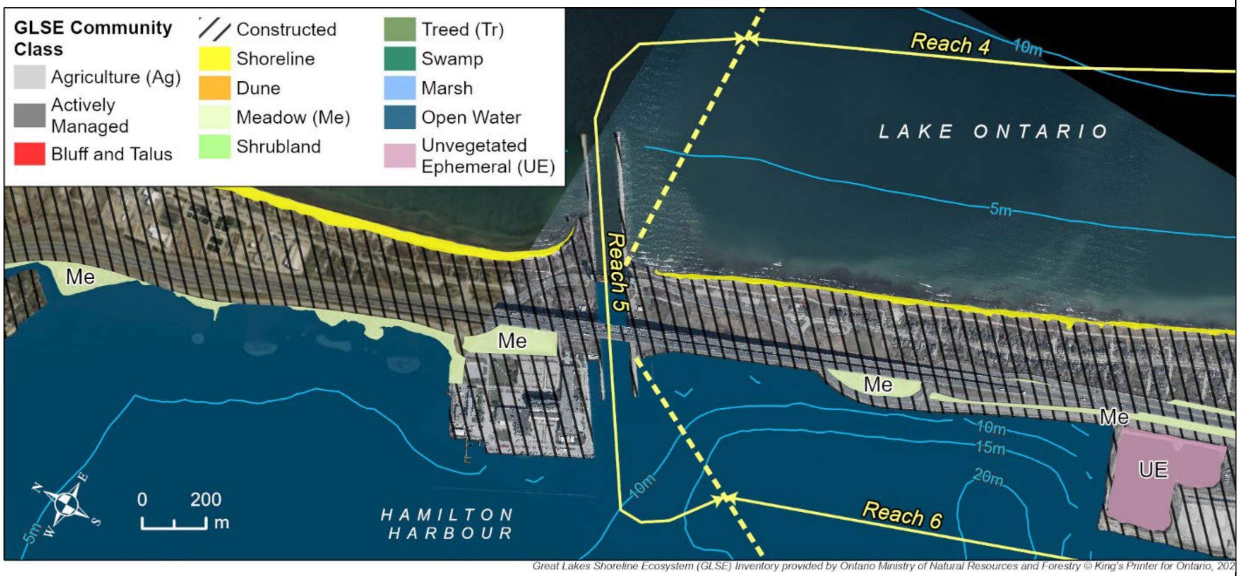
Lake Ontario Jetties



Hamilton Harbour Jetty and Boat Launch



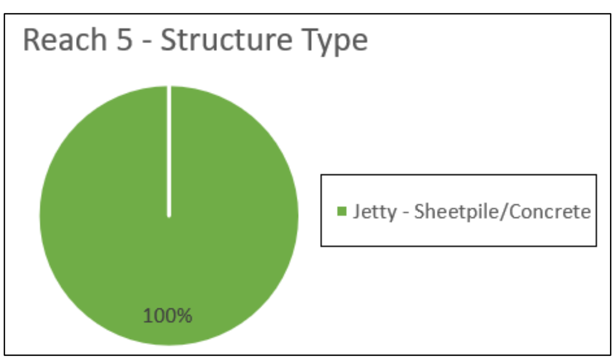
Great Lakes Shoreline Ecosystem Classification

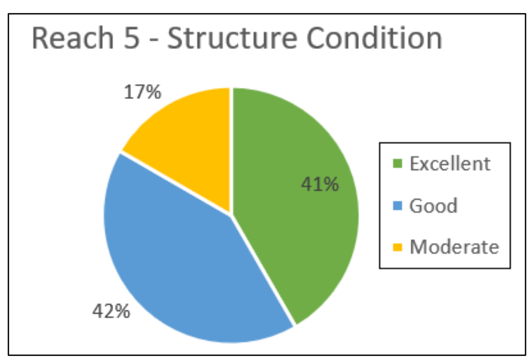


- The southern side of the navigation channel represents Reach 5. The shoreline has been stabilized with a steel sheet pile wall and 100% is covered by the constructed category of the GLSE classification.
- There is no natural shoreline in Reach 5.

Shoreline Condition and Structure Type

- Reach 5 covers the federal navigation channel and surrounding infrastructure and is therefore made up of entirely hardened or engineered shoreline.
- The majority (83%) of the shoreline appears to be in good or excellent condition. No portion of the shoreline was deemed to be in poor or failed condition.
- The entire armoured shoreline is made up of sheet pile and concrete caisson type jetty infrastructure.

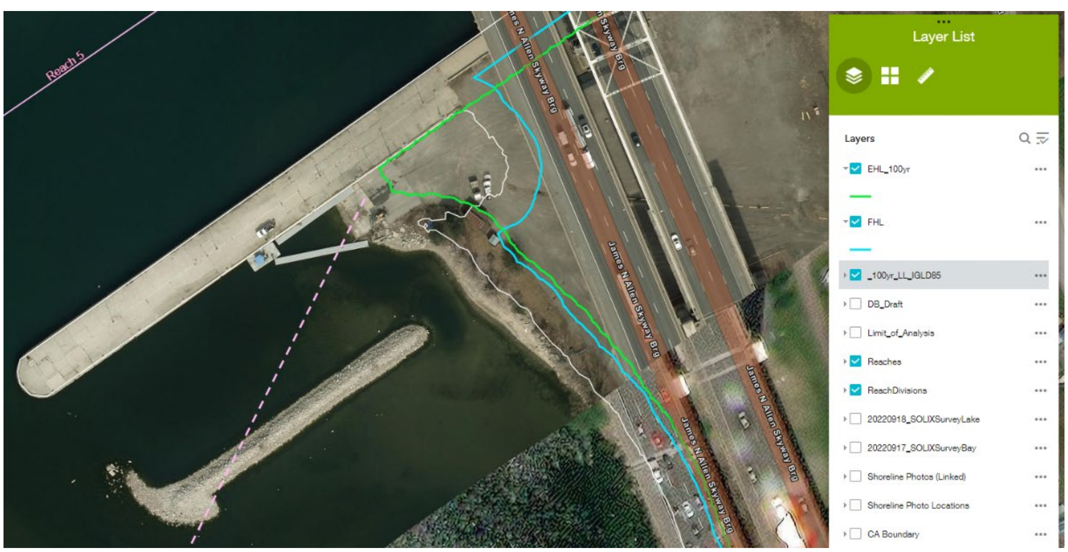




Challenges Associated with Natural Hazards

- Due to the reflective nature of the vertical steel sheet pile walls from which the jetty is principally constructed, wave reflection is very high both from the south side of the jetty towards Hamilton Beach (impacting the north portion of the beach where the beach has historically suffered from erosion) and within the navigation channel itself, between the north and south jetties (impacting safe navigation).

- The boat launch south of the jetty on the Hamilton Harbour side is partially protected by a breakwater, but is open to the longest fetch in Hamilton Harbour (7.5 km). The boat launch is subjected to significant wave exposure when winds are from the southwest. See map below.
- The flood hazard limit also extends inland to include the parking lot adjacent to the boat launch.



Technical Basis for Natural Hazard Mapping

- Recession Rate for Erosion Hazard Limit: not applicable.
- 100-year Flood Level and Wave Uprush Limit:

Sub-Reach	100-year Flood Level (m IGLD'85)	Horizontal Uprush Allowance (m)	Calculated Wave Uprush Elevation (m IGLD85')
Federal Navigation Channel	76.2	10 m	-

- Dynamic Beach(es): not applicable
- Offshore Wave Climate:

WIS Station	ARI (years)	Depth (m)	Hs (m)	Tp (s)	DIR (deg)
91138	25	16	5.4	10.5	60 – 70
	100	16	5.8	11.0	60 – 70

Shoreline Management Recommendations

- **Preserve:** there are no natural shorelines to preserve.
- **Avoid:** future upgrades of the navigation channel jetties should consider the latest guidance on 100-year flood levels and the impacts of the changing climate when designing maintenance upgrades.
- **Retreat and Realign:** not applicable.
- **Accommodate:** structural modifications to the boat launch breakwater would improve the sheltering it provides from waves and storm surge.
- **Protect:** monitor and implement maintenance improvements to the jetty as required. A spur jetty, constructed on the south side of the south jetty in Lake Ontario may trap additional sand and gravel in a vulnerable area and reduce future sedimentation in the navigation channel. A spur jetty and/or a stone berm along the root of the south facing jetty will also reduce wave reflection and may reduce the erosion risks at the north end of Hamilton Beach.

Use Disclaimer

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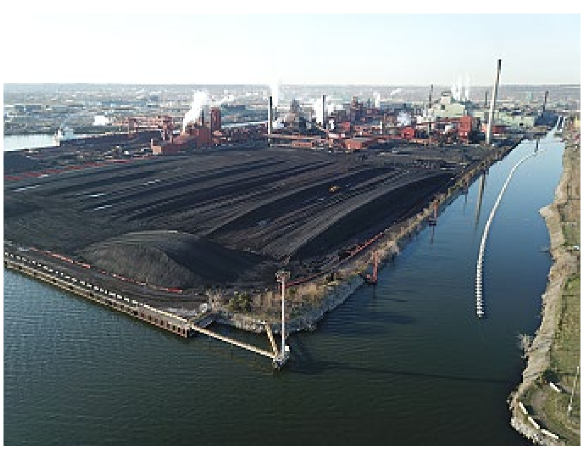
Reach 6 – Port of Hamilton

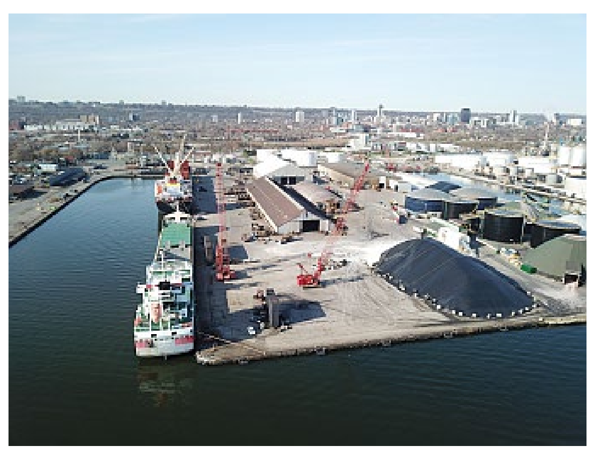
Reach Overview

- Reach Length: approximately 12.3 km (not including the shipping berths).
- The reach encompasses the industrial sector of the harbour and was built on a massive lakefill project.
- The port lands are managed by the Hamilton-Oshawa Port Authority and feature a variety of industries that capitalize on the sheltered deep draft harbour, including steel production.
- The shoreline is armoured with a variety of protection types including steel sheet pile, armour stone, and old ship hulls.
- Work is approaching completion on the capping of Randle Reef, one of the most contaminated sites on the Canadian side of the Great Lakes.

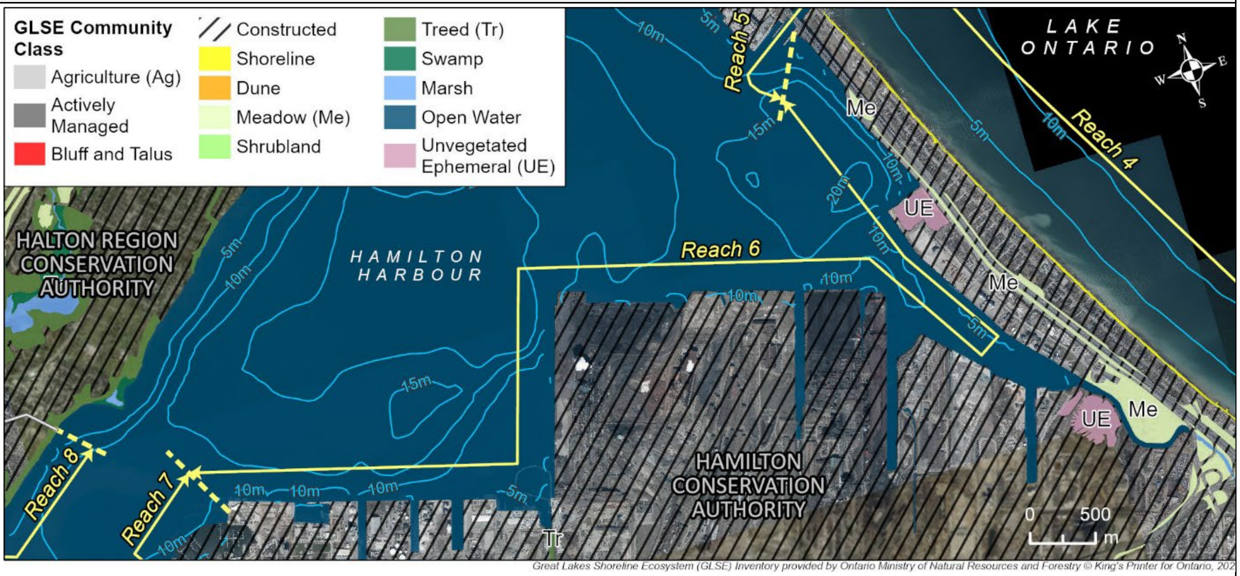
Iron Stockpile in Industrial Sector



North End Slip



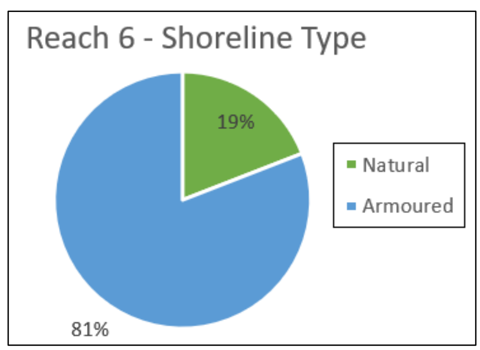
Great Lakes Shoreline Ecosystem Classification

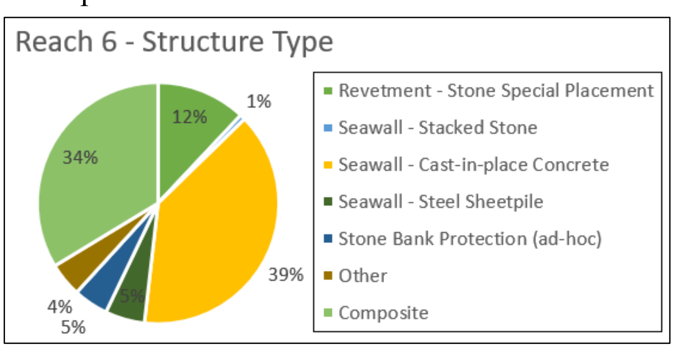


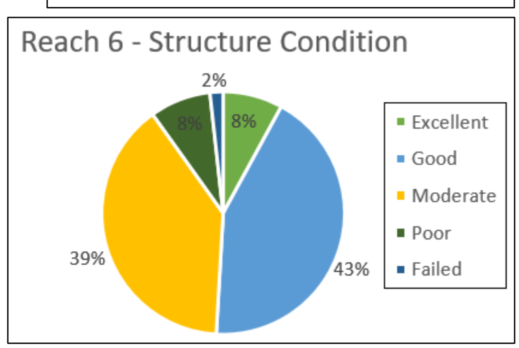
- The port and industrial lands of Reach 6 were created with lakefill and thus the entire reach is classified as constructed in the Great Lakes Shoreline Ecosystem classification.
- Redhill Creek drains into Reach 6 and feature wetland habitat along the riverbanks, including restoration areas.

Shoreline Condition and Structure Type

- Reach 6 features 19% natural shoreline and 81% armoured.
- Of the armoured shoreline, 44% is cast-in-place concrete or steel sheet pile seawall or wharf infrastructure. 34% are composite structures that do not fit into a single category, but are generally comprised of multiple iterations of vertical wall (stacked stone, concrete or sheet-pile).
- 86% of the shoreline infrastructure appears to be moderately or well engineered.
- Approximately half the shoreline features infrastructure in good or excellent condition. A further 39% is in moderate condition, and ~10% is in poor condition or failed.







Challenges Associated with Natural Hazards

- There are limited flood risks in Reach 6 given the shoreline is extensively armoured and in many cases the crest elevation of the shore protection is high due to the industrial land use and ship berthing that occurs.
- Some occurrences of bank erosion were identified where shore protection is not continuous (see below).

- The sheer volume/length of shoreline protection/wharf infrastructure within Reach 6 presents a challenge due to ongoing monitoring and maintenance requirements.

Technical Basis for Natural Hazard Mapping

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

Geographic Area	Recession Rate (m/year)
Entire Reach	0.1

- 100-year Flood Level and Wave Uprush Limit:

Sub-Reach	100-year Flood Level (m IGLD'85)	Horizontal Uprush Allowance (m)	Calculated Wave Uprush Elevation (m IGLD85')
Port Lands	76.2	10 m	-

- Dynamic Beach(es): not applicable.
- Offshore Wave Climate:

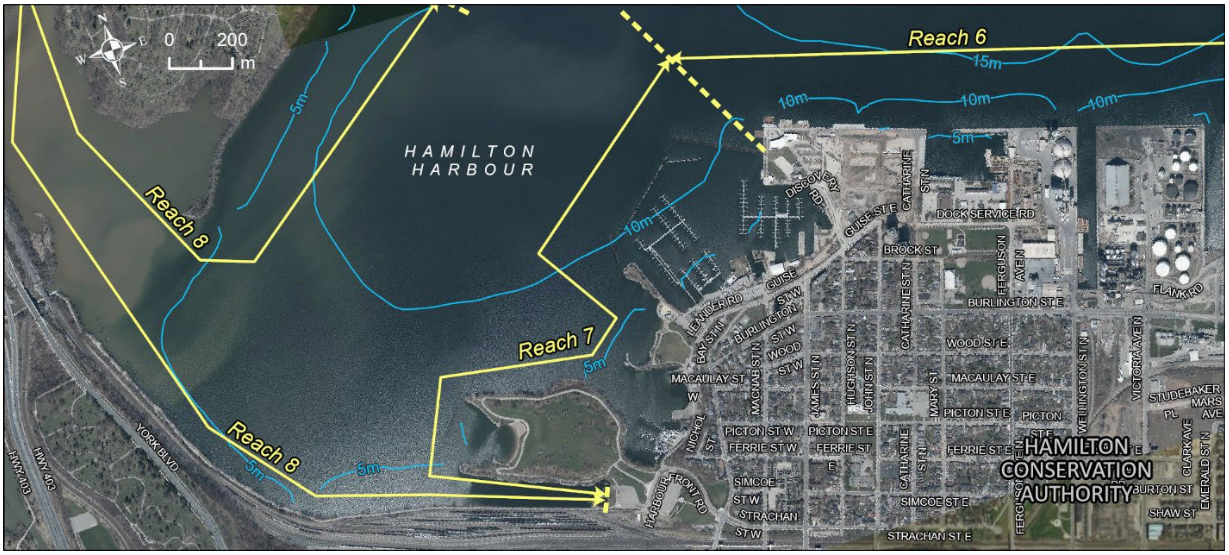
WIS Station	ARI (years)	Depth (m)	Hs (m)	Tp (s)	DIR (deg)
n/a	25+	12.0	2.0	5.0	All

Shoreline Management Recommendations

- **Preserve:** the restoration work of the Redhill Creek, which is beyond the limits of the reach, should continue to return natural shorelines to Hamilton Harbour.
- **Avoid:** ensure new development occurs outside of hazardous lands, and prohibit development/re-development in areas that are inaccessible during major floods.
- **Accommodate:** not applicable in Reach 6.
- **Retreat and Realign:** The re-alignment of some industrial lands has already occurring and this strategy could further expand public open space and access to the waters edge.
- **Protect:** all shoreline protection structures should be monitored and upgraded/repaired with appropriate engineered solutions as required.

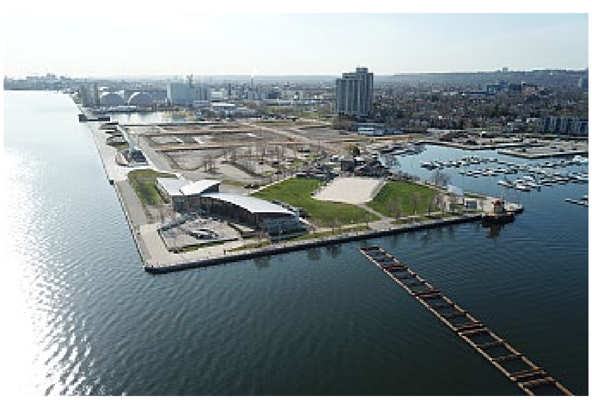
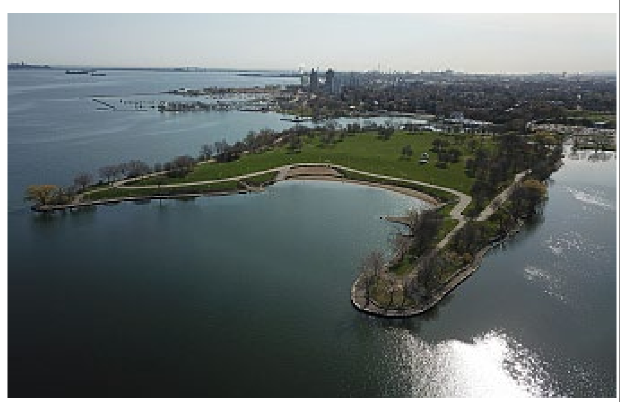
Use Disclaimer

Reach 7 – Discovery Centre to Bayfront Park

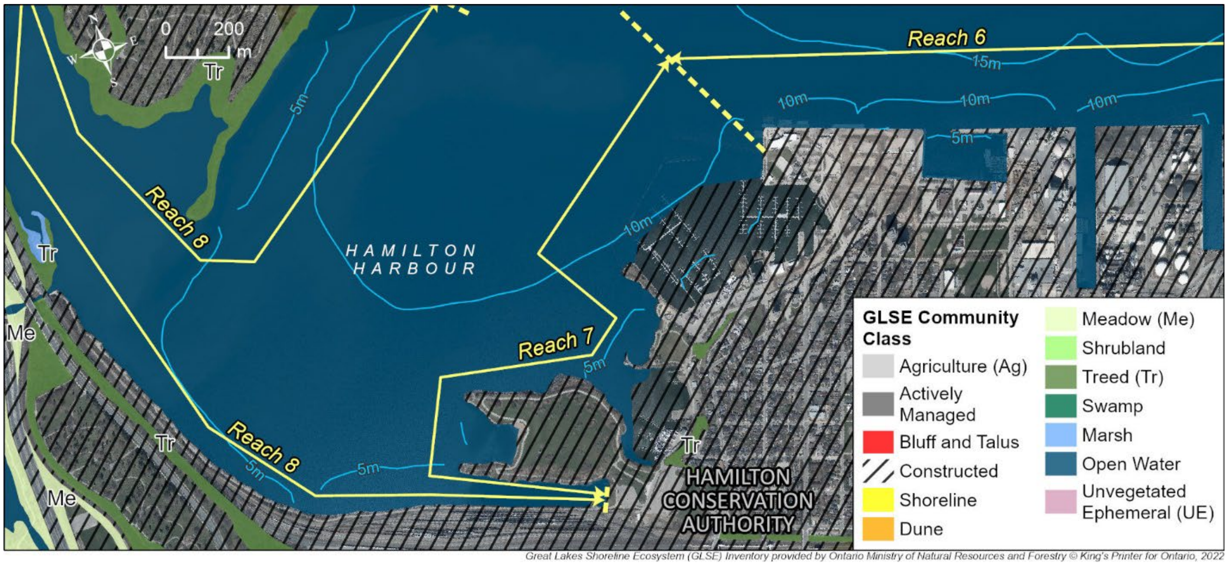


Reach Overview

- Reach Length: approximately 3.6 km.
- The large Harbour West Marina is protected by floating breakwaters.
- The Macassa Bay Yacht Club is sheltered by adjacent lakefills and does not require a breakwater.
- Bayfront Park is a popular waterfront feature with extensive trail system along the shore.
- Due to limited circulation, water quality is a challenge, especially at the boundary of Reach 7 and 8.
- Wave exposure is limited by the small fetches inside Hamilton Harbour.
- Most of the shoreline (93%) is armoured.

Discovery Centre	*Bayfront Park*
	

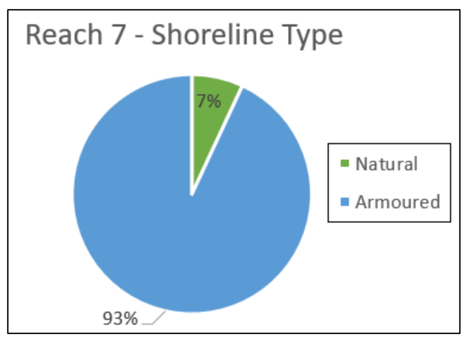
Great Lakes Shoreline Ecosystem Classification

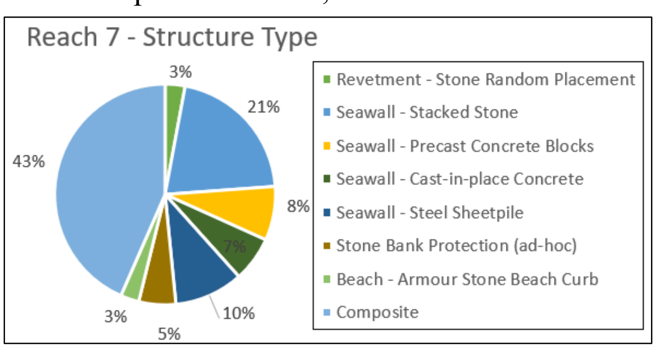


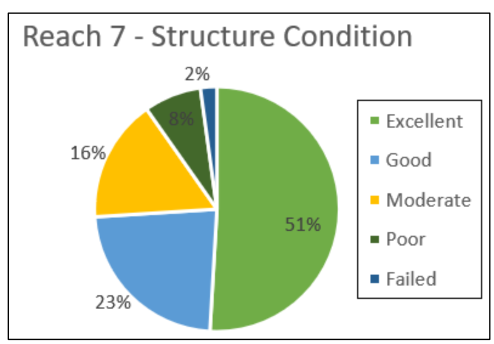
- The entire reach features a constructed/engineered shoreline, including the lakefill at Bayfront Park, floating breakwaters at Harbour West Marina, and armour stone/vertical walls in between.

Shoreline Condition and Structure Type

- Reach 7 features only 7% natural shoreline and 93% armoured.
- Of the armoured shoreline, 46% is some form of vertical seawall, with the majority of those being stacked armour stone. 43% of the armoured shoreline is comprised of composite structures that do not fit into a single structure category. The vast majority (91%) of those composite structures are combinations of vertical, seawall-type structures at different elevations and setbacks, predominantly comprised of stacked armour stone (53%).
- 65% of the shoreline infrastructure appears to be moderately or well engineered.
- 74% of the shoreline infrastructure appears to be in good or excellent condition. Only 8% was deemed to be in poor condition, and 2% in a state of failure.



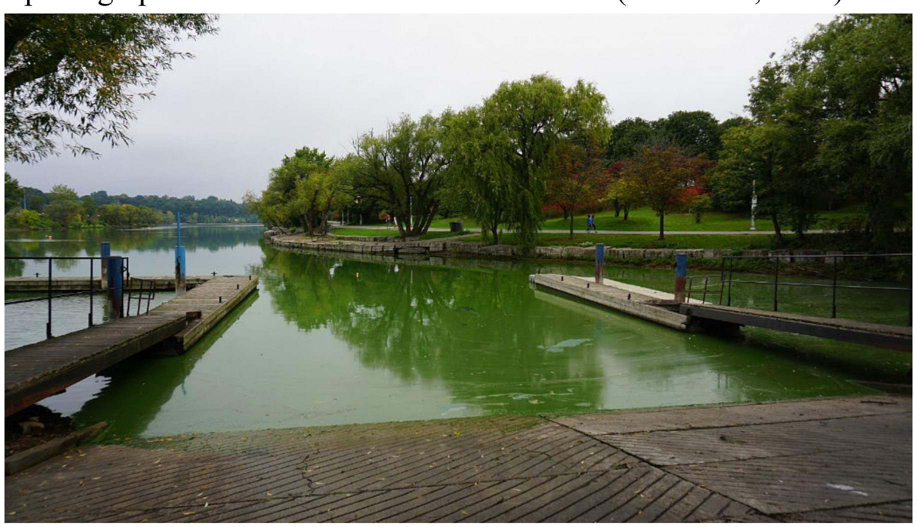




Challenges Associated with Natural Hazards

- There is limited flood risk in Reach 7 given the significant amount of shore protection, small wave heights inside the bay, and existing land-uses, which are mostly recreational.
- Minor bank erosion was observed above the shore protection around Bayfront Park. See below, possibly associated with the record high lake levels in 2017 ands 2019.

- There are significant water quality challenges in the channel between Reach 7 and 8, as seen in the photograph below taken from the boat launch (October 3, 2021).



- Due to the extensive shoreline armouring that exists on public lands, ongoing monitoring and maintenance will be required indefinitely.

Technical Basis for Natural Hazard Mapping

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

Geographic Area	Recession Rate (m/year)
Entire Reach	0.1

- 100-year Flood Level and Wave Uprush Limit:

Sub-Reach	100-year Flood Level (m IGLD'85)	Horizontal Uprush Allowance (m)	Calculated Wave Uprush Elevation (m IGLD85')
Hamilton Waterfront	76.2	10 m	-

- Dynamic Beach(es): not applicable.

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

- Offshore Wave Climate:

WIS Station	ARI (years)	Depth (m)	Hs (m)	Tp (s)	DIR (deg)
n/a	25+	12.0	2.0	5.0	All

Shoreline Management Recommendations

- **Preserve:** maintain natural shorelines, geodiversity, 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 with safe access challenges, as identified through the hazard mapping. Floodproof buildings, raise foundations, and upgrade septic systems on flood prone lands.
- **Retreat and Realign:** flood prone buildings and infrastructure to support marina and park operations could be relocated further inland if risks become severe in the future.
- **Protect:** all shoreline protection structures should be monitored and upgraded/repaired with appropriate engineered solutions as required.

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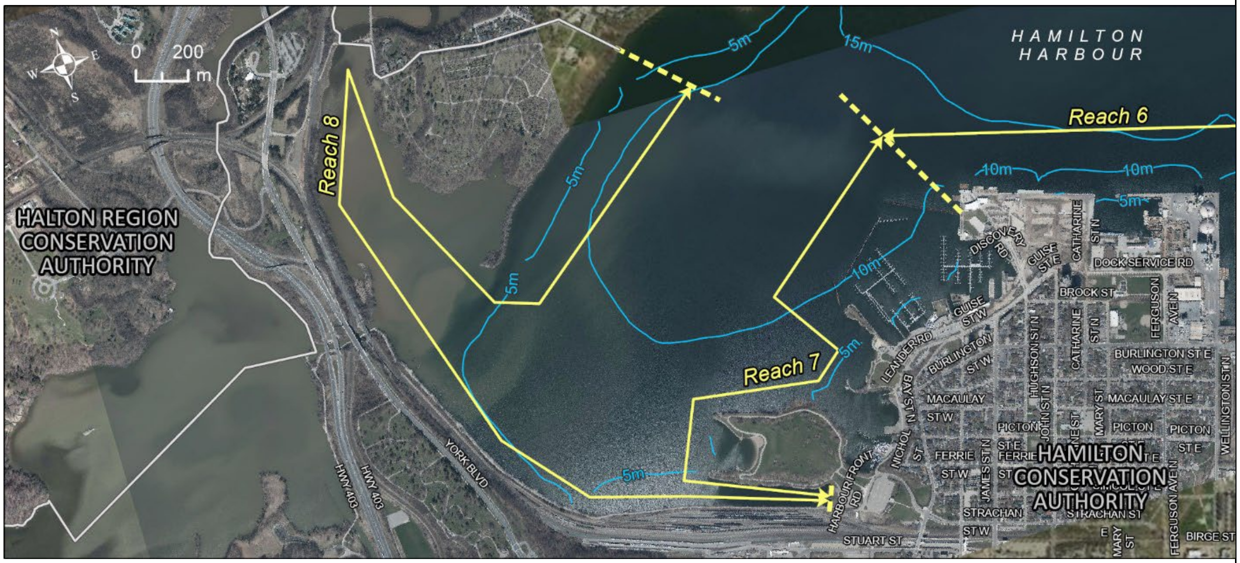
Reach 8 – Bayfront Park to Woodland Cemetery



Reach Overview

- Reach Length: approximately 5.3 km in length.
- Public boat launch and rowing hub.
- Publicly accessible shoreline with waterfront trail.
- Armoured shoreline is augmented by several nearshore habitat islands and shoals.
- Channel to Cootes Paradise, with carp barrier.
- Wave exposure is limited to wind generated waves in the bay and recreational/commercial boat wakes.
- The northern limit of the reach features a nature sanctuary (Carroll's Bay) where motorized boat traffic is prohibited.
- High banks at Woodland Cemetery feature toppled trees.

Waterfront Trail and Habitat Islands

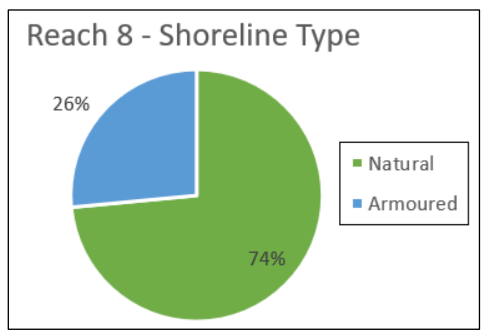
Woodland Cemetery

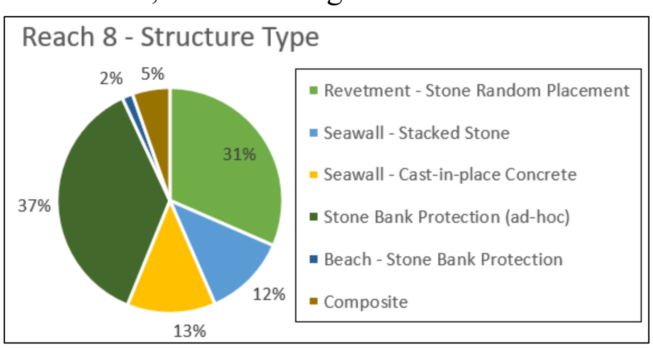
Great Lakes Shoreline Ecosystem Classification

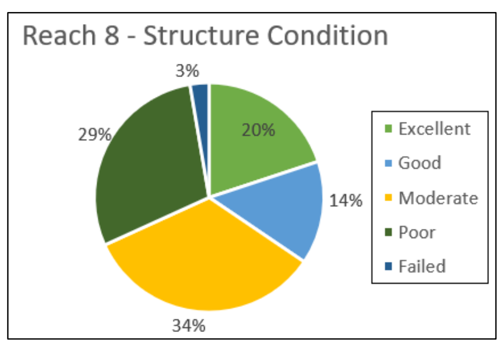
- The southern half of Reach 8 features a constructed shoreline with continuous armouring and a paved waterfront trail.
- The northern half features a natural shoreline and wooded bluffs along the cemetery.

Shoreline Condition and Structure Type

- Reach 8 features 74% natural shoreline and 26% armoured.
- Of the armoured shoreline, 68% is either revetment comprised of randomly placed stone or ad-hoc stone bank protection. 25% is split between stacked armour stone seawalls and cast-in-place concrete seawalls.
- The majority of the shore protection in Reach 8 can be described as ad-hoc, with only 6% appearing to be 'well-engineered'.
- The condition of shoreline infrastructure in Reach 8 is highly variable with 35% being in good or excellent condition, 34% being in moderate condition, 29% being in poor condition, and 3% being in a state of failure.





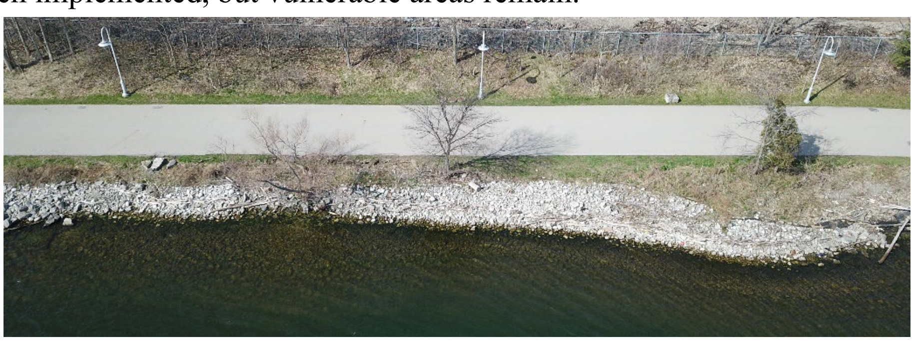


Challenges Associated with Natural Hazards

- Minor slope instability along the bluffs fronting Woodland Cemetery, as seen in the photo below.

- Algae bloom in Reach 8 on September 17, 2022.

- Waterfront trail is low-lying and vulnerable to both erosion and flooding along the majority of its length, particularly during periods of high lake levels, which may be higher in the future. Shoreline protection upgrades including bank protection and habitat islands have been implemented, but vulnerable areas remain.



Technical Basis for Natural Hazard Mapping

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

Geographic Area	Recession Rate (m/year)
Entire Reach	0.1

- 100-year Flood Level and Wave Uprush Limit:

Sub-Reach	100-year Flood Level (m IGLD'85)	Horizontal Uprush Allowance (m)	Calculated Wave Uprush Elevation (m IGLD85')
Hamilton Waterfront to Woodland Cemetery	76.2	10 m	-
Woodland Cemetery to East Boundary	76.2	-	+77.6 m

- Dynamic Beach(es): Coordinates in UTM Zone 17N, NAD 1983

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

- Offshore Wave Climate:

WIS Station	ARI (years)	Depth (m)	Hs (m)	Tp (s)	DIR (deg)
n/a	25+	12.0	2.0	5.0	All

Shoreline Management Recommendations

- **Preserve:** the toe of the bluffs fronting Woodland Cemetery could be protected with a nature based solution, such as nearshore shoals, habitat islands, or enhanced beaches.
- **Avoid:** ensure new development occurs outside of hazardous lands, and prohibit development/re-development in areas that are inaccessible during major floods. This pertains to new/future burials at Woodland Cemetery as well.
- **Accommodate:** not applicable.
- **Retreat and Realign:** not applicable.
- **Protect:** all existing shoreline protection structures should be monitored and upgraded/repaired with appropriate engineered solutions as required. Flood and erosion protection to the waterfront trail should be upgraded in the future through engineered revetments and/or habitat islands to fill gaps and create continuous protection along the entire length of trail. The bluffs fronting Woodland Cemetery should be monitored for a future nature-based solution.

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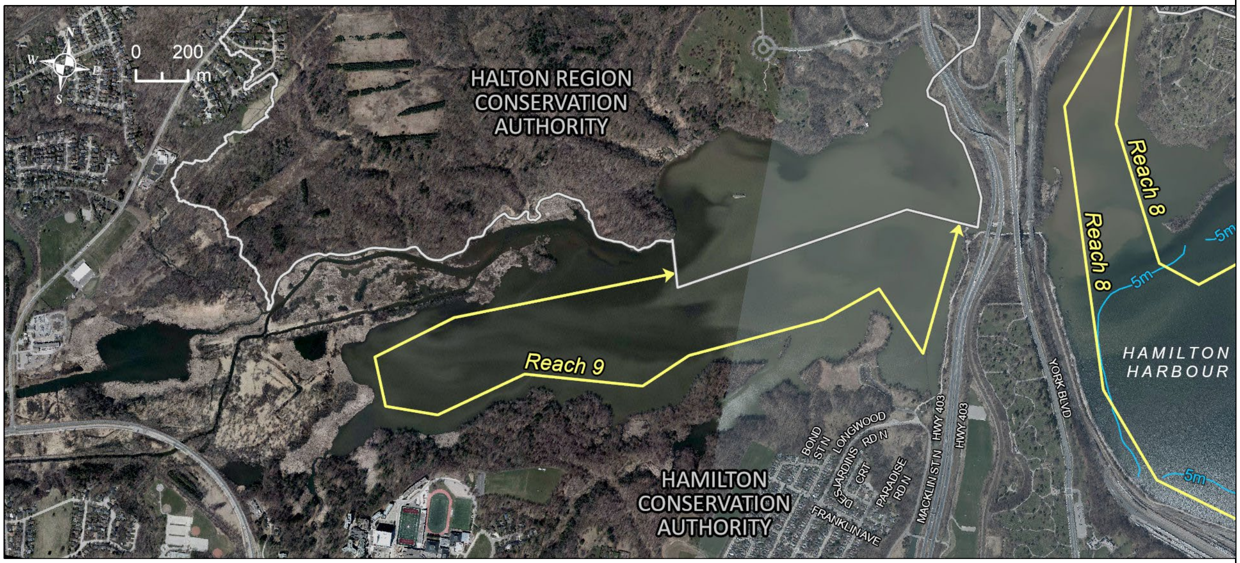
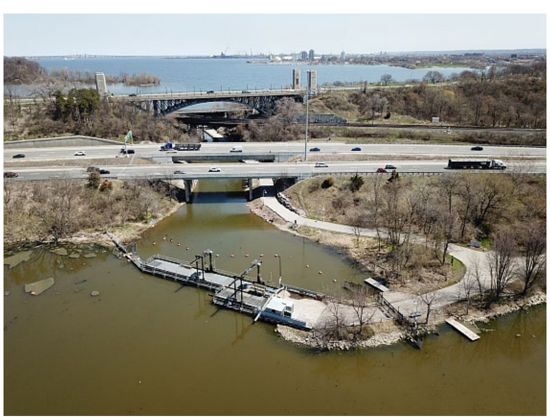
Reach 9 – Cootes Paradise



Reach Overview

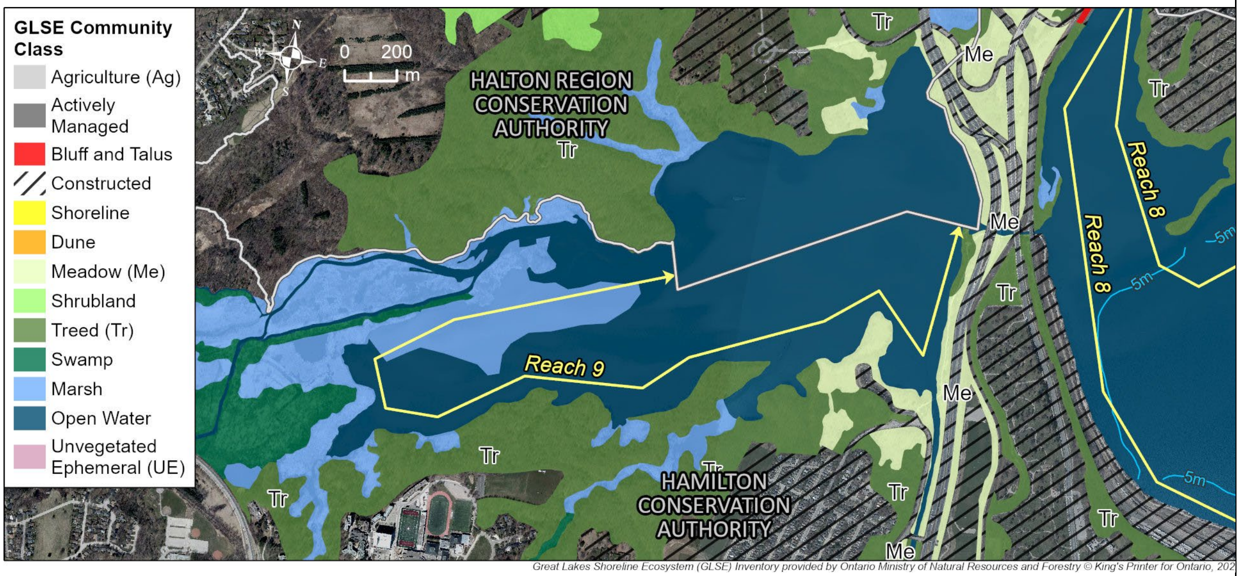
- Reach Length: approximately 6.0 km in length.
- The majority of the shoreline is owned and managed by the Royal Botanical Gardens and includes extensive natural areas.
- The bay can be traversed and observed along numerous trails and lookouts.
- While wind generated waves are small given the limited fetches in the bay, isolated locations of slope instability were observed from the oblique photographs.
- Spenser Creek and Chedoke Creek are the largest tributaries but there are many other smaller local creeks that drain into the bay.
- The hydraulic connect to Hamilton Harbour features a carp barrier.

Carp Barrier at Connection to Hamilton Harbour



Cootes Paradise Marsh and Wooded Shoreline

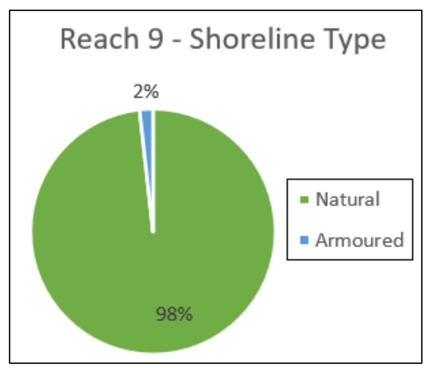
Great Lakes Shoreline Ecosystem Classification

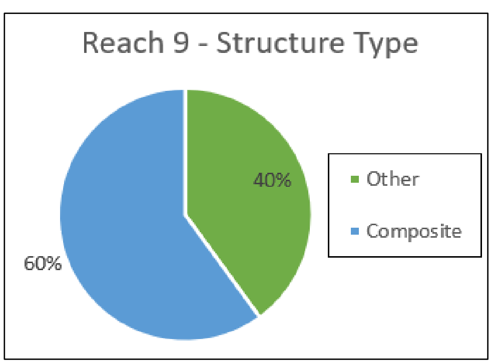


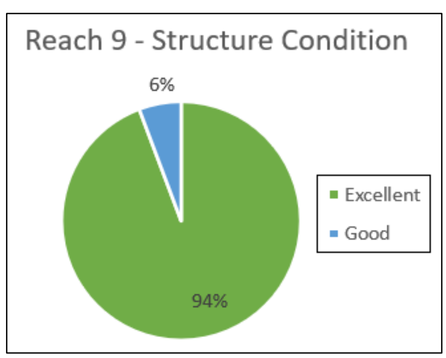
- Cootes Paradise features extensive marsh, meadow and treed habitat around the perimeter of the bay. The central and eastern portion features open water.
- The northeast corner of the bay falls under the jurisdiction Halton Region Conservation Authority.

Shoreline Condition and Structure Type

- 98% of Reach 9 features a natural shoreline.
- Of the armoured shoreline, 60% features a composite structure and the remaining 40% falls into the "other" category.
- The limited shoreline structures that do exist are generally in excellent condition.







Challenges Associated with Natural Hazards

- Given the sheltered conditions in Cootes Paradise and natural shoreline conditions, there are only limited challenges with natural hazards in Reach 9.
- Minor shoreline erosion and slope instability were observed at select locations, often at headlands with exposure to the largest fetches in the bay.

- The location of future trails and especially lookouts should consider the stability of the shoreline and the potential for additional erosion and slope instability. See example of lookout below where the shoreline appears to feature a low recession rate with evidence of minor slope failures.

Technical Basis for Natural Hazard Mapping

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

Geographic Area	Recession Rate (m/year)
Entire Reach	0.1

- 100-year Flood Level and Wave Uprush Limit:

Sub-Reach	100-year Flood Level (m IGLD'85)	Horizontal Uprush Allowance (m)	Calculated Wave Uprush Elevation (m IGLD85')
Cootes Paradise	76.2	10 m	-

- Dynamic Beach(es): Coordinates in UTM Zone 17N, NAD 1983

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

- Offshore Wave Climate:

WIS Station	ARI (years)	Depth (m)	Hs (m)	Tp (s)	DIR (deg)
n/a					

Shoreline Management Recommendations

- **Preserve:** the marsh and wooded shoreline of Cootes Paradise are currently preserved and resilient to natural hazards. Care should be taken to avoid introducing additional engineered structures along the shoreline and emphasis should be placed on nature-based solutions if shoreline modifications are required.
- **Avoid:** locating new trails and lookouts in proximity to unstable shorelines.
- **Accommodate:** not applicable.
- **Retreat and Realign:** re-align trails further inland if susceptible to erosion in the future.
- **Protect:** If lookouts and trails are threatened by erosion in the future, nature-based solutions should be pursued to stabilize the shoreline and create nearshore habitat.

Use Disclaimer

APPENDIX B – Reach 4 Shoreline Change Maps

Zuzek inc.
ONE WORLD

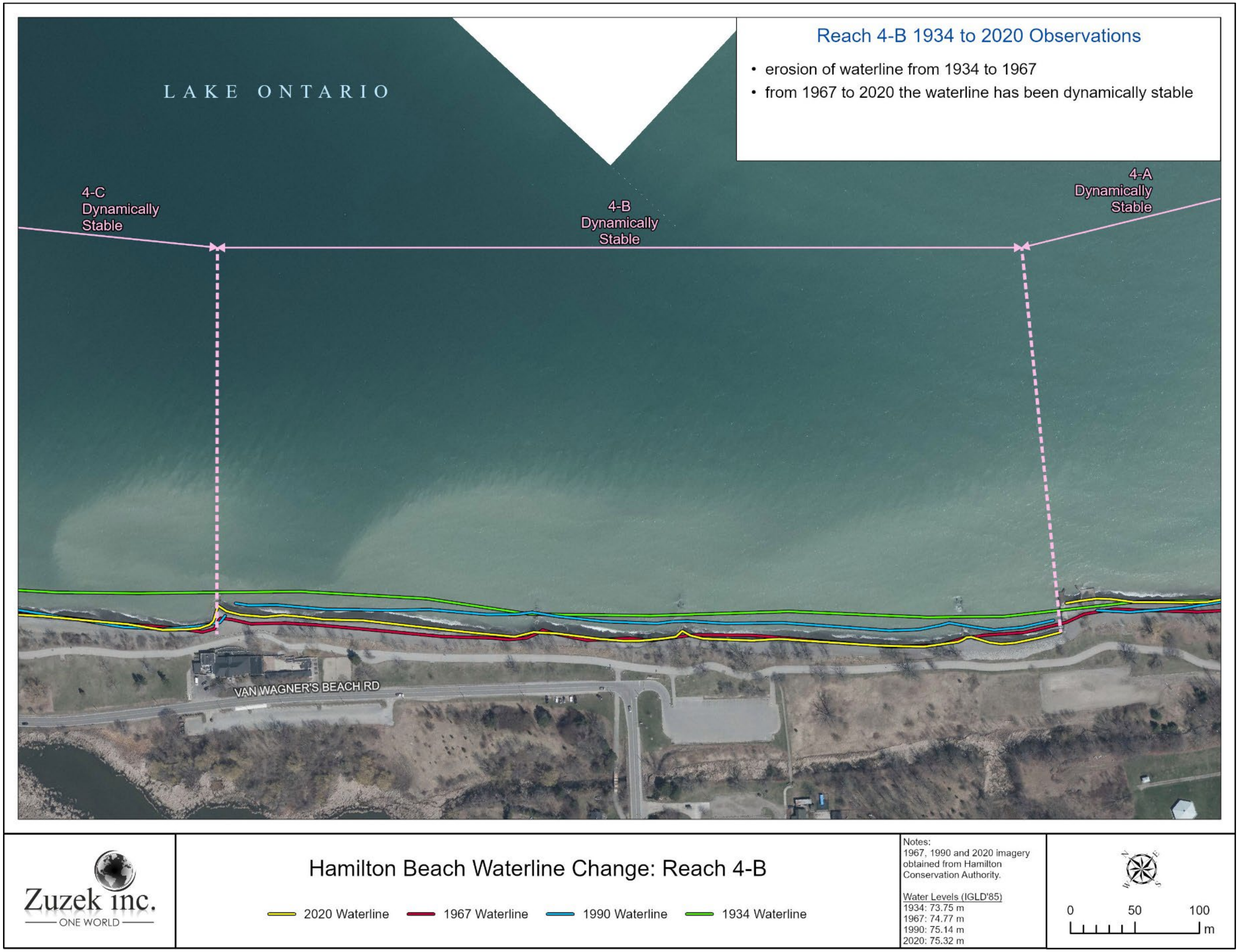
Hamilton Beach Waterline Change: Reach 4-A

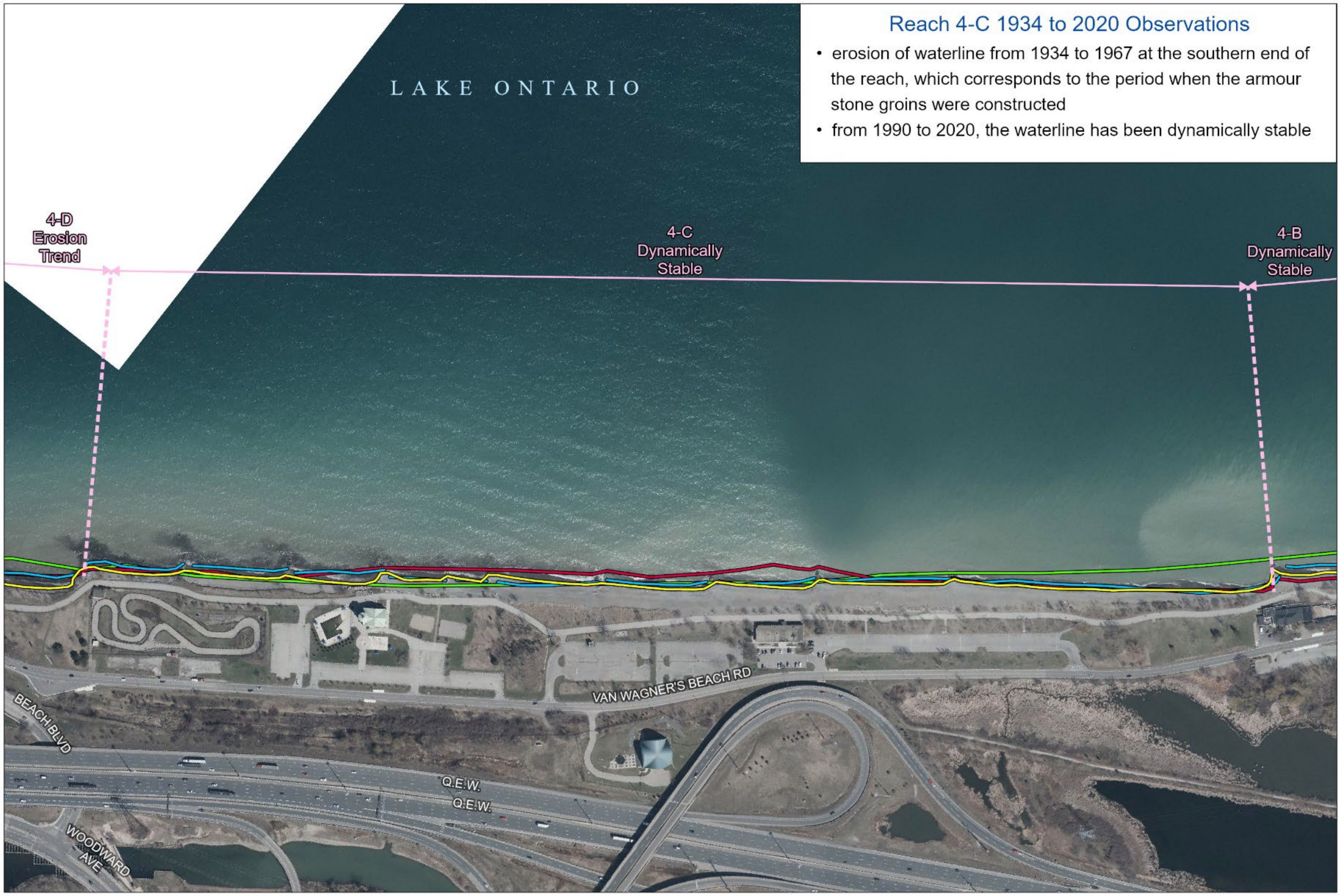
2020 Waterline | 1967 Waterline | 1990 Waterline | 1934 Waterline

Notes:
1967, 1990 and 2020 imagery obtained from Hamilton Conservation Authority.

Water Levels (IGLD'85)
1934: 73.75 m
1967: 74.77 m
1990: 75.14 m
2020: 75.32 m

0 50 100 m


Reach 4-B 1934 to 2020 Observations
• erosion of waterline from 1934 to 1967
• from 1967 to 2020 the waterline has been dynamically stable
LAKE ONTARIO
4-C Dynamically Stable
4-B Dynamically Stable
4-A Dynamically Stable
VAN WAGNER'S BEACH RD
Zuzek inc.
ONE WORLD
Hamilton Beach Waterline Change: Reach 4-B
2020 Waterline
1967 Waterline
1990 Waterline
1934 Waterline
Notes:
1967, 1990 and 2020 imagery obtained from Hamilton Conservation Authority.
Water Levels (IGLD'85)
1934: 73.75 m
1967: 74.77 m
1990: 75.14 m
2020: 75.32 m
N E W S
0 50 100
m



Zuzek inc.
ONE WORLD

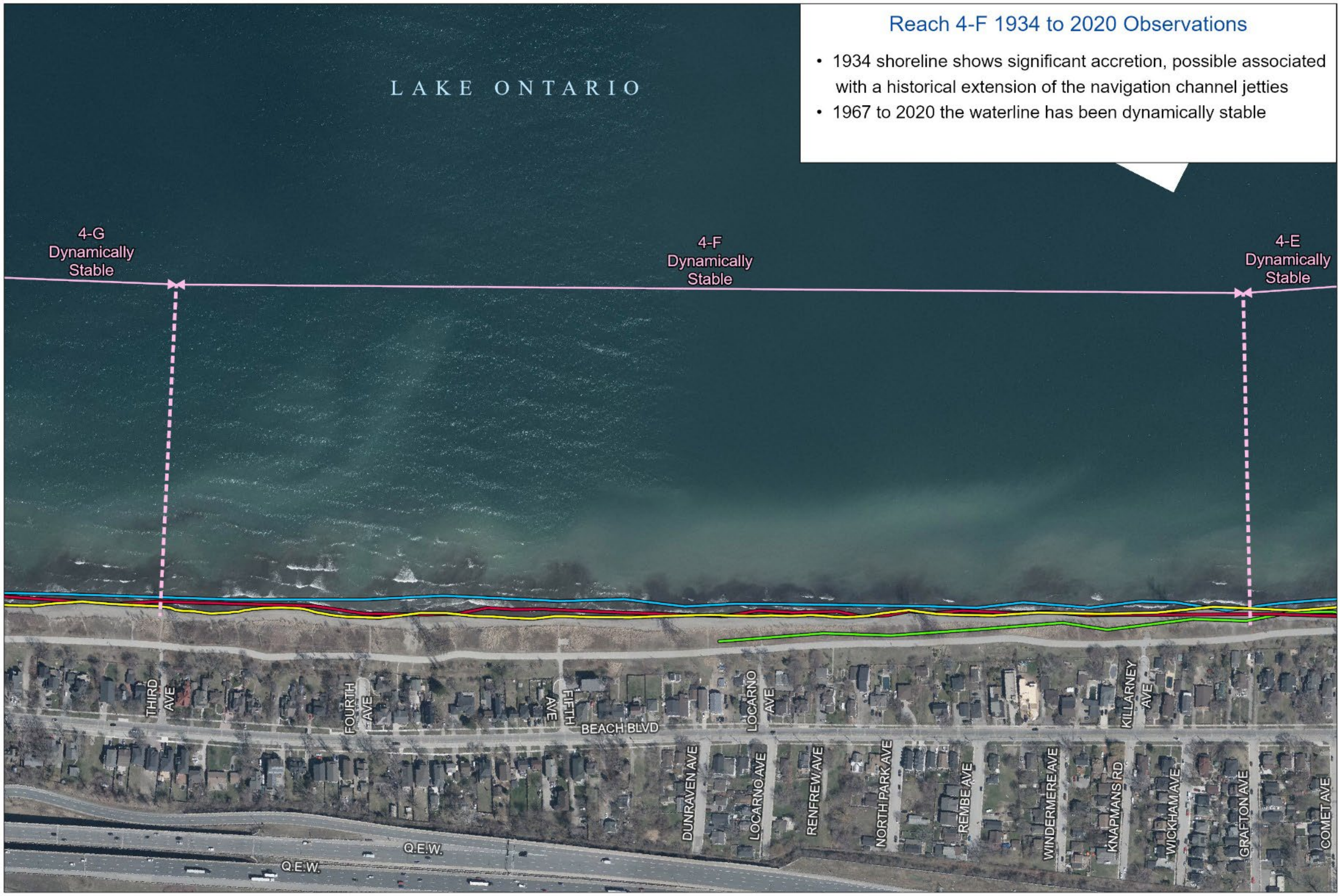
Hamilton Beach Waterline Change: Reach 4-C

2020 Waterline — 1967 Waterline — 1990 Waterline — 1934 Waterline

Notes:
1967, 1990 and 2020 imagery obtained from Hamilton Conservation Authority.

Water Levels (IGLD'85)
1934: 73.75 m
1967: 74.77 m
1990: 75.14 m
2020: 75.32 m

0 50 100 m



Zuzek inc.
ONE WORLD

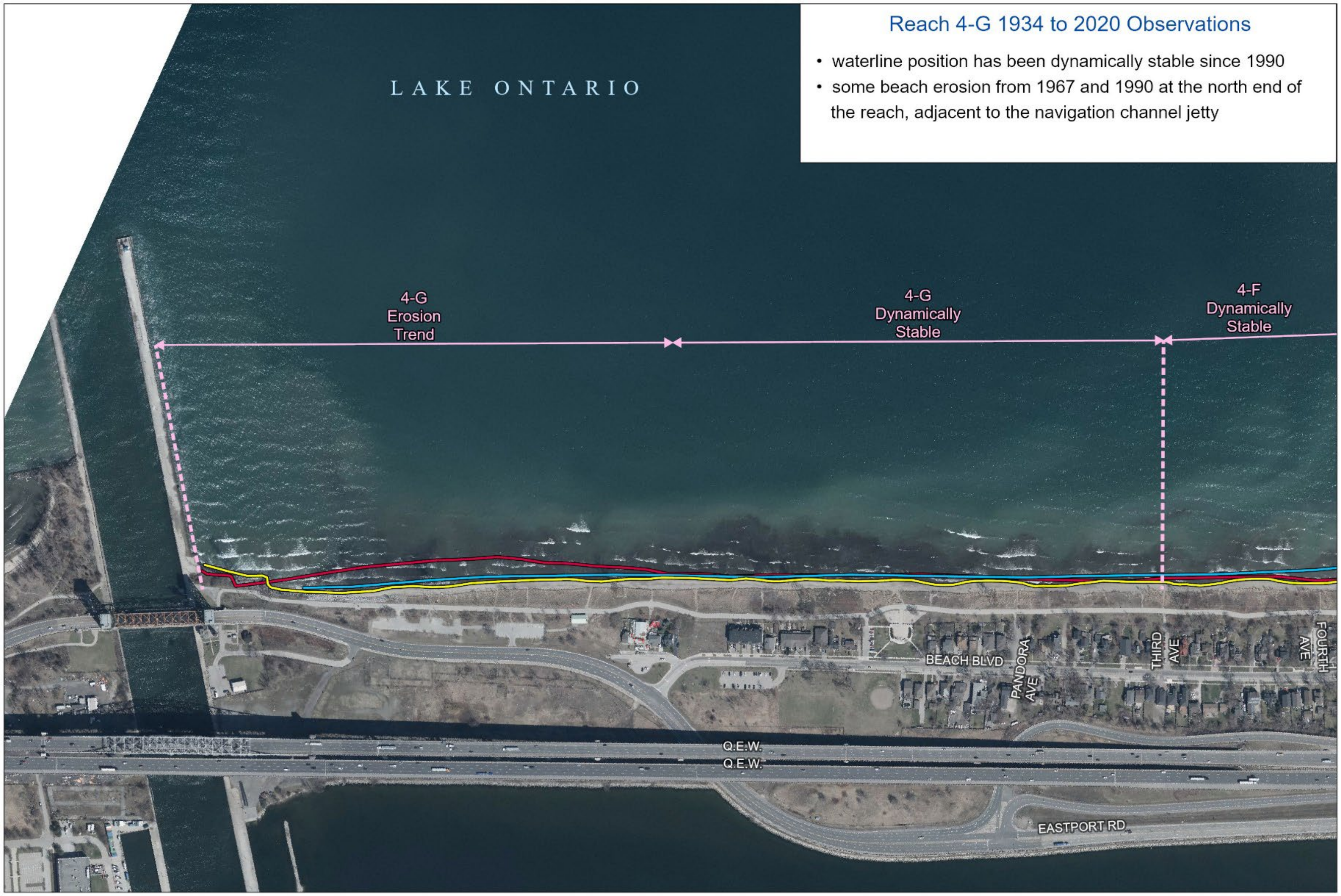
Hamilton Beach Waterline Change: Reach 4-F

2020 Waterline — 1967 Waterline — 1990 Waterline — 1934 Waterline

Notes:
1967, 1990 and 2020 imagery obtained from Hamilton Conservation Authority.

Water Levels (IGLD'85)
1934: 73.75 m
1967: 74.77 m
1990: 75.14 m
2020: 75.32 m

0 50 100 m



Zuzek inc.
ONE WORLD

Hamilton Beach Waterline Change: Reach 4-G

2020 Waterline 1967 Waterline 1990 Waterline 1934 Waterline

Notes:
1967, 1990 and 2020 imagery obtained from Hamilton Conservation Authority.

Water Levels (IGLD'85)
1934: 73.75 m
1967: 74.77 m
1990: 75.14 m
2020: 75.32 m

0 50 100 m

APPENDIX C – Hazard Maps

(*Not attached to this PDF version of the report*)