Essex Region Coastal Flood Hazard Mapping

Prepared for:

County of Essex and Essex Region Conservation Authority

June 13, 2024

Prepared by:

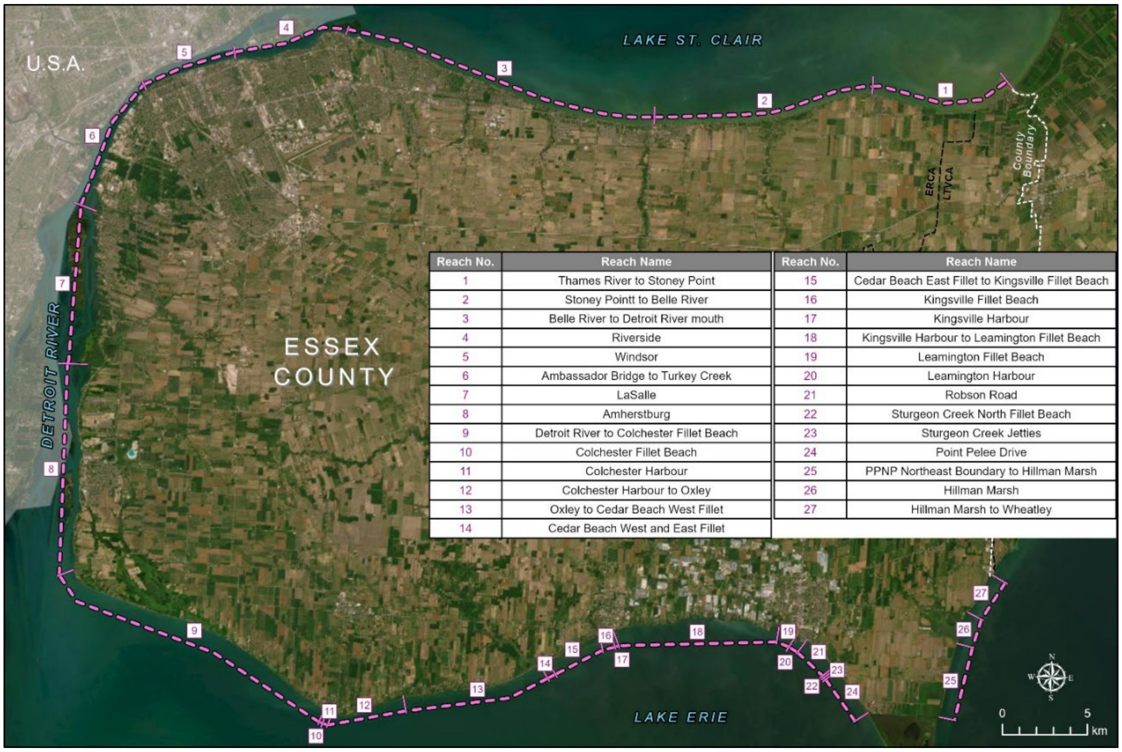
Zuzek inc.
ONE WORLD

In association with:

SJL ENGINEERING

DHI

Map of shoreline reaches for the flood hazard mapping



Reach No.	Reach Name	Reach No.	Reach Name
1	Thames River to Stoney Point	15	Cedar Beach East Fillet to Kingsville Fillet Beach
2	Stoney Pointt to Belle River	16	Kingsville Fillet Beach
3	Belle River to Detroit River mouth	17	Kingsville Harbour
4	Riverside	18	Kingsville Harbour to Leamington Fillet Beach
5	Windsor	19	Leamington Fillet Beach
6	Ambassador Bridge to Turkey Creek	20	Leamington Harbour
7	LaSalle	21	Robson Road
8	Amherstburg	22	Sturgeon Creek North Fillet Beach
9	Detroit River to Colchester Fillet Beach	23	Sturgeon Creek Jetties
10	Colchester Fillet Beach	24	Point Pelee Drive
11	Colchester Harbour	25	PPNP Northeast Boundary to Hillman Marsh
12	Colchester Harbour to Oxley	26	Hillman Marsh
13	Oxley to Cedar Beach West Fillet	27	Hillman Marsh to Wheatley
14	Cedar Beach West and East Fillet		

Disclaimer:

Zuzek Inc. in association with SJL Engineering Inc., and DHI (collectively the Consultants) prepared this report for the County of Essex and the Essex Region Conservation Authority. The standard of care typically applied to such an assignment was followed using available data to produce the report. The Consultants assume no responsibility for the use of this report by a third party. Furthermore, if used by a third party, they agree that the information is subject to change without notice and the Consultants assume no responsibility for the consequences of such use or changes in the information. Under no circumstances 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 report by a third party.

TABLE OF CONTENTS

List of Tables

List of Figures

1.0 INTRODUCTION

In partnership with the Essex Region Conservation Authority, the County of Essex received funding from the Ontario Flood Hazard Identification and Mapping Program (FHIMP), which is part of a national flooding program administered by Natural Resources Canada (NRCan). Section 1.0 of the report presents the study and scope of the project. The remaining report sections review the legislative direction for flood mapping in Ontario, field investigations, the technical analysis, mapping approach, and knowledge sharing with the community.

1.1 Study Area

The study area shoreline extends from the mouth of the Thames River in the southeast corner of Lake St. Clair, includes the entire Detroit River shore, and the Lake Erie shoreline in the western basin and the east side of the Pelee Peninsula to Wheatley. Refer to Figure 1.1.

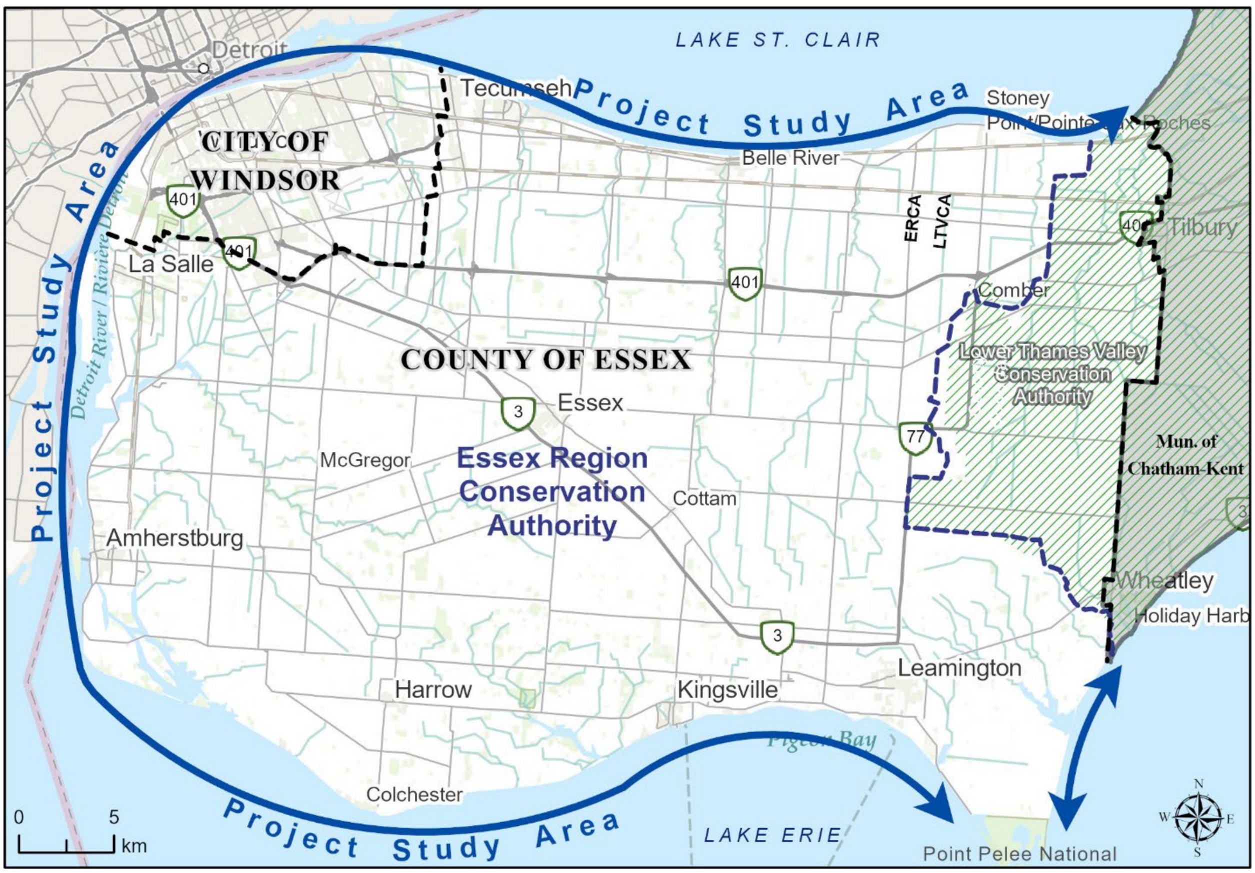


Figure 1.1 Study area

While the City of Windsor is a separate municipal jurisdiction than the County of Essex, they contributed to the study and the flood hazard mapping was extended to cover all of Essex Region.

Most of the study shoreline falls within the jurisdiction of the Essex Region Conservation Authority, with the exception of the northeast corner at the mouth of the Thames River, where the Lower Thames River Conservation Authority regulates shoreline development. This area is hatched in Figure 1.1.

1.2 Scope of Investigation

The Essex Region Coastal Flood Hazard Mapping project updated the existing shoreline flood hazard mapping originally published in 1976. While the mapping is now over 46 years, it is still used for land use decision making and development regulation through the Planning Act and the Conservation Authorities Act. The scope of the project included the following:

- Communication and Knowledge Sharing: websites, meetings, and data sharing to communicate the study findings.
- Data Collection: the project leveraged existing data (previous bathymetry surveys of the lake depths) and collected new oblique drone imagery and bathymetric data where needed.
- Technical Analysis: updated statistical analysis of water level gauges, integration of projected climate change impacts, and numerical modelling of waves and storm surge.
- Flood Mapping: updated flood hazard mapping based on historical extremes and the projected impacts of climate change will be generated for the entire study area shoreline.
- Deliver Mapping and Project Data: at the completion of the project, the updated flood hazard mapping will be delivered as static maps and geospatial layers. Other data collected and generated for the project, such as oblique photographs, will be forwarded.

2.0 LEGISLATION AND TECHNICAL DIRECTION FOR FLOOD MAPPING

Section 2.0 of the report reviews the legislation and technical documents that guided the development of the updated *flood hazard* mapping.

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 for subdividing land. The *Act* requires that local citizens be informed about the planning process in their community, are encouraged to provide feedback, and can appeal some 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 being released in 2020. A draft document is currently under review, but not yet implemented at the time of this writing. 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 that planners and regulators: 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 Lake St. Clair, Detroit River, and Lake Erie shoreline represents an area where the diversity and connectivity of natural features and their long-term ecological function should be maintained, restored, or improved. 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 those features, their ecological functions, or the environment in general.

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, dynamic beach hazards* or unstable soil or bedrock. More explicitly, development and site alteration shall not be permitted in areas that would be rendered inaccessible to people and vehicles during times of *flooding hazards, erosion hazards,* or *dynamic beach 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 increase in the future, this information should be integrated into planning decisions. At the time of this writing, the Ministry of Natural Resources and Forestry (MNRF) was in the process of revising an updated Technical Guidance document that includes new methods and direction for the inclusion of climate change factors in regulatory hazard mapping (original report by Zuzek Inc., 2023). These draft methods were applied for the generation of the updated *flood hazard* mapping documented in this report.

2.2 Conservation Authorities Act and Regulatory Framework

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, the hazard mapping produced as a component of this project and the policies surrounding regulation within those hazards may require updating. Prior to the current framework, CAs had the authority to make regulations applicable to activities under its jurisdiction, such as prohibiting or regulating development if the control of flooding, erosion, dynamic beaches, pollution, or the conservation of land may be adversely affected.

Until recently, Ontario Regulation 158/06: Essex Region Conservation Authority: Regulation of Development, Interference with Wetlands and Alteration of Shorelines and Watercourses, governed how the Essex Region Conservation Authority regulated development activities. In general, the objectives were as follows:

- 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.
- Regulate the draining or filling of wetlands, which contribute to flood attenuation and reduce sedimentation in downstream watercourses.
- Regulate development on or adjacent to potentially hazardous slopes.
- Reduce soil erosion from valley slopes.

Recently, the individual CA-specific regulations were repealed by Minister of Natural Resources and Forestry and replaced with a single regulation: Ontario Regulation 41/24: Prohibited Activities, Exemptions, and Permits. This regulation governs Section 28 responsibilities under the CA Act and defines the applicable flood event standards for all conservation authorities. O. Reg. 41/24 enables the prohibition or regulation of activities (development, alterations, interferences, etc.) that may impact the control of flooding, erosion, dynamic beaches, unstable soils, or bedrock. The objectives are generally the same as Ontario Regulation 158/06 listed above. For the shorelines 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 period 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 of 15 m as prescribed by Ontario Regulation 41/24. The CA 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, unstable soils, or bedrock will not be affected by the development.

2.2.1 Essex Region Conservation Authority: Ontario Regulation 41/24

Ontario Regulation 41/24 provides the Essex Region Conservation Authority (ERCA) with the authority to regulate development and activities to straighten, change, divert, or interfere with rivers, creeks, streams, watercourses, wetlands, and shorelines. This regulation replaces ERCA's previous CA specific regulation (158/06) and is the mechanism by which ERCA fulfills its mandate to prevent the loss of life and property. Commensurate the with *CA Act* (discussed above), development is restricted or prohibited on the lands adjacent to the shoreline of the Great Lakes and Detroit River that may be affected by flooding, erosion, or dynamic beaches, based on the furthest landward extent of the *flooding hazard, erosion hazard,* and *dynamic beach hazard*, plus an additional allowance of 15 metres inland. This inland extent is collectively known as the 'Regulation Limit'.

2.2.2 Lower Thames Valley Conservation Authority: Ontario Regulation 41/24

As detailed above, Ontario Regulation 41/24 replaced Lower Thames Valley Conservation Authority's CA-specific regulation, 152/06. It is through this same framework that development and activities to straighten, change, divert, or interfere with rivers, creeks, streams, watercourses, wetlands, and shorelines are regulated by the Lower Thames Valley Conservation Authority.

2.3 Guidance Documents

The technical methods followed to assess and map the *flood hazard* 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 (now MNRF) released the Technical Guide for Great Lakes – St. Lawrence River System and Large Inland Lakes (MNR, 2001a). These guidelines provide the technical basis and general 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.

A substantial update to this document was completed in 2023 (Zuzek Inc.) and is currently under review by the MNRF. The update improves upon the technical adequacy of the guidance and presents new methodologies 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 version of this document is presently unknown. While not yet adopted by the MNRF, such procedures were implemented throughout this project to ensure that the results were based on the application of the most current available practices and scientific principles.

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 (Section 3.1) contained in 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 (CO & MNR, 2005)

Additional technical information for establishing the limits of hazardous lands adjacent to the coastline of the Great Lakes St. Lawrence River System are provided by Conservation Ontario (CO) 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 41/24* is provided, including the following details relevant to this *flood hazard* mapping update:

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

3.0 FIELD INVESTIGATION AND DATA AQUISITION

The field investigation and new data collection for the flood study is summarized in Section 3.0.

3.1 Oblique Aerial Photograph Collection

Approximately 3,000 oblique photographs of the Essex Region shoreline were captured during April, 2023, using an unmanned aerial vehicle (UAV). The photographs were geotagged and compiled into a georeferenced photographic database. Most of the Essex Region shoreline was captured in the photographic database, including the south shore of Lake St. Clair, the Canadian side of the Detroit River, the western basin of Lake Erie, and the east side of the Pelee Peninsula.

The photo database was an important source of information for the characterization of the project shoreline for the wave effects calculations discussed in Section 4.3.5. 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 or lack of public access points. Figure 3.1 provides a map showing the locations of all geotagged photographs captured for the project.

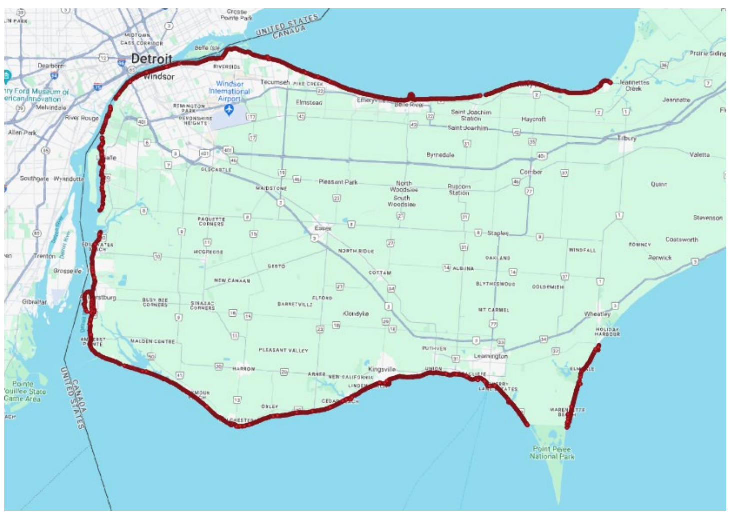


Figure 3.1 Locations of all geotagged oblique photographs of the Essex Region shoreline (red dots) captured between April 20 to 27, 2023

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 60 – 80 m above lake level, a horizontal distance of 80 – 120 m offshore, and with shore parallel spacing of individual images established such that overlap between subsequent photos was generally achieved. This allowed for near complete coverage of the Essex Region shoreline with sufficient resolution to assess shoreline characteristics that influence flooding. Where appropriate, images were captured from a higher elevation to provide an increased range of view. Sample photographs of the Essex Region shoreline from the compiled photo database are provided in Figure 3.2, Figure 3.3 and Figure 3.4, for Lake St. Clair, the Detroit River, and Lake Erie, respectively.

Figure 3.2 Sample photographs from the Essex Region photographic database (Lake St. Clair)

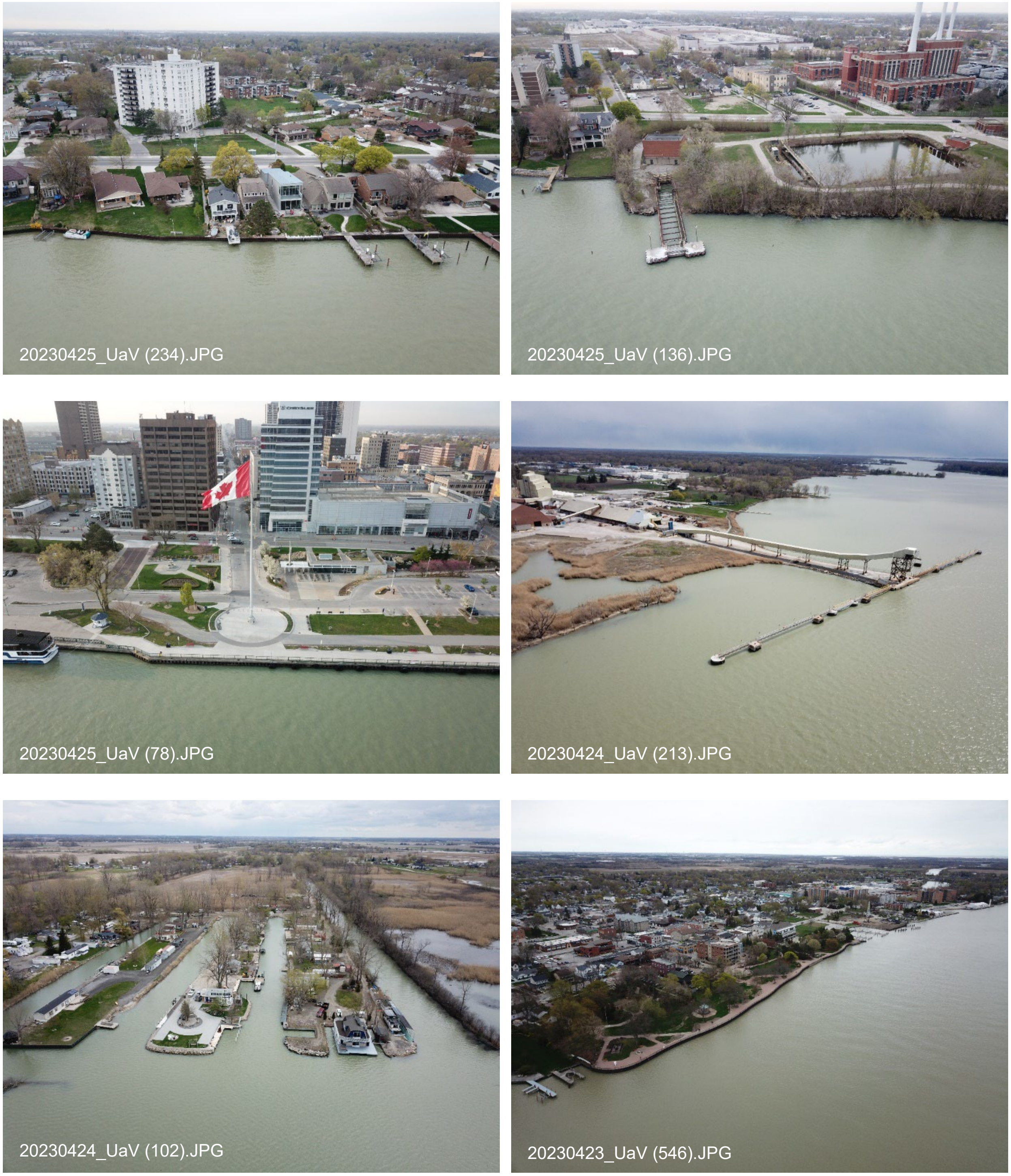


Figure 3.3 Sample photographs from the Essex Region photographic database (Detroit River)

Figure 3.4 Sample photographs from the Essex Region photographic database (Lake Erie)

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 Bathymetry

Zuzek Inc. had several recent bathymetric datasets in our project archive for Essex Region from 2019 and 2020, and supplemented this information with two historical surveys for the Pelee Peninsula from 2005 and 2007. The existing bathymetric data used to generate beach profiles and establish nearshore slope for the wave effect calculations in Section 4.3.5 is summarized in Figure 3.5 and the bullets below:

- 2005: east side survey of the Pelee Peninsula (provided by ERCA).
- 2007: west side of the Pelee Peninsula (provided by ERCA).
- 2019: east and west side of the Pelee Peninsula for the Southeast Leamington Graduated Risk Floodplain Mapping project (Zuzek Inc., 2021).
- 2019: Lake St. Clair shoreline within the Municipality of Lakeshore for a shoreline management plan update (Stantec, 2022).
- 2020: Flood risk assessment for the Tecumseh shoreline of Lake St. Clair (Zuzek Inc., 2022).
- 2020: Hillman Marsh Survey by Zuzek Inc. (unpublished).

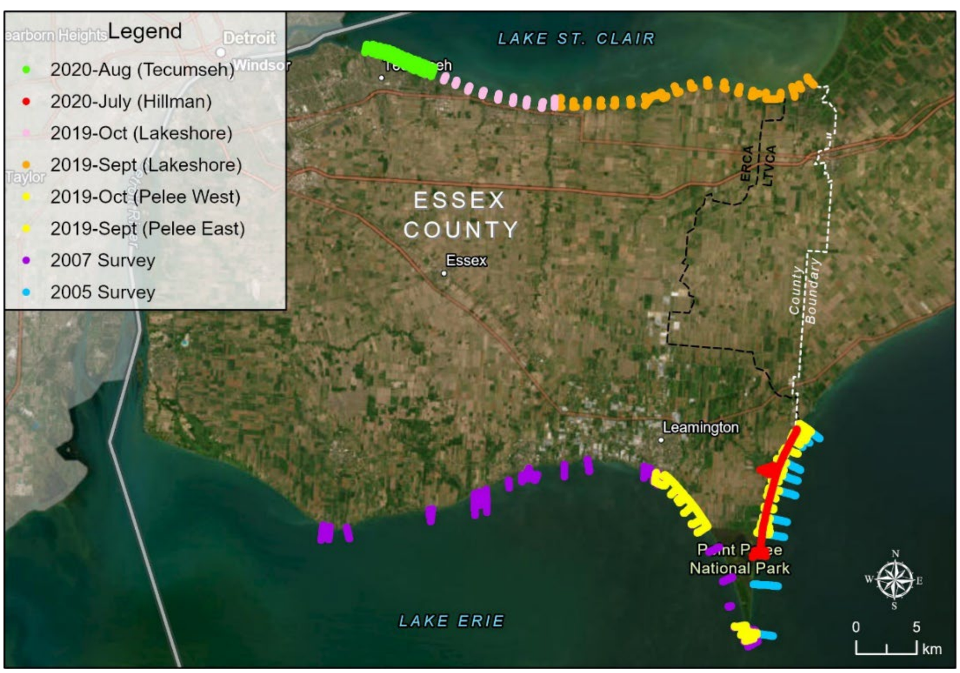


Figure 3.5 Historic bathymetry data

3.2.2 Spring 2023 Nearshore Survey

Staff from Zuzek Inc. conducted nearshore bathymetry surveys from May 30 to June 2, 2023, covering the Lake Erie western basin shoreline, Hillman Marsh and a verification survey of the Lake St. Clair shoreline. 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 3.6. The unit auto-corrects for the depth of the transducer below the lake surface, with depths recorded every second.

Figure 3.6 SOLIX data collection unit and transducer mount

A total of 51 recordings were collected within the project study area. See Figure 3.7 for an overview of the shore perpendicular transects collected.

Figure 3.7 SOLIX bathymetry surveys in 2023

The depth readings for the Lake Erie western basin profile survey were corrected using an average of hourly measured water levels for the day of the survey from the Kingsville water level gauge (#12065), 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 on June 2, 2023, was 174.60 m IGLD'85, taken from the Kingsville gauge. A SOLIX depth of -1.5 m would translate to a corrected elevation of 173.10 m (174.60 + (-1.5)). The hourly water level data for Kingsville can be found here: https://tides.gc.ca/en/stations/12065.

For the Hillman Marsh survey, an average of the water levels from both the Kingsville and Erieau (#12250) water level gauges were used. The average hourly water level for the duration of the survey completed on May 30, 2023, was 174.61 m IGLD'85, taken from an average of the Kingsville and Erieau gauges. A SOLIX depth of -1.5 m would translate to a corrected elevation of 173.11 m (174.61 + (-1.5)). The hourly water level data for Erieau can be found here: https://tides.gc.ca/en/stations/12250.

A similar process was followed for correcting the Lake St. Clair profile survey depth readings using an average of hourly measured waters levels for the day of the survey from the Belle River water level gauge (#11965). The average hourly water level for the duration of the survey completed on June 1, 2023, was 175.44 m IGLD'85, taken from the Belle River gauge. A SOLIX depth of -1.5 m would translate to a corrected elevation of 173.94 m (175.44 + (-1.5)). The hourly water level data for Belle River can be found here: https://tides.gc.ca/en/stations/11965.

The spring 2023 Lake St. Clair profiles were compared to the previous survey data discussed in Section 3.2.1 to evaluate potential lake bottom changes and applicability of the 2019 and 2020 nearshore profiles for the currently flood calculations. The results for Profile 16 in the Town of Tecumseh are typical (Figure 3.8) and document limited changes between the 2020 and 2023 data. Therefore, it was determined the older 2020 data was suitable for the flood study.

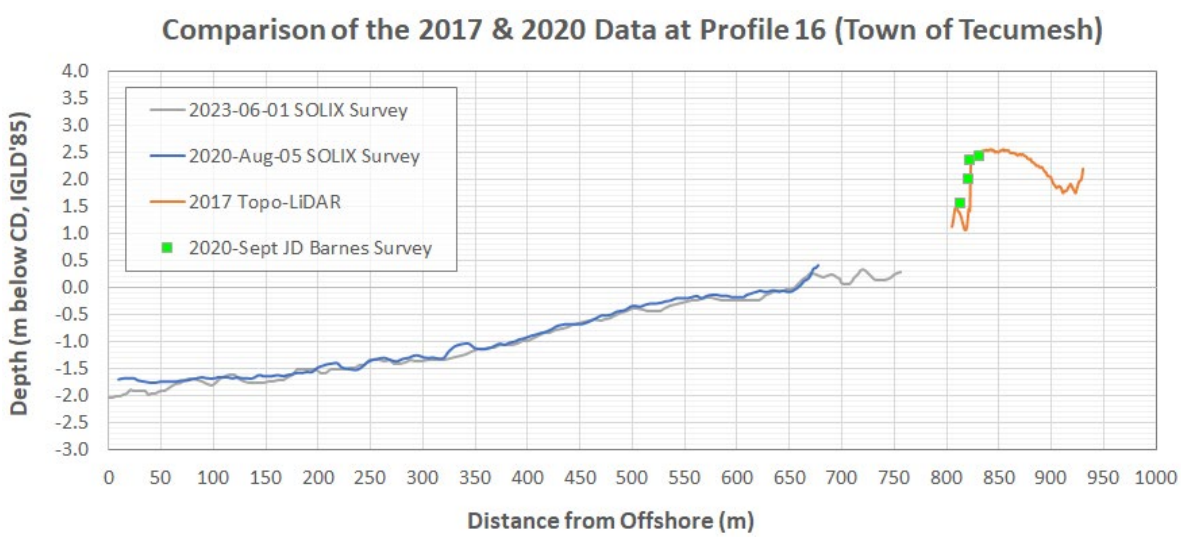


Figure 3.8 Profile 16 for the Town of Tecumseh Study (Zuzek Inc., 2022)

3.3 Topographic LiDAR

Topographic LiDAR was collected in 2017 for the Essex Region as part of a larger data collection effort by the Ministry of Natural Resources and Forestry (MNRF). ERCA provided a copy of this LiDAR dataset clipped to the project study area with elevations corrected to the CGVD28:78 vertical datum, in a raster format for use in GIS.

3.3.1 Vertical Datum Corrections

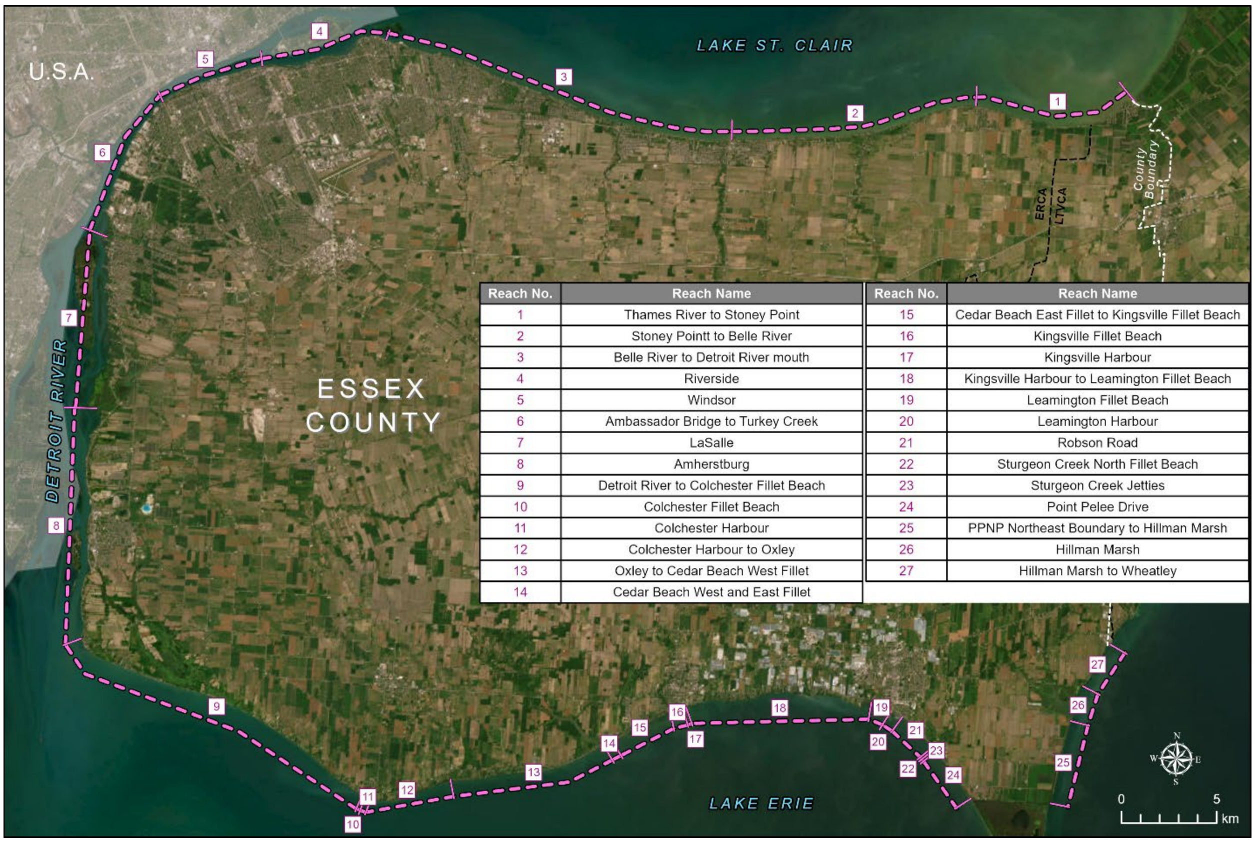
Passive control network data from Natural Resources Canada provides elevations for markers and benchmarks across Canada. The elevations are given in CGVD2013, CGVD28:78 and IGLD'85. The differences in elevations for each vertical datum were averaged between data locations for each waterbody: Lake Erie western basin, Detroit River, and Lake St. Clair. Refer to Table 3.1. For the western basin, the difference in IGLD'85 datum and CGVD28:78 is negligible while the IGLD'85 datum is an average of 47 cm higher than the CGVD2013 datum, as noted in Table 3.1. For the Detroit River, the difference in IGLD'85 datum and CGVD28:78 is negligible while the IGLD'85 datum is an average of 48 cm higher than the CGVD2013 datum. For Lake St. Clair, the difference in IGLD'85 datum and CGVD28:78 is also negligible while the IGLD'85 datum is an average of 47 cm higher than the CGVD2013 datum.

Table 3.1 Elevations

		Elevation of Beachmarks			Difference (m)	Difference (m)
UniqueNo	Location	CGVD2013 (m)*	CGVD28:78 (m)	IGLD85 (m)	IGLD85 - CGVD28:78	IGLD85 - CGVD13
Lake Erie - Wheatley to Detroit River						
81U025	Wheatley Harbour	176.33	176.81	176.80	-0.01	0.47
XXU9536	Sturgeon Creek	174.88	175.34	175.35	0.01	0.47
81U029	Leamington Harbour Wharf	175.42	175.89	175.89	0.00	0.47
61U9506	Kingsville	175.89	176.36	176.36	-0.01	0.47
71U109	Colchester	182.44	182.91	182.90	-0.01	0.46
81U055	Bar Point	175.32	175.79	175.80	0.00	0.47
				Average Difference (m):	**0.00**	**0.47**
Detroit River						
81U055	Bar Point	175.32	175.79	175.80	0.00	0.47
71U114	Amherstburg	177.25	177.73	177.73	0.00	0.48
64U9504	Lasalle	175.07	175.54	175.55	0.01	0.48
59U3032	Windsor	175.51	175.99	175.98	-0.01	0.47
				Average Difference (m):	**0.00**	**0.48**
Lake St. Clair						
24U3565	Pike Creek	176.21	176.69	176.68	0.00	0.47
59U3039	Belle River	176.59	177.06	177.06	0.00	0.47
71U155	Jeannettes Creek (Thames River mouth)	177.18	177.65	177.65	0.00	0.47
				Average Difference (m):	**0.00**	**0.47**

3.4 Hazard Mapping Reaches

A total of 27 hazard mapping reaches were defined for the Essex Region shoreline, as shown geographically in Figure 3.9. Reaches were defined to identify sections of shoreline with similar exposure to wave energy, shoreline and nearshore geology, shoreline morphology, physical processes such as erosion and deposition, development density, and sensitive ecological habitat. Each of the 27 mapping reaches is described below. Coastal processes essential to the evaluation and delineation of the shoreline *flooding* and *erosion hazard,* such as long-term erosion rates and wave uprush and overtopping setbacks, were defined for each reach. In some cases, sub-reaches were established to account for local differences in the shoreline conditions prior to mapping the shoreline hazards.



Reach No.	Reach Name	Reach No.	Reach Name
1	Thames River to Stoney Point	15	Cedar Beach East Fillet to Kingsville Fillet Beach
2	Stoney Pointt to Belle River	16	Kingsville Fillet Beach
3	Belle River to Detroit River mouth	17	Kingsville Harbour
4	Riverside	18	Kingsville Harbour to Leamington Fillet Beach
5	Windsor	19	Leamington Fillet Beach
6	Ambassador Bridge to Turkey Creek	20	Leamington Harbour
7	LaSalle	21	Robson Road
8	Amherstburg	22	Sturgeon Creek North Fillet Beach
9	Detroit River to Colchester Fillet Beach	23	Sturgeon Creek Jetties
10	Colchester Fillet Beach	24	Point Pelee Drive
11	Colchester Harbour	25	PPNP Northeast Boundary to Hillman Marsh
12	Colchester Harbour to Oxley	26	Hillman Marsh
13	Oxley to Cedar Beach West Fillet	27	Hillman Marsh to Wheatley
14	Cedar Beach West and East Fillet		

Figure 3.9 Mapping reaches

- Reach 1 - Thames River to Stoney Point: Reach 1 is location in the northeast corner of the study area, from the mouth of the Thames River to Stoney Point.

- Reach 2 - Stoney Point to Belle River: A long reach of homogeneous shoreline conditions (low plain and heavily armoured) from Stoney Point to the Belle River jetties.

- Reach 3 - Belle River to Detroit River mouth: A long reach of low plain shoreline vulnerable to flooding from the jetties at Belle River to the mouth of the Detroit River.

- Reach 4 - Riverside: First reach on the Detroit River is referred to as 'Riverside'.

- Reach 5 - Windsor: Reach 5 covers the central portion of the Windsor Detroit River shoreline.

- Reach 6 – Ambassador Bridge to Turkey Creek: Reach 6 extends from the Ambassador Bridge south to the mouth of Turkey Creek.

- Reach 7 - LaSalle: The river shoreline for the community of LaSalle is Reach 7.

- Reach 8 - Amherstburg: Reach 8 generally corresponds to the Amherstburg shoreline on the Detroit River.

- Reach 9 - Detroit River Mouth to Colchester Fillet Beach: Reach 9 is a long reach that extends from the mouth of the Detroit River to the western limit of the Colchester fillet beach.

- Reach 10 - Colchester Fillet Beach: Corresponds to the small sandy beach west of Colchester Harbour.

- Reach 11 - Colchester Harbour: Reach 11 is the Colchester Harbour.

- Reach 12 - Colchester Harbour to Oxley: The bluff shoreline from the east limit of the Colchester Harbour to Oxley is Reach 12.

- Reach 13 - Oxley to Cedar Beach West Fillet: A low bank shoreline from Oxley to Cedar Beach west fillet.

- Reach 14 - Cedar Beach West and East Fillet: The sandy west and east fillet beaches are Reach 14.

- Reach 15 - Cedar Beach East Fillet to Kingsville Fillet Beach: The shoreline between Cedar Beach and Kingsville was identified as Reach 15.

- Reach 16 - Kingsville Fillet Beach: Reach 16 is the depositional west fillet beach at Kingsville.

- Reach 17 - Kingsville Harbour: Reah 17 is a small reach corresponding to the harbour at Kingsville.

- Reach 18 - Kingsville Harbour to Leamington Fillet Beach: The bluff shoreline between Kingsville and Leamington is Reach 18.

- Reach 19 - Leamington Fillet Beach: The sandy west fillet beach at Leamington is Reach 19.

- Reach 20 - Leamington Harbour: The harbour at Leamington is Reach 20.

- Reach 21 – Robson Road: Reach 21 corresponds to the Robson Road shoreline from Leamington Harbour to Sturgeon Creek.
- Reach 22 - Sturgeon Creek North Fillet Beach: The north fillet beach at Sturgeon Creek is Reach 22.
- Reach 23 - Sturgeon Creek Jetties: The rock jetties at Reach 22 are Reach 23.
- Reach 24 – Point Pelee Drive: Reach 24 consists of the shoreline along Point Pelee Drive to the northwest boundary of Point Pelee National Park (PPNP).
- Reach 25 - PPNP Northeast Boundary to Hillman Marsh: The shore from the northeast boundary of PPNP to the Hillman Marsh is Reach 25.
- Reach 26 - Hillman Marsh: The barrier beach shoreline fronting the Hillman Marsh is Reach 26.
- Reach 27 - Hillman Marsh to Wheatley: Reach 27 extends from the north limits of the Hillman Marsh to Wheatley.

4.0 Technical Analysis

The technical analysis completed to update the Essex Region hazard maps including updated water level gauge statistics, assessment and integration of climate change research on future lake levels, numerical modelling of storm surge gradients and nearshore waves, and wave effects calculations.

4.1 Water Level Analysis

A critical component in the assessment of shoreline hazards 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) of the two variables. For this study, the 100-year flood level was assessed four times, with the first being the historical data (the “historical 100-year flood level”), and the remaining three scenarios based on future climate change projections.

Water levels on the Great Lakes and connecting channels 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 between April and July for Lake St. Clair and Lake Erie. Longer-term fluctuations in lake levels can also occur over decades due to climatic factors (e.g., wet and dry periods) and the influence of 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 historical period, accounting for seasonal variations and using the best available statistical analysis techniques.

Historically, 100-year flood levels used in the regulation of most Canadian Great Lakes shorelines were based on work completed by the MNR in the 1980s and published in a report titled “Great Lakes System Flood Levels and Water Related Hazards” (MNR, 1989). For the Essex Region however, regulatory levels have primarily been based on an even older study published by M.M. Dillon Ltd. in 1976 (Dillon, 1976). Since the Dillon study was completed, nearly 50 years of high-resolution (at least hourly resolution) water level data has been logged at numerous water level gauges around the Great Lakes, including at Belle River, Bar Point and Kingsville within the study area. Additionally, measured monthly mean lake levels from a coordinated network of water level gauges for Lake St. Clair and Lake Erie are now available covering a period of more than 100 years. Figure 4.1 illustrates this historical dataset for Lake Erie.

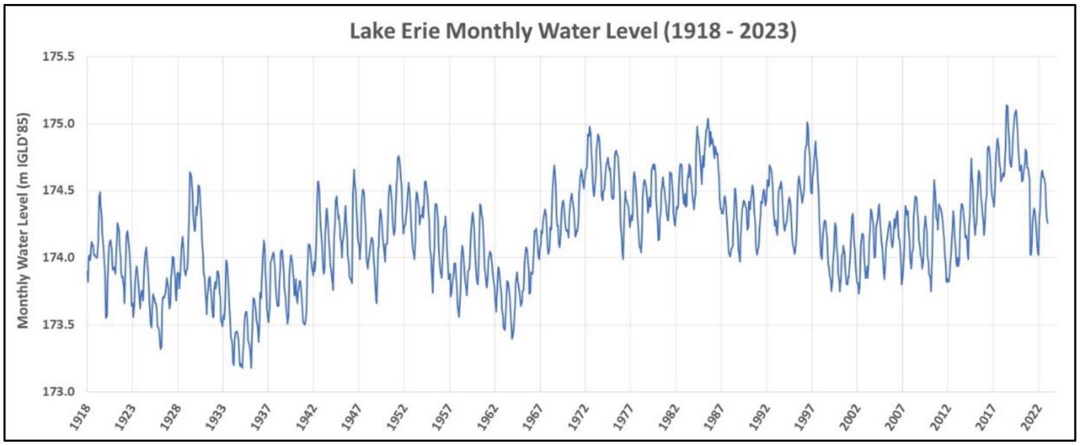


Figure 4.1 1918 to 2023 monthly mean water levels on Lake Erie

4.1.1 Historical 100-year Flood Level

As discussed above, the 100-year flood level is a combination of two independent components, namely static lake level and local storm surge. To assess the 100-year flood level therefore requires statistical analyses of each component separately, followed by a joint probability analysis (JPA). These analyses are summarized in the following sections.

4.1.1.1 Static Lake Levels

For the static lake level component of the analysis, measured data from 1900 to 2022 was used for both Lake St. Clair and Lake Erie. The historical static lake levels were adjusted such that they were representative of the modern basin configuration and stage-discharge relationships following the 2012 Basis of Comparison (International Joint Commission, 2012). The historical static lake level datasets were separated into 12 monthly datasets, and several probability distributions were fit to each. The distribution producing the best overall correlation coefficient was selected for each month, with resulting lake levels for a selection of return periods presented in Table 4.1 for Lake St. Clair and Table 4.2 for Lake Erie. As expected, the highest monthly static lake levels are most likely to occur between May and July for both lakes. The governing 100-year static lake levels are +176.01 m IGLD'85 and +175.14 m IGLD'85 for Lake St. Clair and Lake Erie, respectively.

Table 4.1 Static lake levels for Lake St. Clair corresponding to a range in average recurrence intervals (Tr) by month, based on data from 1900 to 2022

	Monthly Static Lake Level - Lake St. Clair (m IGLD85')												
Tr	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	MAX
1.5	174.72	174.71	174.78	174.88	174.98	175.05	175.09	175.06	174.99	174.87	174.77	174.76	175.09
2	174.89	174.87	174.93	175.03	175.12	175.19	175.22	175.19	175.12	175.00	174.91	174.89	175.22
5	175.22	175.18	175.24	175.33	175.41	175.47	175.50	175.47	175.39	175.29	175.19	175.18	175.50
10	175.39	175.35	175.41	175.50	175.56	175.62	175.65	175.61	175.54	175.44	175.35	175.34	175.65
20	175.53	175.49	175.56	175.63	175.69	175.75	175.77	175.73	175.66	175.57	175.49	175.48	175.77
25	175.57	175.54	175.60	175.67	175.72	175.78	175.81	175.77	175.69	175.61	175.53	175.52	175.81
50	175.68	175.65	175.72	175.78	175.83	175.89	175.91	175.86	175.79	175.72	175.64	175.64	175.91
100	175.78	175.76	175.84	175.88	175.92	175.98	176.01	175.95	175.88	175.82	175.75	175.75	176.01
200	175.87	175.86	175.94	175.97	176.01	176.07	176.08	176.03	175.96	175.91	175.84	175.85	176.08
MAX Obs.	175.80	175.79	175.83	175.91	175.98	176.02	176.04	175.97	175.88	175.89	175.77	175.75	176.04
Year	2020	2020	2020	2020	2020	2020	2019	2020	2020	1986	1986	1986	

Table 4.2 Static lake levels for Lake Erie corresponding to a range of average recurrence intervals (Tr) by month, based on data from 1900 to 2022

	Monthly Static Lake Level - Lake Erie (m IGLD85')												
Tr	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	MAX
1.5	173.87	173.87	173.96	174.12	174.20	174.23	174.21	174.16	174.07	173.97	173.96	173.87	174.23
2	174.00	174.01	174.09	174.25	174.33	174.35	174.34	174.27	174.19	174.08	174.06	173.99	174.35
5	174.28	174.29	174.39	174.53	174.59	174.62	174.60	174.52	174.43	174.33	174.30	174.26	174.62
10	174.44	174.46	174.56	174.69	174.74	174.77	174.74	174.66	174.56	174.47	174.44	174.42	174.77
20	174.57	174.60	174.71	174.82	174.86	174.89	174.86	174.77	174.66	174.58	174.56	174.55	174.89
25	174.62	174.64	174.75	174.86	174.89	174.93	174.90	174.80	174.70	174.62	174.60	174.59	174.93
50	174.73	174.76	174.87	174.97	175.00	175.04	175.00	174.90	174.78	174.72	174.71	174.71	175.04
100	174.84	174.86	174.99	175.07	175.09	175.14	175.09	174.98	174.86	174.81	174.81	174.82	175.14
200	174.94	174.96	175.10	175.16	175.17	175.22	175.18	175.06	174.94	174.89	174.90	174.92	175.22
MAX Obs.	174.82	174.90	174.95	175.05	175.08	175.14	175.13	175.02	174.87	174.88	174.81	174.86	175.14
Year	1987	2020	2020	2020	2020	2019	2019	2019	2019	1986	1986	1986	

4.1.1.2 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 across a water body. 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 air-water 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, wind duration, wind 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).

The Canadian Hydrographic Service (CHS) maintains water level gauges at Belle River, Bar Point and Kingsville within the study area, from which storm surge events can be isolated and analysed. All three water level gauges feature hourly or better water level data from the 1960s up to present day. Storm surge events were isolated from background 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. Positive residuals above a given threshold represent potential storm surge events, with the residual representing the magnitude of the surge experienced at the gauge location. Significant events at all three gauge locations 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.

Maximum residuals (surge magnitude) from identified surge events at each of the three water level gauges within the study area were ranked and separated into 12 monthly datasets to capture seasonality. In general, storm surge events on Lake St. Clair and Lake Erie are more frequent and severe during the late fall and winter months. Since storm surge events are random occurrences, an event that occurred on the last day of a given month, could conceivably have occurred on the first day of the following month instead. To remove this potential bias from the analysis and to smooth the seasonality in the analysis, the 12 monthly datasets at each gauge location 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 (12) for each gauge location (3) 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 at each gauge location, with results provided in Table 4.3, Table 4.4 and Table 4.5 for Belle River, Bar Point, and Kingsville, respectively.

Table 4.3 Monthly storm surge magnitudes at Belle River for a range of average recurrence intervals (Tr) based on historical data from 1961 – 2022 (in metres)

	Monthly Storm Surge - Belle River (m)												
Tr	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	MAX
1.5	0.18	0.17	0.20	0.20	0.19	0.16	0.15	0.15	0.17	0.21	0.22	0.21	0.22
2	0.20	0.19	0.22	0.22	0.21	0.18	0.16	0.16	0.19	0.22	0.23	0.23	0.23
5	0.26	0.25	0.29	0.28	0.26	0.22	0.19	0.20	0.23	0.26	0.27	0.27	0.29
10	0.31	0.30	0.34	0.31	0.30	0.25	0.21	0.23	0.27	0.30	0.31	0.31	0.34
20	0.37	0.36	0.39	0.35	0.34	0.27	0.24	0.26	0.30	0.35	0.36	0.36	0.39
25	0.39	0.38	0.40	0.36	0.35	0.28	0.26	0.27	0.31	0.36	0.38	0.38	0.40
50	0.44	0.44	0.45	0.40	0.39	0.31	0.29	0.31	0.35	0.42	0.44	0.45	0.45
100	0.50	0.51	0.50	0.44	0.43	0.33	0.33	0.34	0.38	0.50	0.52	0.54	0.54
200	0.56	0.57	0.55	0.47	0.47	0.36	0.38	0.39	0.42	0.60	0.61	0.63	0.63
MAX Obs.	0.43	0.53	0.39	0.40	0.27	0.36	0.26	0.23	0.32	0.35	0.59	0.40	0.59
Date	1992-01-14	2009-02-11	1973-03-17	1963-04-30	1963-05-10	1963-06-09	1983-07-21	1963-08-13	2008-09-14	2012-10-30	1966-11-02	1965-12-26	

Table 4.4 Monthly storm surge magnitudes at Bar Point for a range of average recurrence intervals (Tr) based on historical data from 1967 – 2022 (in metres)

	Monthly Storm Surge - Bar Point (m)												
Tr	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	MAX
1.5	0.58	0.53	0.54	0.51	0.46	0.36	0.32	0.34	0.40	0.50	0.58	0.59	0.59
2	0.63	0.56	0.57	0.54	0.50	0.39	0.34	0.36	0.43	0.53	0.63	0.64	0.64
5	0.78	0.66	0.65	0.63	0.60	0.48	0.42	0.41	0.51	0.63	0.77	0.79	0.79
10	0.90	0.74	0.72	0.69	0.67	0.55	0.48	0.45	0.58	0.69	0.89	0.90	0.90
20	1.02	0.83	0.79	0.76	0.72	0.61	0.55	0.48	0.66	0.75	1.00	1.02	1.02
25	1.06	0.87	0.81	0.78	0.74	0.63	0.57	0.49	0.68	0.77	1.03	1.05	1.06
50	1.18	0.97	0.88	0.84	0.79	0.70	0.64	0.52	0.77	0.83	1.14	1.17	1.18
100	1.30	1.07	0.94	0.91	0.83	0.76	0.71	0.55	0.85	0.88	1.26	1.28	1.30
200	1.42	1.18	1.01	0.97	0.86	0.82	0.78	0.58	0.94	0.92	1.37	1.40	1.42
MAX Obs.	1.03	0.85	0.98	0.74	0.68	0.71	0.47	0.46	0.53	0.81	0.80	1.24	1.24
Date	1999-01-02	1986-02-07	1985-03-04	2011-04-15	2021-05-28	1973-06-17	1992-07-30	2005-08-31	2018-09-09	2001-10-16	1972-11-14	1990-12-03	

Table 4.5 Monthly storm surge magnitudes at Kingsville for a range of average recurrence intervals (Tr) based on historical data from 1962 – 2022 (in metres)

	Monthly Storm Surge - Kingsville (m)												
Tr	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	MAX
1.5	0.49	0.46	0.46	0.44	0.39	0.28	0.26	0.27	0.34	0.41	0.47	0.50	0.50
2	0.53	0.50	0.49	0.47	0.43	0.30	0.27	0.29	0.35	0.43	0.51	0.54	0.54
5	0.66	0.60	0.57	0.55	0.51	0.37	0.31	0.34	0.42	0.52	0.64	0.67	0.67
10	0.75	0.67	0.62	0.61	0.56	0.42	0.36	0.37	0.49	0.59	0.73	0.75	0.75
20	0.83	0.73	0.67	0.66	0.61	0.48	0.41	0.41	0.57	0.65	0.81	0.84	0.84
25	0.86	0.75	0.69	0.67	0.62	0.50	0.43	0.42	0.59	0.67	0.84	0.86	0.86
50	0.94	0.81	0.73	0.72	0.66	0.56	0.49	0.45	0.68	0.74	0.93	0.94	0.94
100	1.02	0.87	0.77	0.76	0.70	0.62	0.55	0.48	0.77	0.81	1.01	1.02	1.02
200	1.09	0.92	0.81	0.81	0.74	0.68	0.62	0.51	0.87	0.87	1.10	1.09	1.10
MAX Obs.	0.82	0.67	0.76	0.66	0.58	0.54	0.34	0.45	0.47	0.78	0.69	0.99	0.99
Date	1964-01-12	1994-02-23	1983-03-21	1982-04-06	2021-05-28	1973-06-17	1992-07-30	2005-08-31	2006-09-02	2011-10-19	1981-11-20	1990-12-03	

As shown above, based on statistical analyses of recorded storm surges dating back to the 1960s, the predicted 100-year storm surge magnitudes at Belle River, Bar Point and Kingsville are 0.54 m, 1.30 m and 1.022 m, respectively.

4.1.1.3 *Joint Probability Analysis*

In order to assess the 100-year flood level at Belle River, Bar Point and Kingsville, a seasonal joint probability analysis was performed at each location to assess the joint probability of the full range of possible static lake level and storm surge combinations. 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, determined in Section 4.1.1.1 and Section 4.1.1.2 above. The convolution formula is then used to determine the joint probability of a combined water level "Z" (where Z = X + Y). The joint probability equation for "Z" can be expressed as:

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

Assessing the above formulation for the full range of possible combined flood elevations (Z) at each water level gauge (3) and for each month of the year (12) results in a series of monthly cumulative joint probability distributions of *combined* flood levels. Flood levels corresponding to a range of average recurrence intervals (Tr) for each month of the year based on historical data are presented in Table 4.6, Table 4.7, and Table 4.8 for Belle River, Bar Point and Kingsville, respectively.

Table 4.6 Monthly flood levels at Belle River for a range of average recurrence intervals (Tr), based on historical data (in metres above IGLD'85)

	Monthly Combined Flood Level - Belle River (m IGLD85')												
Tr	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	MAX
1.5	174.55	174.58	174.71	174.78	174.89	174.93	174.95	174.92	174.88	174.83	174.75	174.73	174.95
2	175.07	175.05	175.13	175.22	175.31	175.34	175.36	175.33	175.29	175.22	175.13	175.10	175.36
5	175.42	175.38	175.46	175.54	175.61	175.63	175.65	175.62	175.57	175.51	175.43	175.39	175.65
10	175.60	175.55	175.64	175.71	175.77	175.79	175.81	175.77	175.72	175.68	175.60	175.57	175.81
20	175.75	175.71	175.80	175.86	175.91	175.93	175.94	175.90	175.85	175.81	175.74	175.72	175.94
25	175.80	175.76	175.85	175.90	175.95	175.97	175.97	175.94	175.89	175.85	175.78	175.77	175.97
50	175.93	175.89	175.99	176.03	176.07	176.09	176.10	176.05	176.00	175.98	175.91	175.91	176.10
100	176.06	176.03	176.14	176.16	176.20	176.21	176.22	176.17	176.11	176.11	176.05	176.05	176.22
200	176.20	176.21	176.33	176.30	176.35	176.35	176.35	176.31	176.25	176.29	176.24	176.24	176.35
MAX Obs.	175.98	175.99	176.19	176.09	176.08	176.11	176.12	176.11	176.04	176.12	175.99	175.90	176.19
Date	2020-01-16	1987-02-08	1973-03-17	1987-04-04	2020-05-19	2020-06-28	2020-07-11	2020-08-03	1986-09-15	1986-10-04	1986-11-04	1985-12-24	

Table 4.7 Monthly flood levels at Bar Point for a range of average recurrence intervals (Tr), based on historical data (in metres above IGLD'85)

	Monthly Combined Flood Level - Bar Point (m IGLD85')												
Tr	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	MAX
1.5	174.24	174.17	174.26	174.39	174.43	174.36	174.31	174.27	174.25	174.26	174.27	174.27	174.43
2	174.64	174.57	174.65	174.78	174.82	174.74	174.68	174.62	174.62	174.61	174.65	174.65	174.82
5	174.97	174.89	174.97	175.08	175.10	175.03	174.95	174.88	174.88	174.88	174.96	174.96	175.10
10	175.15	175.07	175.15	175.25	175.26	175.18	175.11	175.02	175.02	175.03	175.13	175.14	175.26
20	175.32	175.23	175.31	175.40	175.39	175.32	175.24	175.15	175.15	175.16	175.29	175.31	175.40
25	175.37	175.28	175.36	175.44	175.44	175.37	175.29	175.18	175.18	175.20	175.34	175.36	175.44
50	175.53	175.42	175.50	175.58	175.56	175.49	175.41	175.29	175.30	175.31	175.49	175.51	175.58
100	175.69	175.56	175.66	175.71	175.68	175.62	175.54	175.40	175.41	175.44	175.65	175.67	175.71
200	175.97	175.79	175.86	175.89	175.85	175.81	175.70	175.53	175.60	175.61	175.90	175.94	175.97
MAX Obs.	175.43	175.59	175.54	175.60	175.53	175.72	175.33	175.36	175.34	175.30	175.39	175.38	175.72
Date	1987-01-19	1986-02-07	1985-03-04	1973-04-09	2020-05-18	1973-06-17	2019-07-07	2019-08-19	2018-09-09	2019-10-03	1972-11-14	1986-12-01	

Table 4.8 Monthly flood levels at Kingsville for a range of average recurrence intervals (Tr), based on historical data (in metres above IGLD'85)

	Monthly Combined Flood Level - Kingsville (m IGLD85')												
Tr	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	MAX
1.5	174.15	174.10	174.18	174.32	174.36	174.28	174.23	174.20	174.18	174.17	174.16	174.17	174.36
2	174.55	174.50	174.57	174.71	174.74	174.65	174.60	174.55	174.55	174.52	174.52	174.54	174.74
5	174.85	174.81	174.89	175.01	175.02	174.94	174.88	174.81	174.81	174.79	174.82	174.83	175.02
10	175.01	174.98	175.07	175.17	175.18	175.10	175.03	174.95	174.95	174.93	174.99	175.01	175.18
20	175.17	175.13	175.22	175.32	175.31	175.23	175.16	175.07	175.07	175.06	175.14	175.16	175.32
25	175.22	175.18	175.27	175.36	175.35	175.27	175.20	175.11	175.10	175.10	175.19	175.21	175.36
50	175.36	175.32	175.41	175.49	175.47	175.40	175.32	175.22	175.22	175.22	175.32	175.35	175.49
100	175.51	175.47	175.56	175.62	175.59	175.52	175.44	175.33	175.33	175.34	175.47	175.50	175.62
200	175.73	175.67	175.75	175.81	175.74	175.68	175.60	175.47	175.52	175.52	175.69	175.71	175.81
MAX Obs.	175.54	175.16	175.28	175.52	175.37	175.57	175.40	175.20	175.20	175.22	175.29	175.32	175.57
Date	1987-01-19	1997-02-28	1985-03-04	1973-04-09	2020-05-18	1973-06-17	2019-07-07	1986-08-01	2018-09-09	1986-10-10	1972-11-14	2019-12-30	

As shown above, based on a joint probability analysis of historical static lake levels and measured storm surges, the predicted 100-year flood levels at Belle River, Bar Point and Kingsville are +176.22 m, +175.71 m and +175.62 m IGLD'85, respectively.

4.1.2 Climate Change 100-year Flood Levels

For the 100-year flood level and regulatory flooding hazard to be mapped in a manner that is consistent with the overall intent of the Provincial Policy Statement (PPS, 2020), the hazard should be based on flood levels that are not only based on historical data, but are also representative of future conditions at the 100-year average recurrence interval. Item 3.1.3 in the PPS states that "Planning authorities shall prepare for the *impacts of a changing climate* that may increase the risk associated with natural hazards".

As a component of this study, and to satisfy the requirements of the FHIMP funding, three additional 100-year flood level scenarios were investigated to account for the projected impacts of climate change. The scenarios assumed both a moderate and high future global emission trajectory and greenhouse gas concentrations; referred to as Representative Concentration Pathways (RCP) 4.5 and RCP8.5 respectively. The three 100-year flood level scenarios differed in that they considered different emission trajectories and time-periods of projected future climate data. These emission scenarios and time periods are summarized as follows:

a) RCP4.5 mid-century 50-year time slice centred on 2050 (2026 – 2075).

b) RCP4.5 late-century 50-year time slice centred on 2075 (2051 – 2100).

c) RCP8.5 late-century 50-year time slice centred on 2075 (2051 – 2100).

A study recently completed by Environment and Climate Change Canada (ECCC) and published in the Journal of Great Lakes Research (Seglenieks and Temgoua, 2022) was leveraged for this analysis. In the ECCC study, 13 combinations of Global Climate Models (GCMs) and Regional Climate Models (RCMs) were used to simulate past and future net basin supplies to all five Great Lakes and Lake St. Clair for the two emission scenarios. Net basin supplies are the combination of over-lake precipitation and runoff entering the lake, minus the losses from over-lake evaporation.

The net basin supplies determined in the ECCC study for projected climate scenarios are a measure of the local (net) water supply that is coming into each lake. The Coordinated Great Lakes Regulation and Routing Model (CGLRRM) (Clites and Lee, 1998) was then used to model lake levels and flows for connecting channels that would result from the modelled net basin supplies. To determine if the water level in the lake goes up or down, the CGLRRM compares net basin supply for each lake with the inflow from the upstream lake (if one is present) and outflow to the downstream water body, based on calibrated stage-discharge rating curves. Physical and operational conditions assumed in the rating curves were consistent with 2012 basis of comparison conditions, as outlined in IJC (2012). The only exception was for Lake Ontario, which featured operational outflow conditions commensurate with the current water level regulation plan, Plan 2014 (refer to IJC, 2014).

Water levels output from the CGLRRM simulations using projected net basin supplies for the two emission scenarios were provided to the study team in the form of monthly projected lake levels from the beginning of the base period in 1961 up to the end of the century (2100). In order to determine the influence that the projected lake levels would have on Lake St. Clair and Lake Erie 100-year flood levels, a seasonal (monthly) extreme value analysis was carried out on the data. The analysis was completed three times for each lake, once for the mid-century time slice (2026 – 2075) using the RCP4.5 data (a), and twice for the late-century time slice (2051 – 2100) using RCP4.5 (b) and RCP8.5 (c), respectively. The resulting monthly probability distributions for each time period were then substituted as the *static lake level* component of the monthly joint probability analysis at the Belle River, Bar Point and Kingsville water level gauges, replacing the historical static lake level probability distributions used in the joint probability analysis presented in Section 4.1.1 above.

The results of this analysis for the mid-century, RCP4.5 scenario (a), are presented in Table 4.9 to Table 4.11. Of the three evaluated climate change scenarios, the mid-century RCP4.5 is the most likely to actually occur and with the least amount of uncertainty when compared to the other two. Under this scenario, the 100-year flood levels at Belle River, Bar Point and Kingsville increase to +176.50 m, +176.00 m, and +175.87 m IGLD'85, respectively.

Table 4.9 Monthly flood levels at Belle River for a range of average recurrence intervals (Tr) and the mid-century time slice and RCP4.5 global emission trajectory (in metres above IGLD'85)

	Monthly Combined Flood Level - Belle River (m IGLD85')												
Tr	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	MAX
1.5	174.84	174.84	174.91	175.03	175.10	175.07	175.06	175.04	174.93	174.90	174.85	174.84	175.10
2	175.42	175.44	175.51	175.63	175.68	175.64	175.63	175.59	175.53	175.49	175.43	175.43	175.68
5	175.76	175.79	175.87	175.98	176.02	175.97	175.96	175.92	175.87	175.83	175.77	175.78	176.02
10	175.92	175.95	176.03	176.13	176.18	176.13	176.12	176.07	176.02	175.99	175.93	175.94	176.18
20	176.05	176.08	176.16	176.25	176.30	176.26	176.23	176.19	176.14	176.11	176.05	176.06	176.30
25	176.08	176.11	176.19	176.29	176.33	176.29	176.26	176.21	176.17	176.14	176.08	176.09	176.33
50	176.18	176.20	176.29	176.38	176.42	176.38	176.35	176.30	176.26	176.23	176.18	176.19	176.42
100	176.28	176.30	176.39	176.46	176.50	176.46	176.43	176.38	176.34	176.32	176.26	176.28	176.50
200	176.41	176.44	176.52	176.51	176.60	176.55	176.44	176.46	176.37	176.45	176.40	176.41	176.60
MAX Obs.	175.98	175.99	176.19	176.09	176.08	176.11	176.12	176.11	176.04	176.12	175.99	175.90	176.19
Date	2020-01-16	1987-02-08	1973-03-17	1987-04-04	2020-05-19	2020-06-28	2020-07-11	2020-08-03	1986-09-15	1986-10-04	1986-11-04	1985-12-24	

Table 4.10 Monthly flood levels at Bar Point for a range of average recurrence intervals (Tr) and the mid-century time slice and RCP4.5 global emission trajectory (in metres above IGLD'85)

	Monthly Combined Flood Level - Bar Point (m IGLD85')												
Tr	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	MAX
1.5	174.43	174.42	174.52	174.64	174.65	174.57	174.50	174.45	174.42	174.40	174.45	174.45	174.65
2	175.00	174.93	175.06	175.18	175.16	175.07	175.00	174.94	174.92	174.91	174.95	174.96	175.18
5	175.34	175.26	175.39	175.50	175.47	175.38	175.30	175.23	175.22	175.21	175.27	175.29	175.50
10	175.52	175.42	175.54	175.64	175.62	175.52	175.44	175.36	175.35	175.36	175.43	175.46	175.64
20	175.66	175.56	175.67	175.76	175.73	175.63	175.54	175.45	175.46	175.47	175.57	175.60	175.76
25	175.70	175.60	175.70	175.79	175.77	175.66	175.57	175.48	175.49	175.50	175.61	175.64	175.79
50	175.84	175.71	175.80	175.89	175.87	175.76	175.65	175.56	175.58	175.59	175.74	175.78	175.89
100	176.00	175.84	175.90	175.98	175.96	175.85	175.75	175.63	175.68	175.69	175.88	175.93	176.00
200	176.26	176.04	176.04	176.14	176.10	175.98	175.90	175.68	175.87	175.80	176.14	176.18	176.26
MAX Obs.	175.43	175.59	175.54	175.60	175.53	175.72	175.33	175.36	175.34	175.30	175.39	175.38	175.72
Date	1987-01-19	1986-02-07	1985-03-04	1973-04-09	2020-05-18	1973-06-17	2019-07-07	2019-08-19	2018-09-09	2019-10-03	1972-11-14	1986-12-01	

Table 4.11 Monthly flood levels at Kingsville for a range of average recurrence intervals (Tr) and the mid-century time slice and RCP4.5 global emission trajectory (in metres above IGLD'85)

	Monthly Combined Flood Level - Kingsville (m IGLD85')												
Tr	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	MAX
1.5	174.32	174.34	174.45	174.58	174.57	174.49	174.42	174.38	174.35	174.30	174.34	174.36	174.58
2	174.88	174.86	174.97	175.11	175.07	174.99	174.92	174.87	174.84	174.82	174.84	174.85	175.11
5	175.22	175.19	175.29	175.42	175.38	175.29	175.21	175.16	175.13	175.12	175.15	175.17	175.42
10	175.39	175.35	175.44	175.57	175.53	175.43	175.34	175.29	175.27	175.26	175.30	175.33	175.57
20	175.52	175.48	175.56	175.68	175.65	175.53	175.44	175.39	175.38	175.37	175.43	175.46	175.68
25	175.56	175.52	175.60	175.70	175.68	175.57	175.47	175.42	175.41	175.41	175.46	175.50	175.70
50	175.67	175.63	175.69	175.79	175.77	175.65	175.56	175.49	175.49	175.50	175.57	175.61	175.79
100	175.79	175.74	175.78	175.87	175.86	175.74	175.63	175.56	175.60	175.58	175.69	175.73	175.87
200	175.99	175.87	175.91	176.01	175.99	175.84	175.75	175.62	175.78	175.74	175.88	175.92	176.01
MAX Obs.	175.54	175.16	175.28	175.52	175.37	175.57	175.40	175.20	175.20	175.22	175.29	175.32	175.57
Date	1987-01-19	1997-02-28	1985-03-04	1973-04-09	2020-05-18	1973-06-17	2019-07-07	1986-08-01	2018-09-09	1986-10-10	1972-11-14	2019-12-30	

In the analysis of the two additional climate change scenarios, namely the late-century RCP4.5 (b) and late-century RCP8.5 (c), the 100-year flood level was found to increase progressively with the later time slice (i.e. late-century as opposed to mid-century) and higher emission trajectory (i.e. RCP8.5 vs. RCP4.5). At Belle River, these increases were 2 cm and 38 cm vs. the mid-century RCP4.5 scenario (a). At Bar Point the 100-year flood level increased 3 cm and 33 cm, while at Kingsville the increases were 6 cm and 36 cm, respectively. In other words, only a small increase in 100-year flood level was observed at all three locations going from mid- to late-century for the same RCP4.5 emission trajectory, while a much larger increase was observed once the RCP8.5 trajectory was adopted.

It is noted that the draft guidance in the updated Technical Guide (Zuzek Inc., 2023) recommends that planning authorities utilize the flood level associated with the mid-century RCP4.5 scenario in their shoreline hazard mapping that accounts for the impacts of a changing climate.

4.2 Numerical Modelling to Evaluate Water Level Gradients

Given that the water level analysis presented in Section 4.1 is only applicable at the location of the three analyzed water level gauges, numerical modelling was completed to determine appropriate 100-year flood levels for all other locations between the gauges. Given that storm surge is the component of the joint probability analysis (discussed in Section 4.1.1.3) that varies along the Essex shoreline (static levels are consistent across each lake), a specific investigation into water level gradients produced during storm surge events is required. Water level gradients down the Detroit River during periods of extreme lake levels must also be known.

The Danish Hydraulic Institute (DHI) MIKE 21 Hydrodynamic (HD) Flexible Mesh (FM) model was used to simulate storm surge and corresponding water level gradients on Lake St. Clair, the Detroit River and Lake Erie to assess appropriate 100-year flood levels for locations between the water level gauging stations. The following sections outline the input and forcing parameters and model results for an ensemble of extreme surge events simulated to establish these gradients.

4.2.1 Model Bathymetry and Computational Mesh

Figure 4.2 presents an overview of the MIKE 21 HD FM model domain and computational mesh, which extends from the St. Clair River to the Niagara River. Despite the focus of the study being on the Essex Region, the inclusion of the entire lakes and rivers system are required for a good representation of lake-wide surge gradients and water balance in Lake St. Clair and Lake Erie.

The model bathymetry was obtained from a combination of sources including Canadian Hydrographic Service (CHS) non-navigational (NONNA) bathymetric data and NOAA's Great Lakes Bathymetric data collection. High resolution shoreline delineation was extracted from the latest GLAHF Shoreline dataset and locally improved based on comparisons with 2022 and 2021 imagery in Essex and SWOOP 2015 in other parts of the lakes.

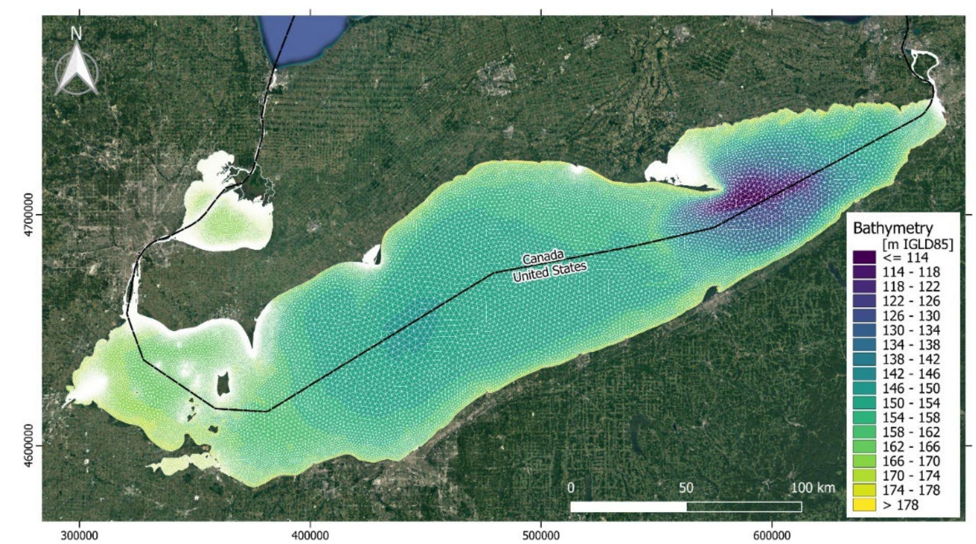


Figure 4.2 Overview of the hydrodynamic model domain and computational mesh for the simulation of storm surge gradients in Lake St-Clair, Lake Erie and Detroit River

The spatial resolution of the adopted flexible mesh varies across the model domain, from approximately 3000 m in the deeper parts of Lake Erie to approximately 50 m along the Essex shoreline. This is to strike a balance between minimizing the computational time necessary to run the model, while maximizing the level of detail captured in the nearshore and along the shorelines. An example of the variable resolution computational mesh near Cedar Beach is presented in Figure 4.3.

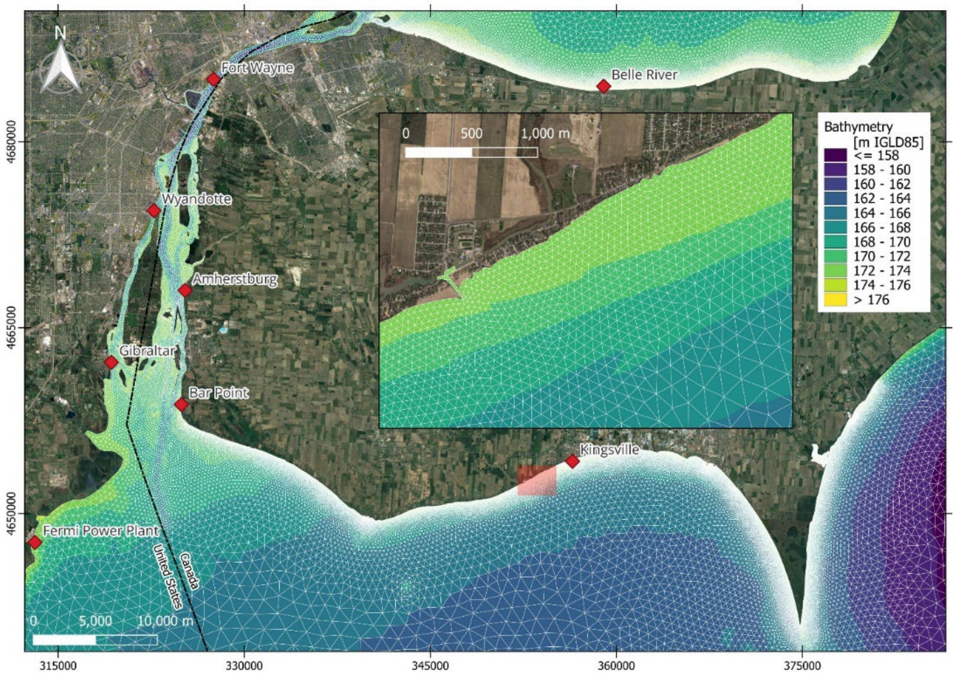


Figure 4.3 Details of the computational mesh and interpolated bathymetry near Cedar Beach. Location of the water level measurement stations across the Essex Region

4.2.2 Model Setup – Forcings, Boundaries and Initial Conditions

The three water level gauges discussed in Section 4.1 were used to select the storm events to be simulated with the storm surge model from which water level gradients between gauge locations could be established. Table 4.12 provides an overview of the ensemble of extreme events selected and their key characteristics in terms of water levels, surge magnitude (residual) and wind conditions at the peak of the event.

Wind conditions were also assessed to identify additional events and wind directions that were not necessarily represented in the largest storms derived from the water level records, but may generate significant surge gradients in other parts of the region. Examples of these events include:

- Storms #7 and #11 feature a period with dominant wind from SE, which may produce significant surge on the Eastern side of the Pelee Peninsula.
- Storm #9 captures a period with winds from NE, targeting surge in the South-Western corner of Lake St. Clair.
- Storm #14: captures a period of very high levels at both the upstream (St. Clair) and downstream (Erie) boundaries of the Detroit River, and features some of the highest hourly water level observations on record at Amherstburg and Fort Wayne.

Table 4.12 Summary of the simulated storms for the evaluation of extreme water levels

Id	Reference Station	Total Water Level event ranking at Ref. Station	Date / Time Peak surge	Water Level		Surge Residual		Maximum wind speed during event	
				(m IGLD85')	Approx RTP (yr)	(m)	Approx RTP (yr)	Speed (km/h)	From Direction (°N)
1	Bar Point	4	19-May-2020 02:00	175.53	~40 yr	0.30	<1 yr	62.9	41
2	Bar Point	6	15-Apr-2018 15:00	175.48	~25 yr	0.72	~4 yr	68.7	47
3	Kingsville	6	09-Apr-1998 20:00	175.35	~20 yr	0.50	~1 yr	78.6	62
4	Kingsville	8*	30-Dec-2019 12:00	175.32	~20 yr	0.69	~7 yr	90.2	213
5	Belle River	1	17-Mar-1973 18:00	176.19	~75 yr	0.39	~20 yr	76.8	346
6	Belle River	5*	09-Apr-2020 09:00	176.09	~40 yr	0.17	<1 yr	58.1	336
7	Kingsville	14*	10-Sep-2018 03:00	175.20	~10 yr	0.44	<1 yr	67.8 (39.5)*	80 (123)*
8	Belle River	3	05-Oct-1986 01:00	176.12	~50 yr	0.09	<1 yr	37.6	346
9	Belle River	45	14-Jan-1999 05:00	175.38	~2 yr	0.11	<1 yr	51.3	30
10	Bar Point	1	17-Jun-1973 08:00	175.72	~100 yr	0.71	~4 yr	57.2	82
11	Bar Point	12	03-Dec-1990 13:00	175.23	~8 yr	1.24	~75 yr	79.3 (59.5)*	89 (149)*
12	Kingsville	1	17-Jun-1973 07:00	175.57	~75 yr	0.54	~2 yr	57.2	82
13	Kingsville	34	03-Dec-1991 03:00	174.87	~3 yr	0.93	~50 yr	70.8	83
14	Kingsville	4	13-Jun-2019 03:00	175.41	~30-35 yr	0.31	<1 yr	40.9	190

* Targeted wind directions and associated wind speeds, which are not necessarily peak conditions during the event.

The most important data in the development of a robust regional storm surge model is a temporally and spatially varying wind and atmospheric pressure hindcast. To resolve this data requirement, two hindcast models were selected, based on their spatial resolution and temporal coverage:

- **HRDPS**: HRDPS is a high-resolution meteorological model with approximately 2.5 km grid resolution over Lake Erie and Lake St. Clair. This model outputs wind and surface pressure (amongst other parameters) across the model domain four times daily and is disseminated in real time by ECCC. Data is available from 2017 to present. Given the quality and resolution of this dataset, it is the preferred choice for events occurring since 2017.

- **ERA5**: ERA5 is the fifth generation European Centre for Medium-Range Weather Forecasts (ECMWF) atmospheric reanalysis of the global climate covering the period from January 1950 to present. ERA5 is produced by the Copernicus Climate Change Service (C3S) at ECMWF and provides hourly estimates of many atmospheric, land and oceanic climate variables. The data cover the Earth on a 30 km grid and resolve the atmosphere using 137 levels from the surface up to a height of 80 km. ERA5 includes information about uncertainties for all variables at reduced spatial and temporal resolutions. The ERA5 dataset was used to force the surge model for simulated events occurring prior to 2017.

4.2.3 Model Calibration and Outputs

An iterative approach was applied to calibrate the hydrodynamic surge model. The principal calibration parameters were:

- Roughness in the St. Clair and Detroit Rivers: This is an important parameter to describe the water exchange between the lakes. The applied roughness was based on the works done in Liu et al. (2012) and Saha (2020). Figure 4.4 presents the applied roughness to the hydrodynamic model, in terms of Manning number [$m^{1/3}/s$].

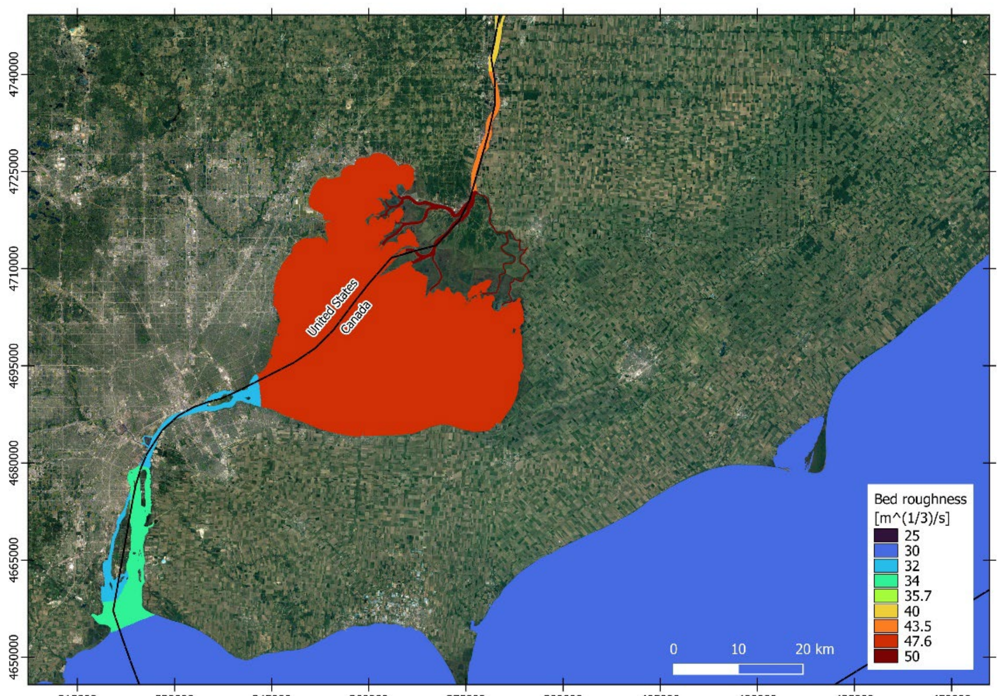


Figure 4.4 Bed roughness [m1/3/s] applied to the hydrodynamic model for the simulation of extreme water levels

- Wind friction: The effect of wind on the water surface was calibrated by adjusting the wind friction parameters. This calibration was conducted for storms forced with the HRDPS dataset.

- Wind speed adjustments: For storms forced with the ERA5 (Prior to 2017), wind speeds were adjusted in the atmospheric forcing based on the comparison between HRDPS and ERA5 datasets for the overlapping period. A multiplying factor of 1.5 and 1.2 to the ERA5 wind speeds were applied in Lake St. Clair and Lake Erie, respectively.

Sample model output illustrating the spatially variably, instantaneous water surface elevation at the peak of storms #5 and #10/12 are provided in Figure 4.5 and Figure 4.6, respectively. These storms feature different principal wind directions (as indicated by the arrows), with #5 producing significant surge on the south shore of Lake St. Clair, and #10/12 providing significant surge on the western shores of Lake St. Clair and the Western Basin on Lake Erie (as indicated by the colour contours). These two events, occurring three months apart in 1973, produced the highest ever recorded hourly water levels at the Belle River (storm #5), Bar Point and Kingsville (storm #10/12) water level gauges.

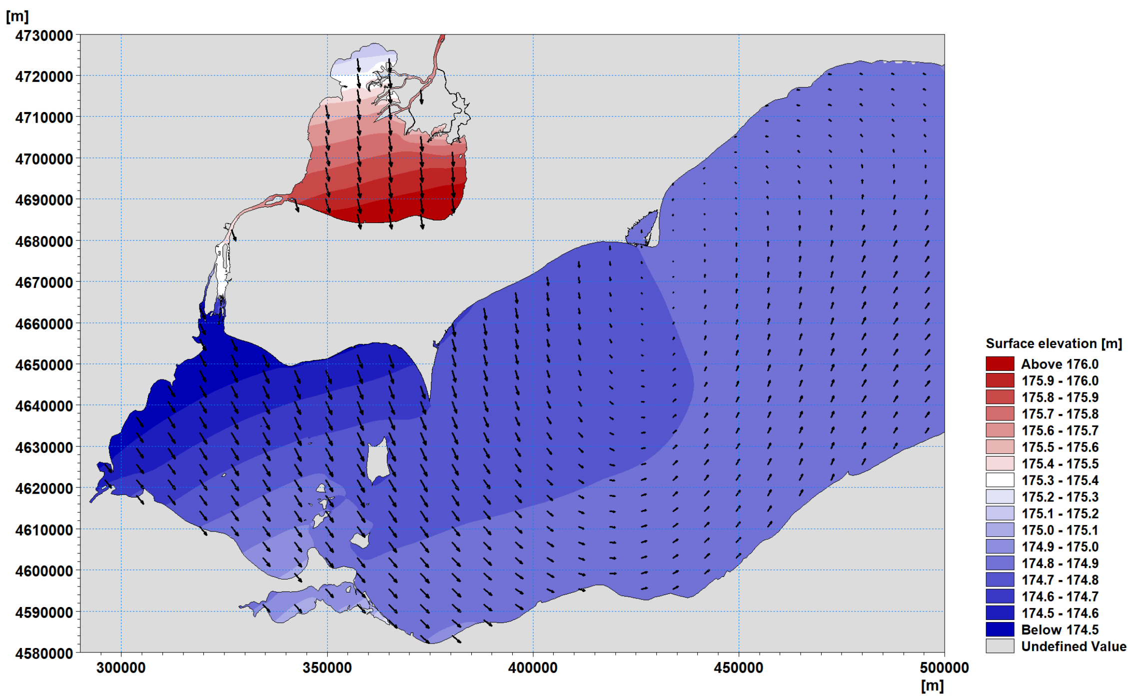


Figure 4.5 Modelled instantaneous water surface elevation and associated wind direction at the peak of event #5, corresponding to the highest hourly water level ever recorded at Belle River

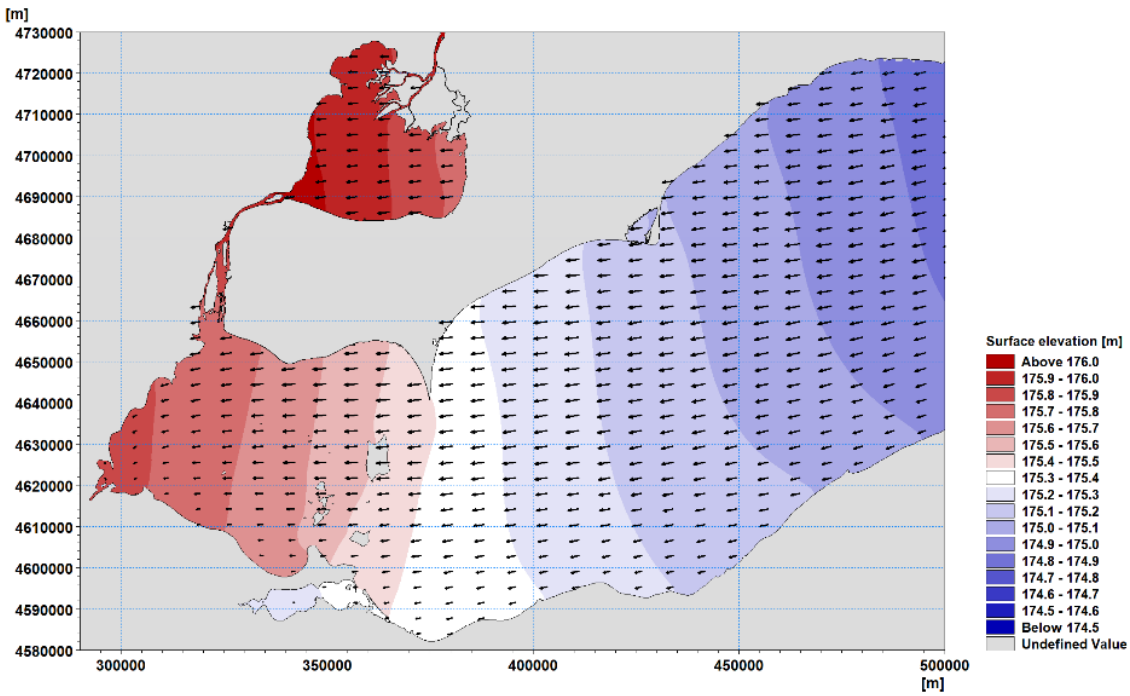


Figure 4.6 Modelled instantaneous water surface elevation and associated wind direction at the peak of event #10/12, corresponding to the highest hourly water level ever recorded at Bar Point and Kingsville

A comparison of the time-history of measured and modelled water levels through the duration of event #5 at the Belle River water level gauge location is presented in Figure 4.7. A comparison of measured and modelled water levels for event #10/12 at the Bar Point and Kingsville water level gauges is provided in Figure 4.8. These plots demonstrate that the hydrodynamic model is generally able to reproduce the observed build up of storm surge both in terms of timing and magnitude, as well as the higher frequency basin scale oscillations (seiche) that follow the peak of the events.

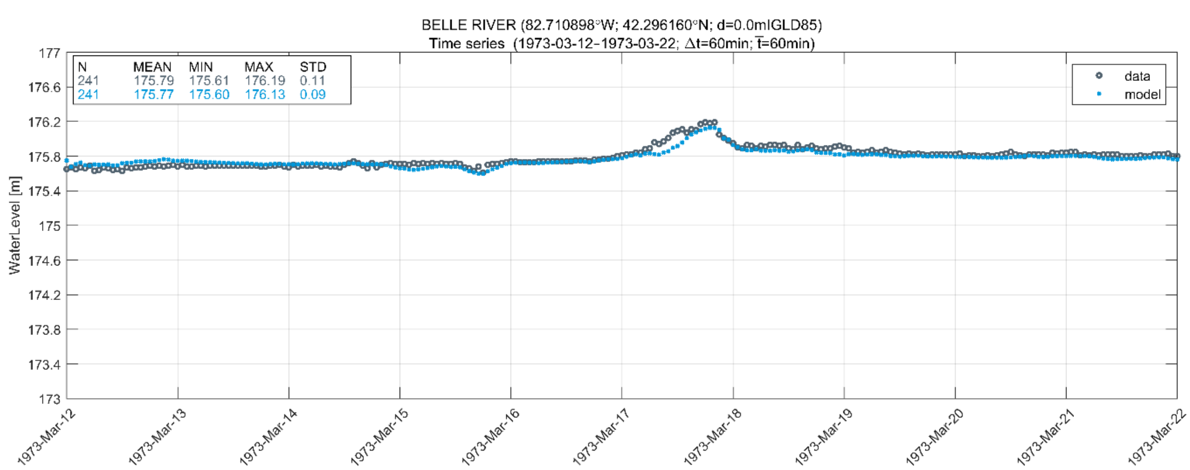


Figure 4.7 Measured vs. modelled water surface elevation at Belle River during event #5

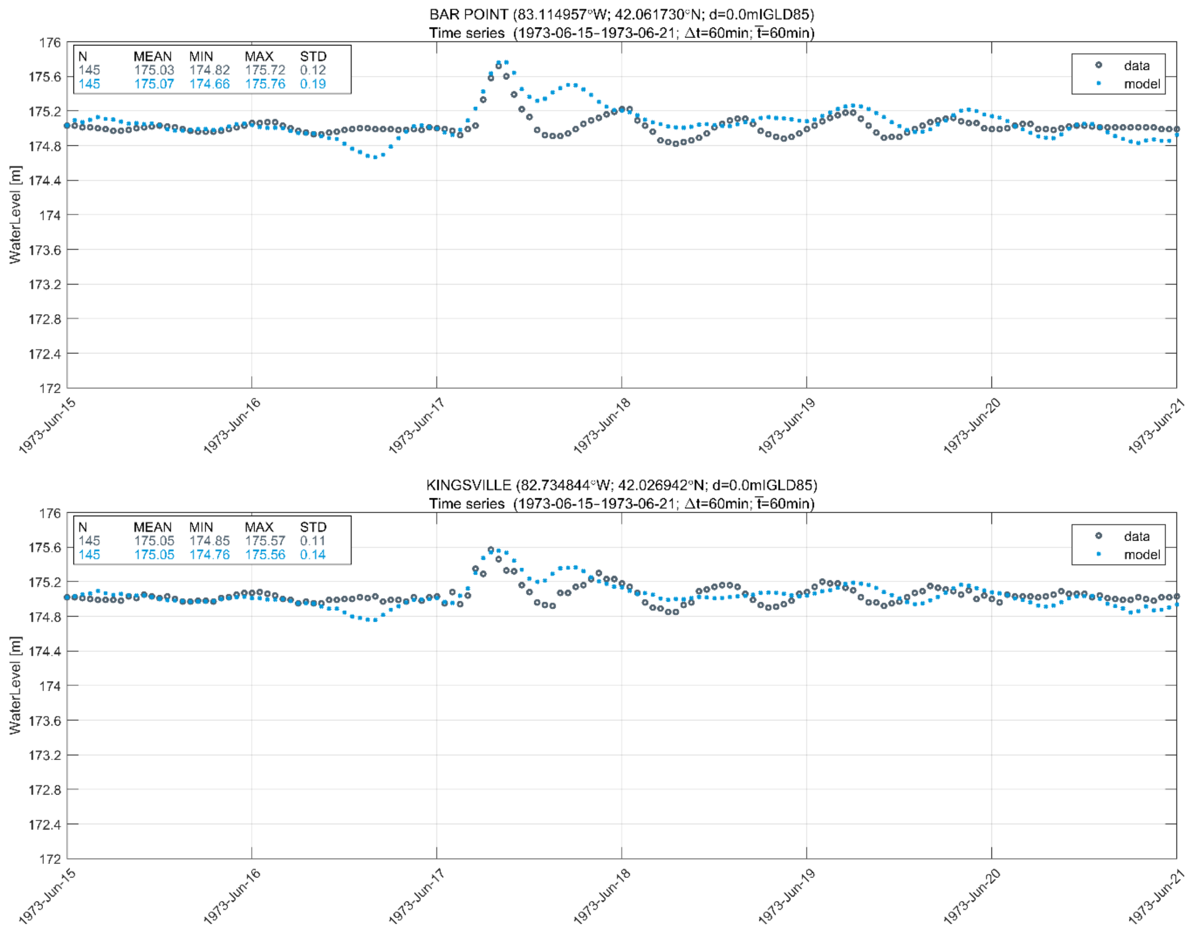


Figure 4.8 Measured vs. modelled water surface elevation at Bar Point and Kingsville during event #10/12

For the Detroit River, maximum instantaneous water levels achieved through the modelled events were compared to measured levels at water level gauges located at Windmill Point, Fort Wayne, Wyandotte, Amherstburg and Gibraltar. This comparison is provided in Figure 4.9 for events #5, #10/12, #4 and #11, with the levels at Belle River and Bar Point also provided for reference. These plots indicate that the observed water level gradients down the Detroit River during periods of high water levels are generally well reproduced by the hydrodynamic model.

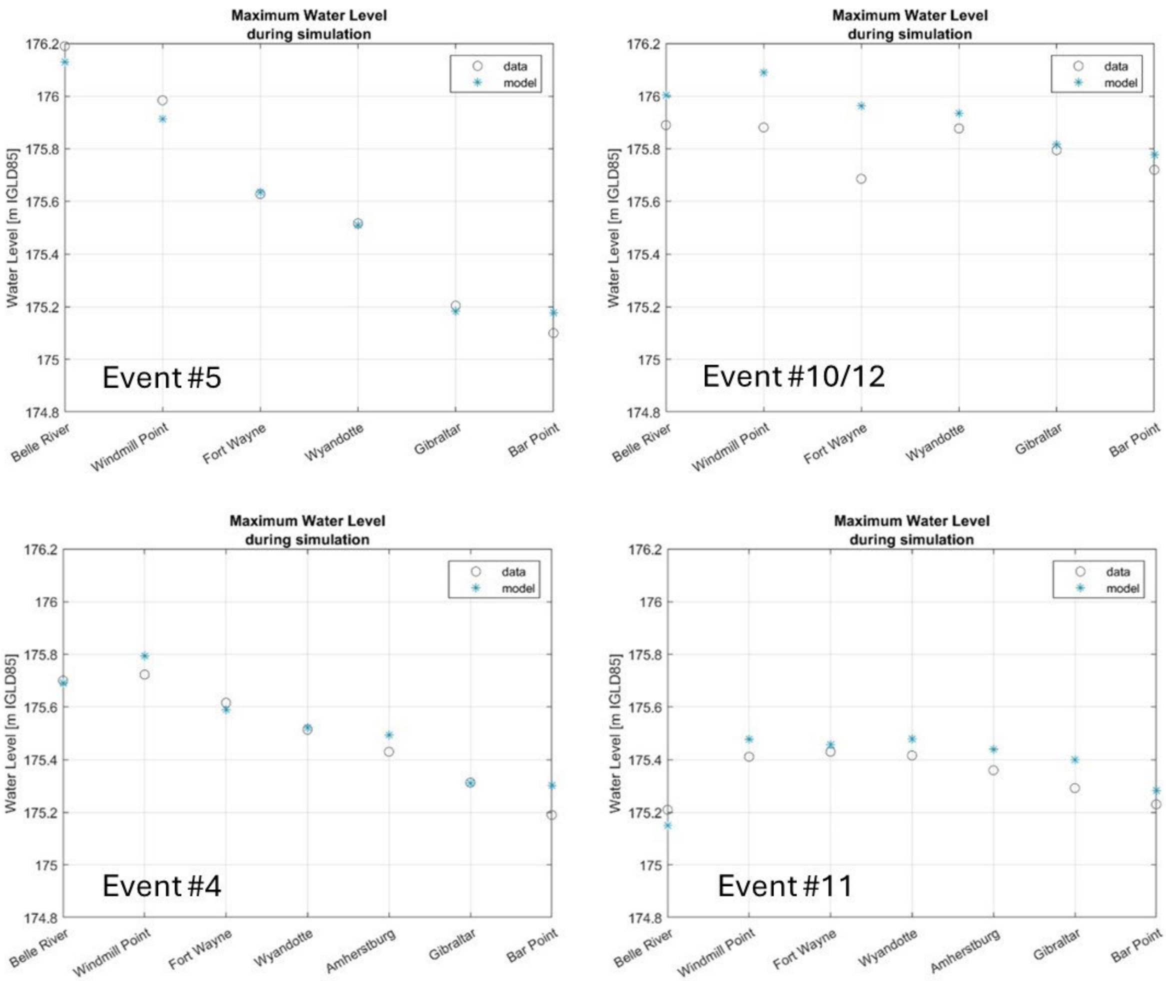


Figure 4.9 Comparison of measured and modelled maximum water level at locations along the Detroit River for events #5 (top left), #10/12 (top right), #4 (bottom left) and #11 (bottom right)

A summary of modelled and measured peak water levels at the referenced water level gauge for each of the simulated storm events is provided in Table 4.13 below. For most simulated storms, the modelled maximum water level is within 10 cm of the measured maximum water level, with the average across all simulated events being approximately +2 cm.

Table 4.13 Comparison of measured and modelled peak water levels for each simulated event at the referenced water level gauging station

Id	Reference Station	Event ranking	Date / Time Peak surge	Measured Total Water Level		Modelled Total Water Level	
				(m IGLD85')	Approx RTP (yr)	(m IGLD85')	Difference
1	Bar Point	4	19-May-2020 02:00	175.53	~40 yr	175.61	0.08
2	Bar Point	6	15-Apr-2018 15:00	175.48	~25 yr	175.57	0.09
3	Kingsville	6	09-Apr-1998 20:00	175.35	~20 yr	175.28	-0.07
4	Kingsville	8	30-Dec-2019 12:00	175.32	~20 yr	175.21	-0.11
5	Belle River	1	17-Mar-1973 18:00	176.19	~75 yr	176.13	-0.06
6	Belle River	5	09-Apr-2020 09:00	176.09	~40 yr	176.00	-0.09
7	Kingsville	14	10-Sep-2018 03:00	175.20	~10 yr	175.17	-0.03
8	Belle River	3	05-Oct-1986 01:00	176.12	~50 yr	176.15	0.03
9	Belle River	45	14-Jan-1999 05:00	175.38	~2 yr	175.35	-0.03
10	Bar Point	1	17-Jun-1973 08:00	175.72	~100 yr	175.76	0.04
11	Bar Point	12	03-Dec-1990 13:00	175.23	~8 yr	175.28	0.05
12	Kingsville	1	17-Jun-1973 07:00	175.57	~75 yr	175.56	-0.01
13	Kingsville	34	03-Dec-1991 03:00	174.87	~3 yr	174.82	-0.05
14	Kingsville	4	13-Jun-2019 03:00	175.41	~30-35 yr	175.38	-0.03

4.2.4 100-year Flood Level Gradients

Once all of the storm surge events listed in the previous section had been simulated using the hydrodynamic numerical model, the maximum surge residual at the peak of each event was extracted at each model grid cell, and overlaid into a single plot for each lake showing the maximum surge residual across all 14 simulations. As discussed above, these simulations covered a wide range of wind directions in order to ensure that maximal historical surge along each portion of the shoreline was captured in at least one event. These plots are illustrated in Figure 4.10 and Figure 4.11 for Lake St. Clair and Lake Erie, respectively, from which gradients in surge potential can readily be identified. Similarly, the maximum total water level (in m above IGLD'85) across the 14 simulations was plotted for the entire study area, and is shown in Figure 4.12, from which gradients in total water level can be discerned.

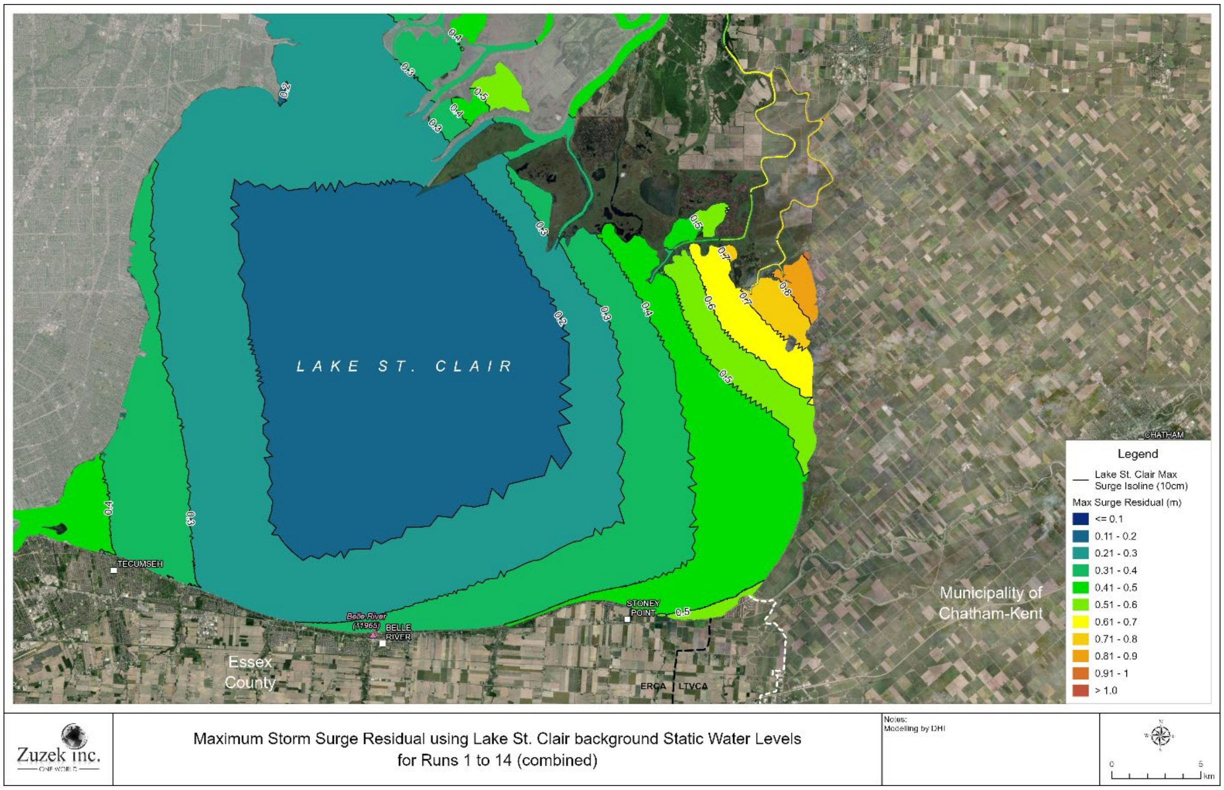


Figure 4.10 Maximum storm surge residual across all 14 simulations (Lake St. Clair)

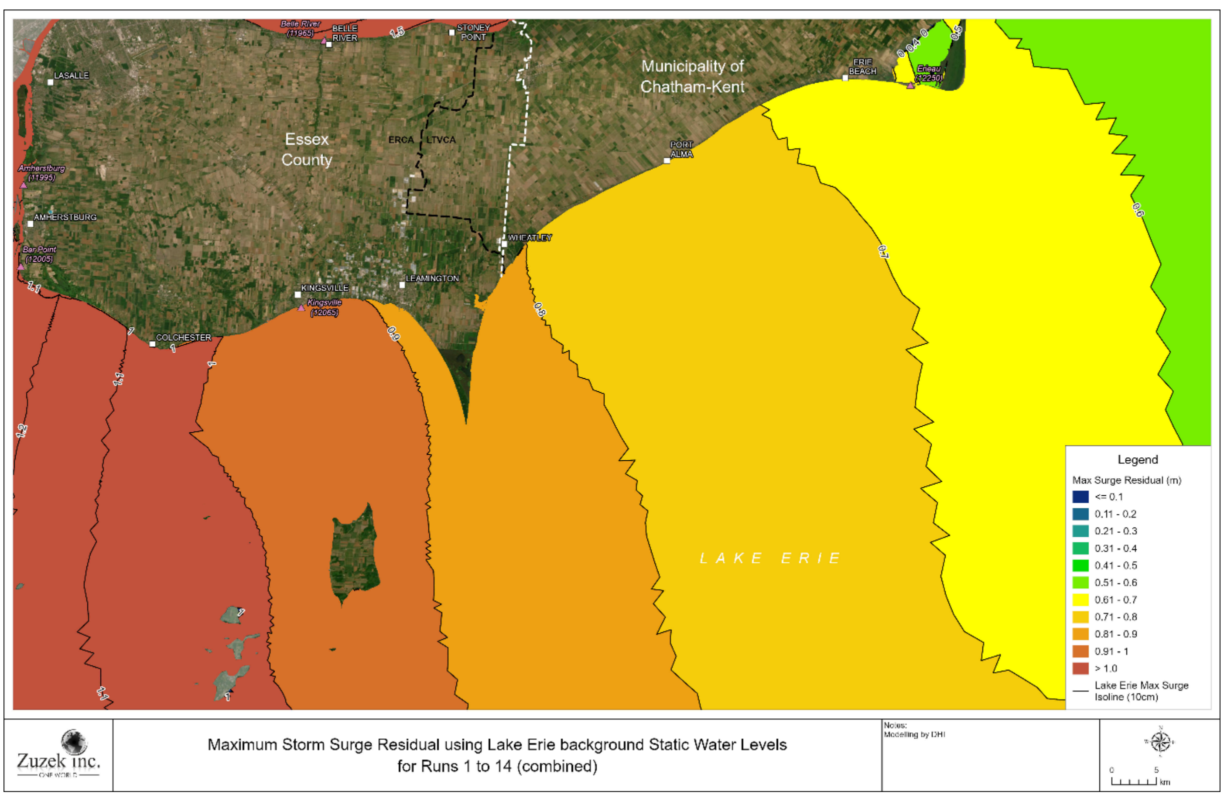


Figure 4.11 Maximum storm surge residual across all 14 simulations (Lake Erie)

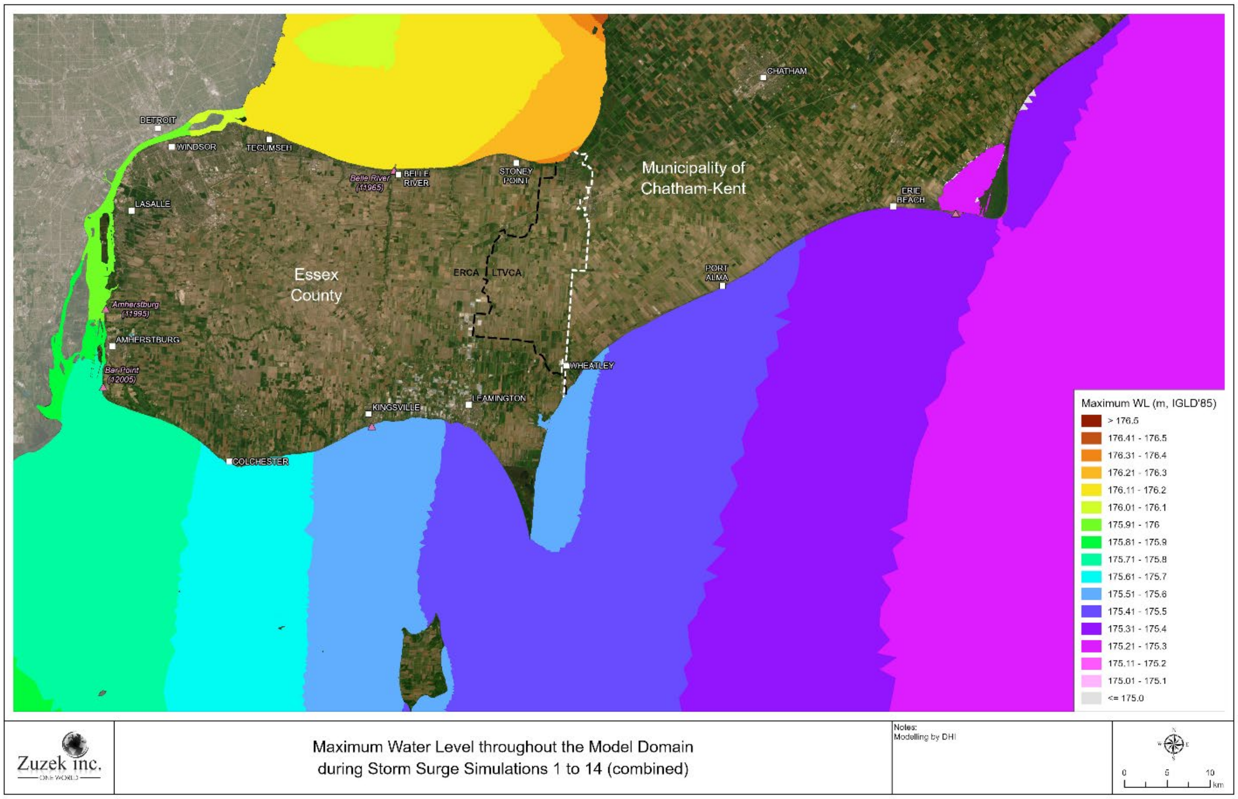


Figure 4.12 Maximum modelled total water level (static + surge) across all 14 simulations for the entire study area

Based on the maximum surge and total water level gradients resulting from the numerical modelling of major historical surge events affecting the Essex shorelines of Lake St. Clair and Lake Erie, appropriate 100-year flood levels were attributed to each of the 27 project reaches defined in Section 3.4. The selected 100-year flood levels were *anchored* by the values determined through the statistical analysis of measured data at the three water level gauge locations (Belle River, Bar Point and Kingsville). This process was completed first for the 100-year flood levels based on historical conditions, and then repeated for each of the three climate change scenarios considered for this study (refer to Section 4.1.2). Table 4.14 below provides a summary of 100-year flood levels for all four scenarios and for each project reach based on the analyses and methodology described herein. For a description of the project reaches, refer to Section 3.4.

Table 4.14 Summary of 100-year flood levels for historical conditions and all three climate change scenarios by project reach

Reach No.	Water Body	100-year Flood Level (m above IGLD'85)			
		Historical	Mid-Century RCP4.5	Late-Century RCP4.5	Late-Century RCP8.5
1	Lake St. Clair	176.4	176.7	176.7	177.1
2	Lake St. Clair	176.3	176.6	176.6	177.0
3*	Lake St. Clair	176.2 / 176.3	176.5 / 176.6	176.5 / 176.6	176.9 / 177.0
4	Detroit River	176.2	176.5	176.5	176.9
5	Detroit River	176.1	176.4	176.4	176.8
6 – 7	Detroit River	176.0	176.3	176.3	176.7
8**	Detroit River	175.9 / 175.8	176.2 / 176.1	176.2 / 176.1	176.6 / 176.5 / 176.4
9 – 13	Lake Erie	175.7	176.0	176.0	176.3
14 – 27	Lake Erie	175.6	175.9	175.9	176.2

*Transition between flood levels occurs at Pike Creek

**Transition between flood levels occurs at Amherstburg, with a second transition occurring at Glen Eden for the Late-Century RCP8.5 scenario only

4.3 Wave Climate for Hazard Mapping

Wave impacts on coastal flooding are primarily related to wave uprush and overtopping, which extend the spatial extent of the *flooding hazard* further inland beyond the 100-year flood level. In order to assess wave uprush, nearshore wave conditions must be understood along the entire Essex shoreline. To accomplish this a spectral wave model was employed. The development and application of this model are discussed in the following sections.

4.3.1 Wave Model Development

Two high resolution DHI MIKE 21 Spectral Wave (SW) Flexible Mesh (FM) models were developed to evaluate 25- and 100-year nearshore wave conditions in combination with 100-year historical and climate change flood levels throughout the study area. The first model focussed on Lake St. Clair, while the second was a lake-wide model for Lake Erie. The underlying bathymetric data used in the development of both models were the same as that which was used in the development of the hydrodynamic (storm surge) model discussed in Section 4.2.1. The model mesh and bathymetric contours for the MIKE21 SW FM Lake St. Clair and Lake Erie models are illustrated in Figure 4.13 and Figure 4.14. Also illustrated in these figures is the location of model output points along nearshore profiles to be used in the assessment of wave uprush, discussed further in Section 4.3.5.

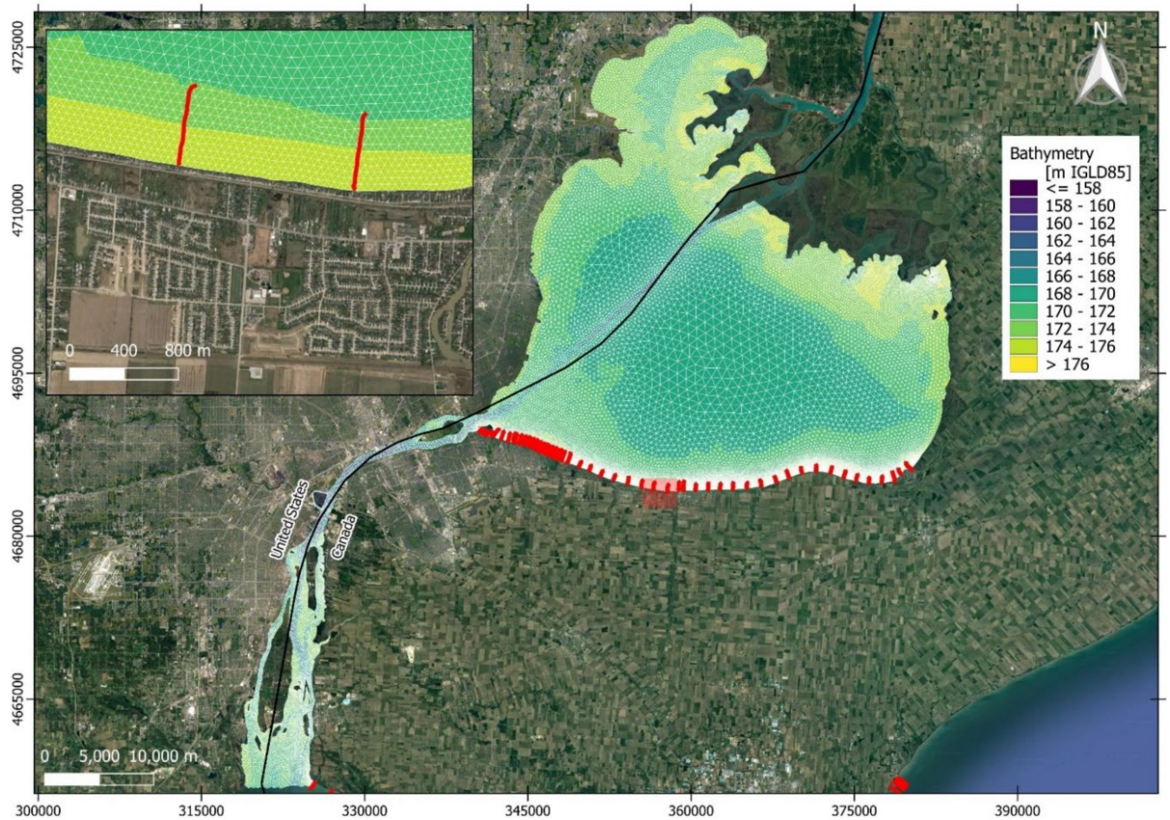


Figure 4.13 MIKE21 SW FM model domain for Lake St. Clair illustrating the computational mesh and interpolated bathymetry. Output profiles for wave uprush calculations shown in red

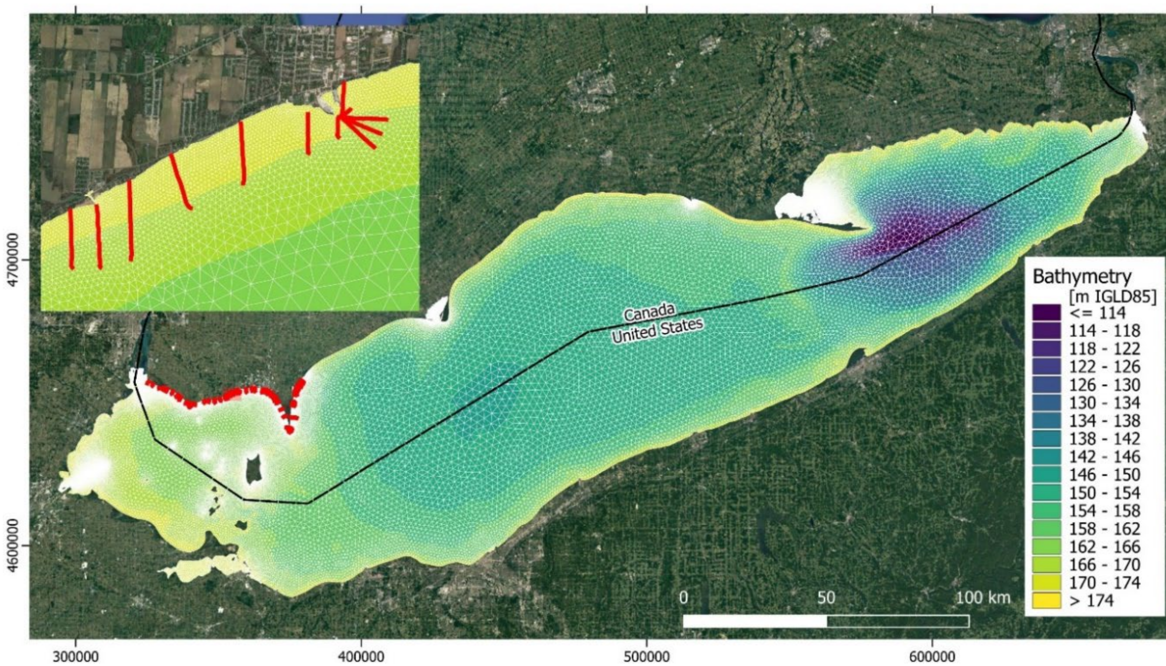


Figure 4.14 MIKE21 SW FM model domain for Lake Erie illustrating the computational mesh and interpolated bathymetry. Output profiles for wave uprush calculations shown in red

4.3.2 Model Setup – Forcings, Boundaries and Initial Conditions

Wind forcing initiates the wave growth process in lakes as the wind transfers energy to the water surface, initiating small ripples that amalgamate and amplify into wind-generated waves when wind persists. Historic wind datasets at Windsor Airport and from the adjusted ERA5 model (see Section 4.2.2) at representative points in Lake St. Clair and Lake Erie were analysed to identify extreme wind conditions to force the wave models. Windsor Airport data covers the period extending from 1953 to 2023 and the ERA5 model data was extracted from 1970 to 2023. The ERA5 dataset was ultimately used to drive the wave models due its spatial coverage, and to be consistent with the forcings used in the hydrodynamic model (see Section 4.2.2).

Wind roses from the ERA5 dataset at select points in central Lake St. Clair and western Lake Erie are presented in Figure 4.15 below. From these plots, it is evident that both Lake St. Clair and Lake Erie feature strong wind conditions from most directions, except the north-west. Wind from the north and north-east are most relevant for driving wave conditions affecting the Essex shoreline of Lake St. Clair. Wind arriving from easterly directions generally produces the most significant wave conditions on the east side of the Pelee Peninsula, while south and south-westerly winds generate significant wave action on the Essex shoreline within the Western Basin of Lake Erie.

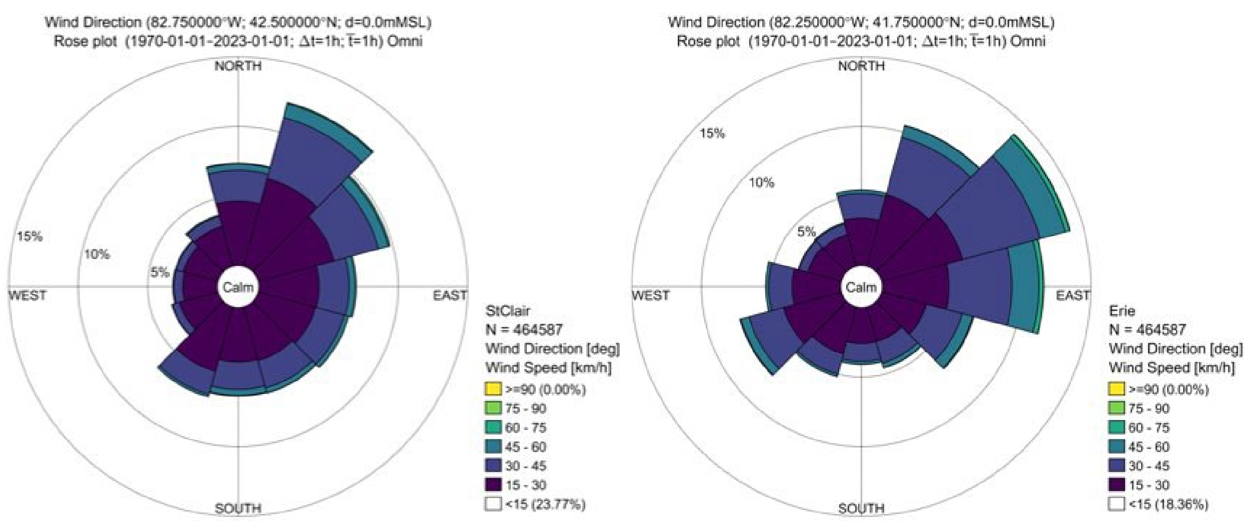


Figure 4.15 Wind roses describing the frequency, magnitude and direction of winds at locations in central Lake St. Clair (left) and western Lake Erie (right) from the ERA5 wind dataset

4.3.3 Model Calibration and Validation

Calibration and validation of the wave models were based on available wave buoy data, with two buoys available in Lake Erie (#45005-US and #C45132-CAN) and one in Lake St. Clair (C45147-CAN). The location of these buoys is shown in Figure 4.16 below. The wave models were run for selected periods with the historical ERA5 wind fields being used to drive wave generation across the model domains. Key model parameters were adjusted including wind speed and wind friction to achieve a good agreement between the modelled waves and the historical record at buoy locations for the same period. The model was than validated against different periods and storm events to ensure the accurate reproduction of historical wave conditions in the numerical environment. Figure 4.17 shows a comparison of modelled and measured wave heights and wave periods for a sample period at buoy #45005 for a 16-day period in the fall of 2019, illustrating the strong performance of the Lake Erie wave model at reproducing historical wave conditions. A similar level agreement was achieved for the Lake St. Clair model.

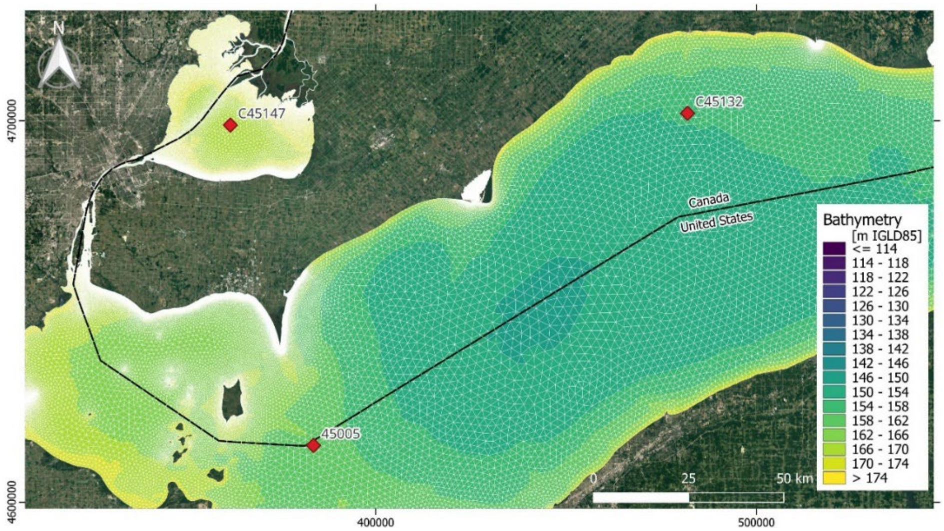


Figure 4.16 Location of wave buoys (red diamonds) for verification of the MIKE21 SW models

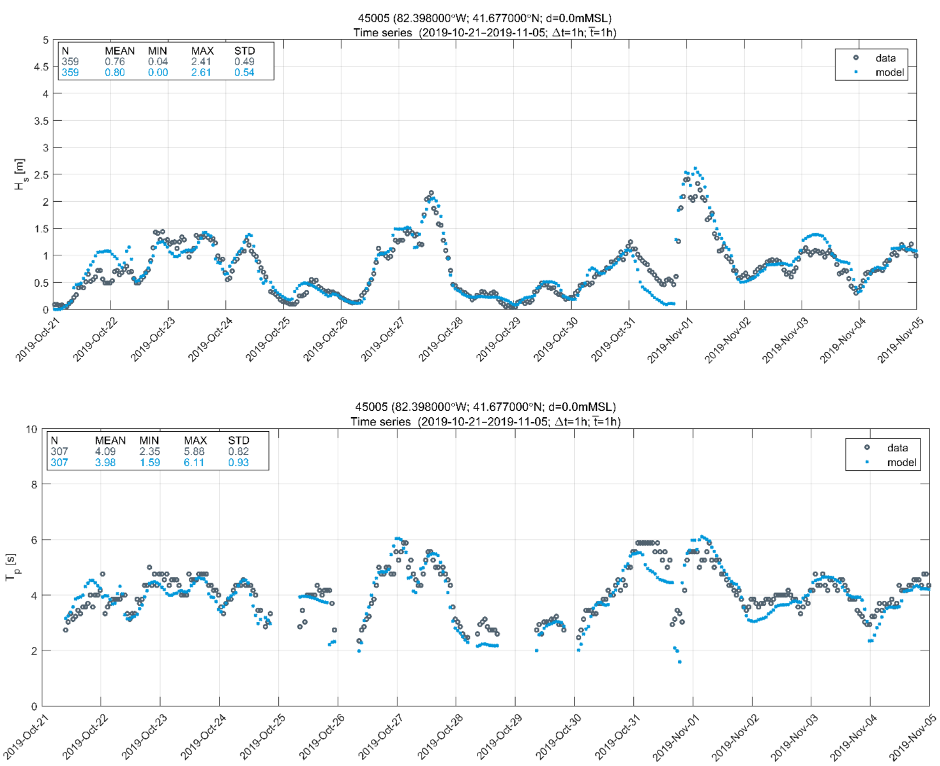


Figure 4.17 Comparison of measured and modelled wave conditions at buoy #45005 for a 16-day period in 2019 (wave height, Hs – top, and wave period, Tp – bottom)

4.3.4 Nearshore Wave Conditions for Hazard Mapping

A multi-directional, extreme value analysis of the hourly ERA5 winds was completed covering the period from 1970 to 2023 for central Lake St. Clair and western Lake Erie to identify wind conditions commensurate with 25-year (for hazard mapping) and 100-year events. The multi-directional analysis was performed in 30 degree directional bins. The results of this analysis are presented in Table 4.15 below.

Table 4.15 Summary of hourly directional wind speeds corresponding to 25-year and 100-year average recurrence intervals for central Lake St. Clair and western Lake Erie

Wind Direction (°N)	Lake St. Clair Wind Speed (km/h)		Lake Erie Wind Speed (km/h)	
	25-yr	100-yr	25-yr	100-yr
0	78.98	85.29	68.27	73.67
30	82.04	88.36	81.60	90.60
60	82.19	88.10	89.31	96.53
90	76.90	83.96	90.34	98.19
120	73.16	80.12	81.22	88.81
150	73.93	80.83	72.82	79.09
180	75.74	82.77	72.34	80.50
210	65.94	71.96	69.20	76.18
240	59.62	66.48	76.83	84.46
270	64.53	72.64	70.69	77.97
300	61.13	67.84	61.42	67.78
330	70.31	78.24	65.16	71.44

4.3.4.1 Lake St. Clair Waves

Discrete event simulations were completed using the Lake St. Clair wave model for 25-year and 100-year wind conditions from all directions producing wave action on the Essex shoreline. This corresponded to directional bins from 270° – 90° (i.e. northwest and northeast quadrants), with corresponding wind speeds provided in Table 4.15 above. Simulations were repeated assuming both historical 100-year water levels and mid-century RCP4.5 water levels (refer to Sections 4.1 and 4.2). Figure 4.18 presents simulated 25-year wave conditions from the 30° and 330° directional bins in the Lake St. Clair model assuming historical 100-year flood level conditions. Nearshore wave conditions were output for both the 25-year and 100-year simulations along 43 shore-perpendicular profiles along the Essex shoreline, as depicted by the red dots in Figure 4.13 above. Governing wave conditions from all directions corresponding to the 25-year average recurrence interval were subsequently used in the assessment of wave uprush, as discussed further in Section 4.3.5.

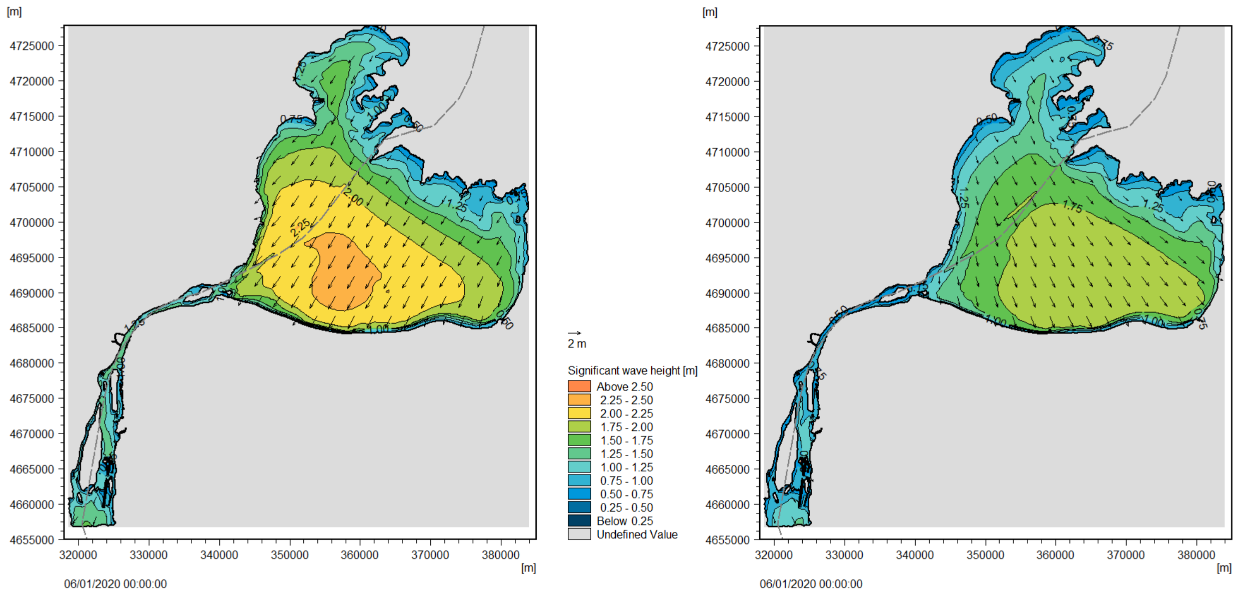


Figure 4.18 Simulated wave fields from the Lake St. Clair MIKE21 SW model for 25-year wind conditions from 30° (left) and 330° (right) assuming historical 100-year flood levels

4.3.4.2 Lake Erie Waves

A slightly different approach was used to assess nearshore wave conditions for the Essex shorelines on Lake Erie. In this case, the existing Wave Information Studies (WIS) hindcast (USACE, 2023) was leveraged to assess governing offshore wave conditions through an extreme value analysis of 25-year and 100-year wave conditions at 21 individual output points spaced ~4 km apart and generally 5 – 10 km offshore of the Essex shoreline (refer to Figure 4.19). The extreme value analysis was performed for the same 30° directional bins as is presented in Table 4.15 above. The WIS hindcast has been extensively calibrated and validated and covers the period from 1979 to 2022.

The MIKE21 SW model discussed in Section 4.3.1 was adjusted to have an offshore boundary that corresponded to the approximate location of the WIS output points and with a greatly refined computational grid for improved spatial resolution in the nearshore. The model grid and location of the WIS output points is shown in Figure 4.19. 25-year and 100-year wave conditions extracted from the WIS database were input along the model boundary for all 30° directional bins affecting the Essex shoreline (30° - 270°) and at all 21 WIS output locations. Model inputs between these discrete locations were interpolated from adjacent input points. Wind was also included to account for wave generation within the model domain based on 25-year and 100-year wind conditions extracted from the extreme value analysis of the ERA5 wind data presented in Table 4.15 above. Model output points were assigned along 60 shore-perpendicular nearshore profiles as depicted by the red dots in Figure 4.19.

Figure 4.20 and Figure 4.21 present MIKE21 SW model results for 25-year wave conditions from the 240° and 150° directional bins, assuming historical 100-year flood levels.

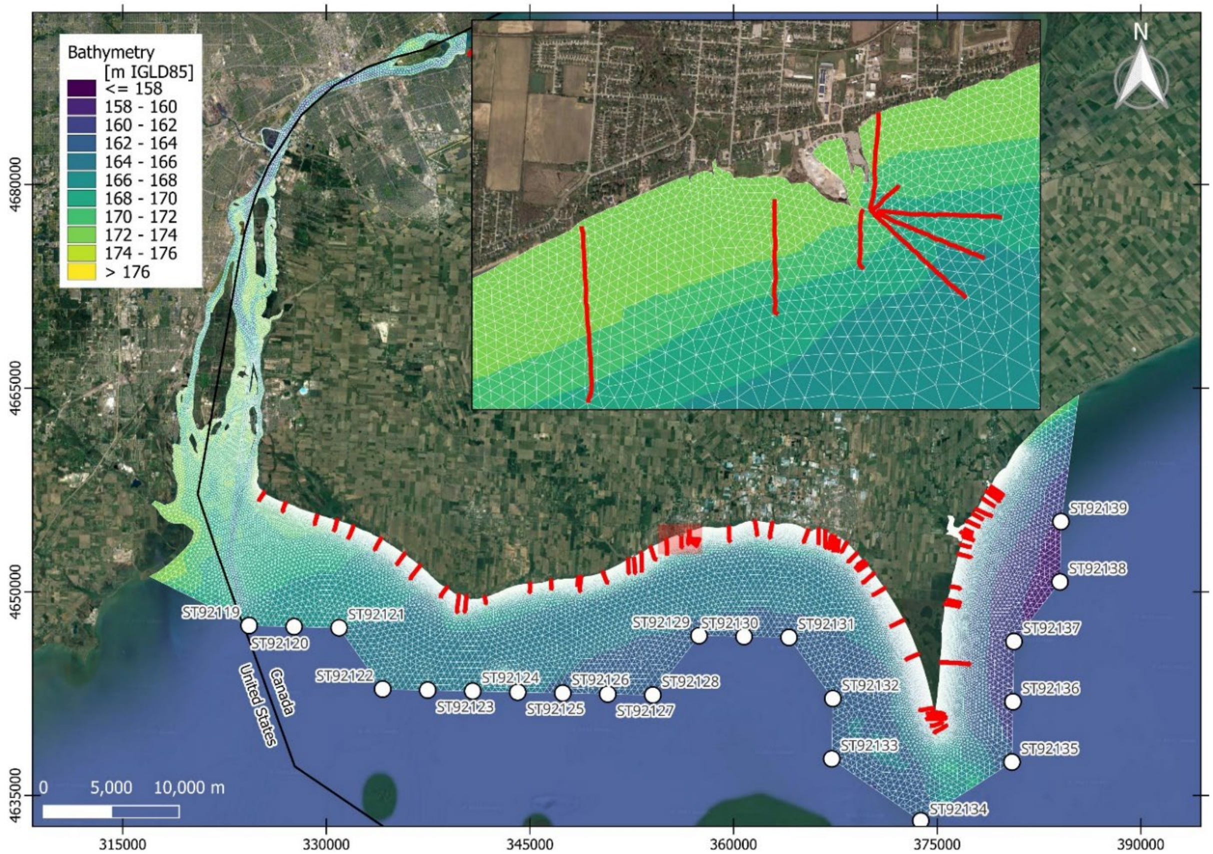


Figure 4.19 Overview of the refined nearshore MIKE21 SW model showing WIS output points (white dots), the model bathymetry, computational mesh, and output points along nearshore profiles (red dots)

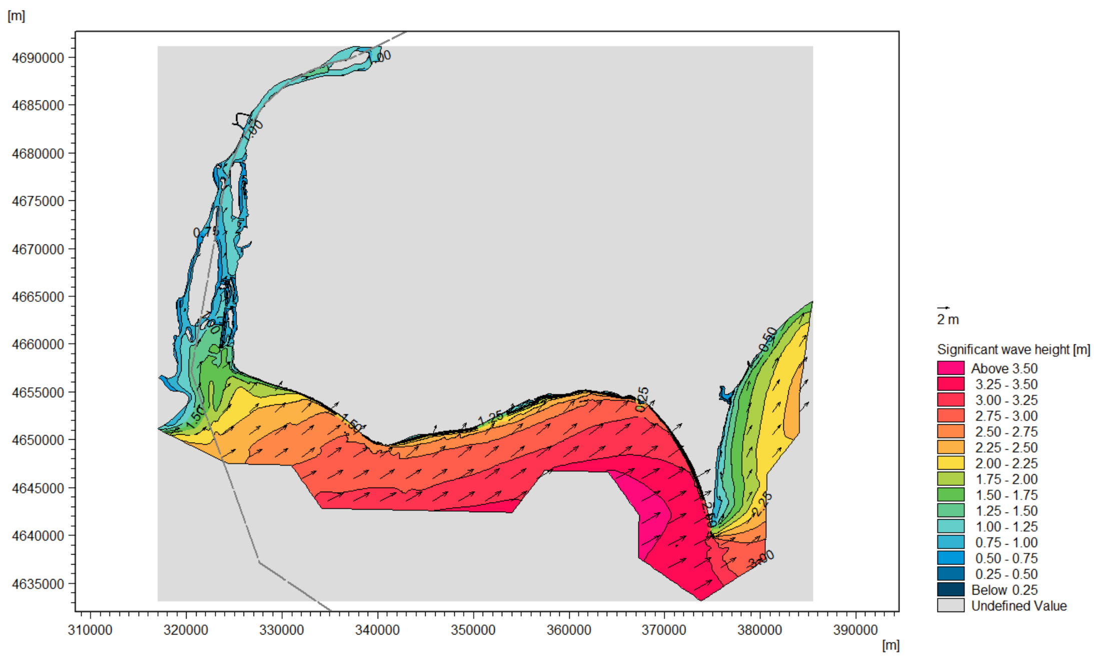


Figure 4.20 Simulated wave field for 25-year wave conditions based on the 240° directional bin

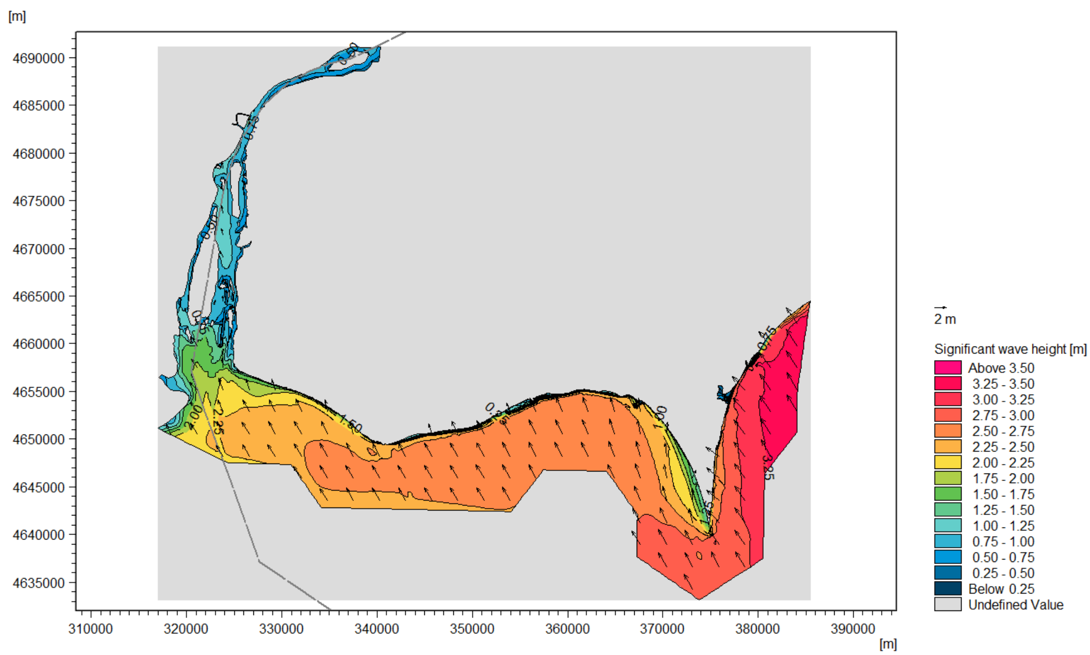


Figure 4.21 Simulated wave field for 25-year wave conditions based on the 150° directional bin

Wave conditions corresponding to the maximum wave height simulated across all directional bins were output from the wave model at specified intervals along each of the 60 shore-perpendicular nearshore profiles shown in Figure 4.19. Waves corresponding to the 25-year wave conditions over both the historical 100-year flood level and the mid-century RCP4.5 100-year flood level were subsequently used in the analysis of wave effects (uprush), as discussed in the following section. In general, waves arriving from southerly directions govern for the south-facing portion of Lake Erie shoreline within the western basin. Waves arriving from southwesterly directions govern for the west side of the Pelee Peninsula, while waves arriving from the east-northeast direction (commensurate with the long axis of the Lake) govern on the east side of the peninsula.

4.3.5 Wave Effects

A critical component of the *flooding hazard* for Great Lakes and connecting channel 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 overtopping, more broadly referred to as “wave effects” (as adopted in the draft Great Lakes Technical Guide, Zuzek Inc., 2023). Wave uprush is the process by which waves surge up the shoreline to an elevation higher than the still water level. A definition sketch of wave uprush in its simplest form on a gentle sloping shoreline is provided in Figure 4.22 below.

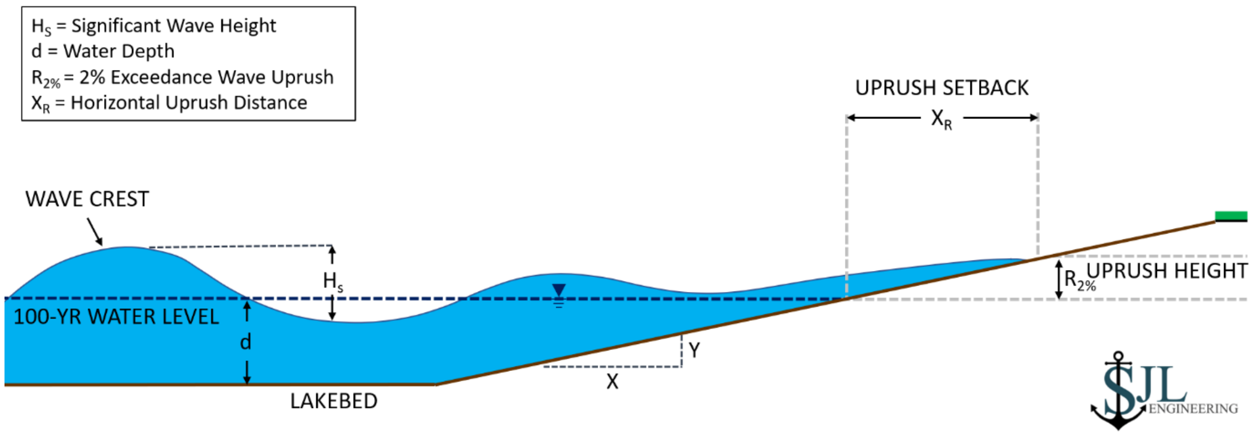


Figure 4.22 Wave uprush definition sketch on a gentle sloping shoreline

To determine appropriate horizontal setbacks to account for wave uprush along the Essex shorelines of Lake St. Clair and Lake Erie, uprush calculations were completed at more than 100 locations corresponding to the nearshore bathymetric profiles discussed in Section 3.2 and shown on the maps provided in Figure 4.13 and Figure 4.14. At each location, the wave uprush elevation was 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 empirical uprush formulations. For this study, the uprush formulations and methodology presented in the EurOtop Manual (2018) and the Upper Bound Method presented in the MNR Technical Guide (MNR, 2001) were used for steep and gentle shoreline slopes, respectively. Steep shorelines were deemed to have slopes in the vicinity of the still water line of 10H:1V or greater. The EurOtop Manual is the industry leading guidance document for the evaluation of wave uprush and overtopping on steep shorelines and coastal structures. The MNR Upper Bound Method provides a simplified version of the EurOtop equations widely used in hazard mapping studies throughout the Great Lakes Basin.

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 selected equations (EurOtop or MNR Upper Bound). The tool then calculates the uprush resulting from progressively smaller, depth-limited wave heights moving in a landward direction 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 topographic portion of the profile above the waterline. The resulting uprush elevation is therefore associated with a specific point on the shoreline, from which a horizontal distance or setback from the waterline can also be determined. The calculation location along the nearshore profile producing the furthest landward excursion of uprush (X_R) is the governing result for that profile.

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 resulting in a process called wave overtopping. This scenario is depicted graphically in Figure 4.23. The uprush elevation calculated in this scenario is no longer tied to a location on the nearshore profile, but is instead a theoretical uprush elevation on the bank or shoreline protection structure if the bank or structure were infinitely high. To assess the horizontal setback associated with wave uprush for these situations, 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 4.23). Another widely used equation for this purpose is the FEMA equation (FEMA, 1991), commonly referred to as the New England Methodology. Inputs to these equations 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 Essex shoreline, the average horizontal setback predicted by the Cox-Machemehl and FEMA equations was used to inform the necessary setback for wave effects in the delineation of the *flooding hazard*.

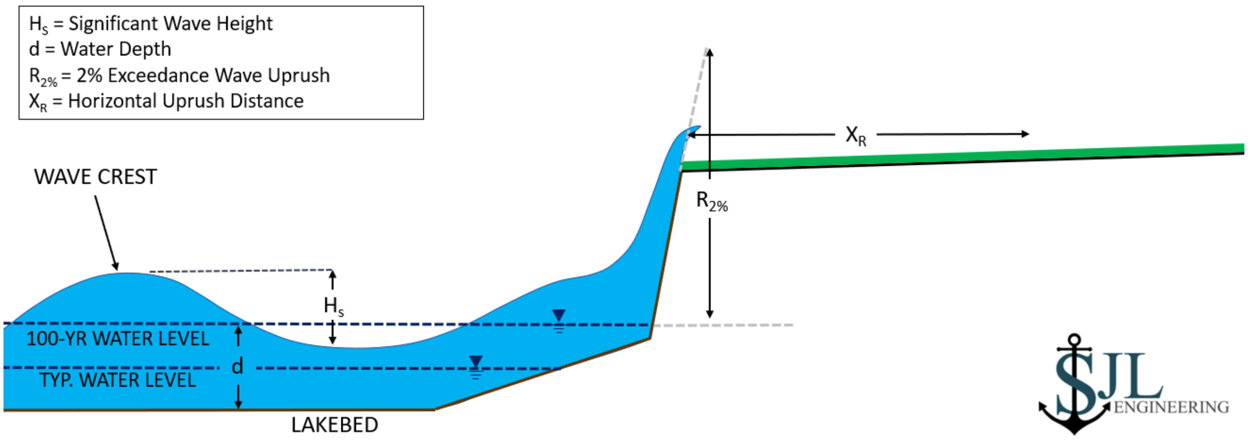


Figure 4.23 Wave uprush on a steep bank or structure resulting in wave overtopping of the bank or structure crest – definition sketch

Wave effects were quantified using the above methodology at all 100+ nearshore profiles for the following two distinct scenarios:

A. 25-year wave conditions and the 100-year flood level based on historical conditions

B. 25-year wave conditions and the mid-century RCP4.5 100-year climate change flood level

Table 4.16 and Table 4.17 below present summaries of wave uprush results for all 100+ nearshore profiles across the Lake St. Clair and Lake Erie shorelines within Essex Region for Scenario A and B above. Profile ID's were generally assigned to provide consistency with profiles evaluated historically as a component of prior studies, including those completed for the Town of Lakeshore (Stantec, 2022), the Town of Tecumseh (Zuzek Inc., 2022), and the Municipality of Leamington (Zuzek Inc., 2021). Missing profiles ID's are those profiles that either aligned with a tributary outlet or passed through an offshore structure such as a harbour breakwater or jetty and were therefore not relevant for the determination of wave effects on the shoreline. Horizontal wave effects setbacks (X_R) are relative to the position of the 100-year flood level on the shoreline for that specific scenario (A or B above). Where the horizontal setback is listed as "n/a", the land elevation on the profile was such that a horizontal uprush setback could not be resolved through either the composite slope method or the average of the

Cox and Machemehl and FEMA methods. This was typical for shorelines that are overtopped and where the land elevation decreases in a landward direction away from the overtopped shoreline, or where land elevations are generally lower than the overtopped shoreline across the entire topographic portion of the profile, as was the case for most of Lake St. Clair. Where the vertical uprush elevation is listed as “n/a”, the static water level is already higher than the shoreline and no uprush elevation can be calculated. For more information on how these situations are resolved in the mapping, and for the specific mapping rules and methodology employed for establishing the wave effects component of the *flooding hazard*, refer to Section 5.1.

It is noted that no wave uprush calculations are provided herein for the Detroit River. Due to the limited fetch and wave exposure within the Detroit River, a standard horizontal setback (X_R) of 5 m is to be used to represent wave effects, as prescribed in both the old (MNR, 2001) and new (Zuzek Inc., 2023) versions of the Great Lakes Technical Guide for connecting channels.

Table 4.16 Summary of wave uprush results for Lake St. Clair

Profile ID	Water Body	Project Reach	Shoreline Type	Scenario A (historical)		Scenario B (CC)	
				Uprush Elev. $R_{2\%}$ (m IGLD'85)	Horizontal Setback X_R (m)	Uprush Elev. $R_{2\%}$ (m IGLD'85)	Horizontal Setback X_R (m)
LSC-LK 2	Lake St. Clair	1	Armoured low shoreline	+178.4*	6	+179.0*	7
LSC-LK 4			Armoured low shoreline	n/a	n/a	n/a	n/a
LSC-LK 5			Armoured low shoreline	n/a	n/a	n/a	n/a
LSC-LK 6			Low bank	+178.8*	12	n/a	n/a
LSC-LK 7			Armoured low shoreline	+179.9*	15	+180.7*	15
LSC-LK 8			Armoured low shoreline	+180.2*	16	n/a	n/a
LSC-LK 9		2	Armoured low shoreline	+179.8*	14	+180.4*	15
LSC-LK 10			Armoured low shoreline	+179.9*	16	n/a	n/a
LSC-LK 11			Armoured low shoreline	+179.8*	15	n/a	n/a
LSC-LK 12			Armoured low shoreline	+178.1*	5	n/a	n/a
LSC-LK 13			Armoured low shoreline	+179.5*	13	n/a	n/a
LSC-LK 14			Armoured low shoreline	+179.9*	14	n/a	n/a
LSC-LK 15			Armoured low shoreline	+179.9*	14	n/a	n/a
LSC-LK 16			Armoured low shoreline	+179.8*	11	n/a	n/a
LSC-LK 17			Armoured low shoreline	+179.9*	15	+180.6*	16
LSC-LK 18			Armoured low shoreline	+179.9*	14	n/a	n/a
LSC-LK 19			Beach	+177.0*	n/a	+177.3*	n/a
LSC-LK 20		3	Beach	+176.9*	n/a	+177.2*	n/a
LSC-LK 21			Armoured low shoreline	+178.6*	7	n/a	n/a
LSC-LK 22			Armoured low shoreline	+179.2*	9	n/a	n/a
LSC-LK 23			Armoured low shoreline	+179.4*	12	+180.2*	14
LSC-LK 24			Armoured low shoreline	+179.0*	8	+179.8*	8
LSC-LK 25			Armoured low shoreline	+178.1*	5	n/a	n/a
LSC-LK 26			Armoured low shoreline	+178.6*	10	+179.3*	11
LSC-LK 27			Armoured low shoreline	+179.0*	11	n/a	n/a
LSC-LK 28			Armoured low shoreline	+179.0*	12	+179.8*	12
LSC 1			Armoured low shoreline	+178.9*	11	+179.7*	13
LSC 3			Armoured low shoreline	+178.8*	9	n/a	n/a
LSC 4			Armoured low shoreline	+179.3*	13	+180.2*	13
LSC 5			Armoured low shoreline	+179.0*	10	+179.9*	12
LSC 6			Armoured low shoreline	+179.5*	14	+180.4*	16
LSC 7			Armoured low shoreline	+179.0*	10	+179.9*	11
LSC 8			Armoured low shoreline	+179.5*	13	+180.4*	14
LSC 9			Beach	+178.7*	n/a	+179.1*	n/a
LSC 10			Armoured low shoreline	n/a	n/a	n/a	n/a
LSC 11			Armoured low shoreline	+179.5*	12	n/a	n/a
LSC 12			Armoured low shoreline	+179.5*	13	n/a	n/a
LSC 13			Armoured low shoreline	+179.5*	12	+180.4*	13
LSC 14			Armoured low shoreline	+179.3*	10	n/a	n/a
LSC 15			Beach	+179.0*	n/a	+179.3*	n/a
LSC 16			Beach	+178.7*	n/a	+179.0*	n/a
LSC 17			Armoured low shoreline	+179.5*	15	+180.4*	16
LSC 18			Armoured low shoreline	+180.6*	16	n/a	n/a

*Shoreline is overtopped. Uprush elevation is theoretical only, determined for an infinitely high bank or structure

Table 4.17 Summary of wave uprush results for Lake Erie

Profile ID	Water Body	Project Reach	Shoreline Type	Scenario A (historical)		Scenario B (CC)	
				Uprush Elev. $R_{2\%}$ (m IGLD'85)	Horizontal Setback X_R (m)	Uprush Elev. $R_{2\%}$ (m IGLD'85)	Horizontal Setback X_R (m)
LE 48	Lake Erie	9	Armoured low shoreline	+177.8*	16	+178.1*	17
LE 49			Armoured low shoreline	+178.6*	22	n/a	n/a
LE 50			Barrier beach	+178.0*	36	+178.4*	38
LE 51			Beach	+178.8*	22	+179.3*	20
LE 52			Armoured low shoreline	+180.1*	21	+180.5*	23
LE 53			Beach	+178.8*	16	n/a	n/a
LE 54			Armoured low shoreline	+178.6*	17	n/a	n/a
LE 55			Low bank	+180.0*	22	+180.8*	24
LE 56			Armoured bluff	+179.8	12	+179.9*	15
LE 1		10	Fillet beach	+176.7	19	+177.1	12
LE 2		12	Armoured bluff	+181.3	9	+182.0	10
LE 3			Bluff	+182.5	9	+183.4	9
LE 3a		13	Armoured low shoreline	+179.1*	17	+179.6*	19
LE 3b			Armoured low shoreline	+180.2*	24	+180.5*	25
LE 5			Armoured low shoreline	+179.3*	18	+179.7*	19
LE 5a			Armoured low shoreline	+179.7*	19	+180.0*	21
LE 6			Armoured low shoreline	+177.9*	24	+178.4*	25
LE 8		15	Beach	176.8*	15	n/a	n/a
LE 8a			Armoured low shoreline	178.9*	19	+179.2*	20
LE 9			Bluff	+178.5	14	+179.1	15
LE 10		16	Fillet beach	+176.1	17	+176.5	16
LE 11		17	Harbour infrastructure	n/a	n/a	n/a	n/a
LE 16		18	Bluff	+179.8	16	+180.2	20
LE 18			Armoured bluff shoreline	+180.0	19	+180.7	21
LE 19			Bluff	+180.3	8	+181.5	10
LE 19a			Bluff	+181.1	11	+182.1	12
LE 19b			Bluff	+182.6	21	+183.7	22
LE 21		19	Beach	+176.5	46	+176.6	81
LE 22			Fillet beach	+175.8	20	+176.2	10
LE 23			Fillet beach	+176.2	50	+176.6	59
LE 25		20	Harbour infrastructure	+178.1*	15	n/a	n/a
LE 27		21	Armoured low shoreline	+183.3*	34	+183.8*	35
LE 28			Armoured low shoreline	+183.5*	36	+184.2*	39
LE 29		22	Armoured low shoreline	+178.2*	45	+178.7*	16
LE 30			Armoured low shoreline	+178.1*	18	+178.5*	18
LE 33		24	Armoured low shoreline	+181.0*	34	+182.0*	37
LE 34			Armoured low shoreline	+183.2*	36	+184.1*	37
LE 34a			Armoured low shoreline	+181.6*	30	+182.2*	30
LE 35			Armoured low shoreline	+178.8*	23	+179.3*	26
LE-L 22a		25	Armoured low shoreline	+182.9*	35	+183.5*	39
LE-L 22			Armoured low shoreline	+179.3*	15	+180.6*	20
LE-L 21			Armoured low shoreline	+181.8*	41	+182.3*	33
LE-L 20a			Armoured low shoreline	+182.0*	32	+182.8*	31
LE-L 20		26	Barrier beach	+182.5*	35	+183.4*	37
LE-L 19b			Barrier beach	+178.3*	20	+178.8*	17
LE-L 19a			Barrier beach	+179.1*	24	+179.6*	26
LE-L 19			Barrier beach	+179.8*	27	+180.2*	28
LE-L 18c		27	Armoured low shoreline	+182.3*	34	+183.3*	37
LE-L 18			Armoured low shoreline	+182.9*	36	+183.4*	35
LE-L 17			Armoured low shoreline	+182.7*	29	+183.5*	32

*Shoreline is overtopped. Uprush elevation is theoretical only, determined for an infinitely high bank or structure

5.0 MAPPING HAZARDOUS LANDS

The following sections summarize the approach to mapping hazardous lands based on historical conditions and accounting for relevant climate change projections. Mapping described herein was performed at a local scale, not lot by lot, based on the conditions within the 27 hazard mapping reaches. In the future, under certain circumstances, lot-specific analysis of shoreline hazards may be warranted.

5.1 Flood Hazard Limit

The *flooding hazard* limit is defined in the Guidelines for Developing Schedules of Regulated Areas (Conservation Ontario and MNR, 2005) as the 100-year flood level plus an allowance for wave uprush and other water related hazards. When CAs map their regulated area, an additional allowance of 15 metres can be added. A definition schematic of the *flooding hazard* is provided in Figure 5.1.

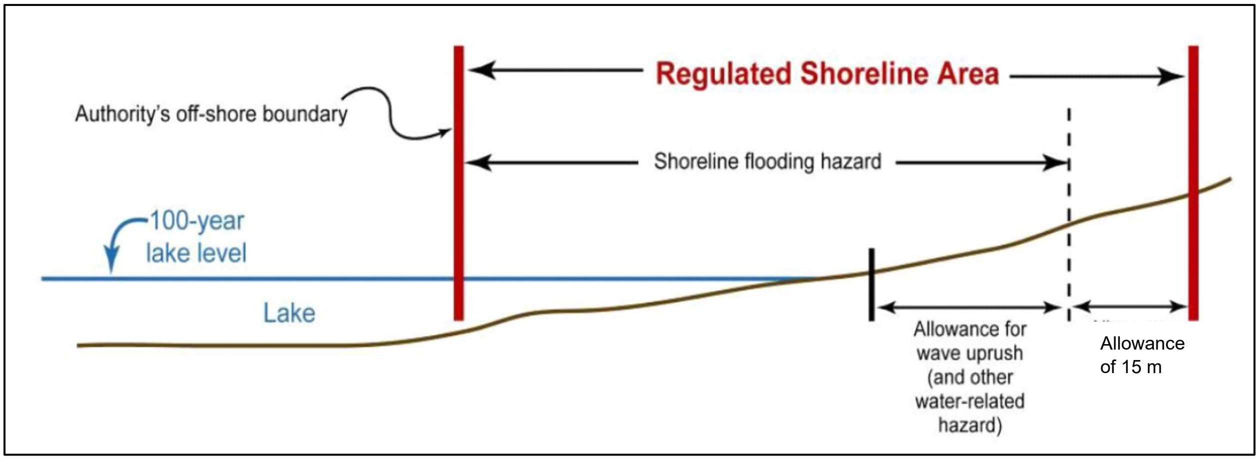


Figure 5.1 Flooding hazard definition (Conservation Ontario and MNR, 2005)

The MNR Technical Guide (MNR, 2001) provides additional information on the allowance for wave uprush and other water related hazards, including the fact that in the absence of detailed wave uprush calculations, a standard minimum setback of 15 m should be adopted.

5.1.1 Mapping Approach for the 100-year Flood Level

For this study the 100-year flood level was mapped for the Essex Region shoreline, for four separate scenarios. These scenarios were discussed in Section 4.1, and are briefly summarized as follows:

- **Scenario A:** Historical 100-year flood level.
- **Scenario B:** Mid-century (~2050) RCP4.5 100-year climate change flood level.
- **Scenario C:** Late-century (~2075) RCP4.5 100-year climate change flood level.

- **Scenario D:** Late-century (~2075) RCP8.5 100-year climate change flood level.

Mapping was completed by first digitizing the topographic contour corresponding to the 100-year flood level. The 100-year flood level varies throughout the study area, as documented in Section 4.2, and specifically provided in Table 4.14. It also differs between each of the above listed scenarios, with the climate change 100-year flood levels being higher than those established based on historical data.

Using the 2017 LiDAR DTM, contours were extracted as polygons using GIS for the historical 100-year flood level and three climate change 100-year flood levels. This contour extraction created a polygon classified as elevations below and above the 100-year flood level (Figure 5.2). These polygons were cleaned to remove features less than 20 m^2 in area, as it was assumed that land areas less than 20 m^2 do not have any significant development potential and therefore could be excluded from the analysis.

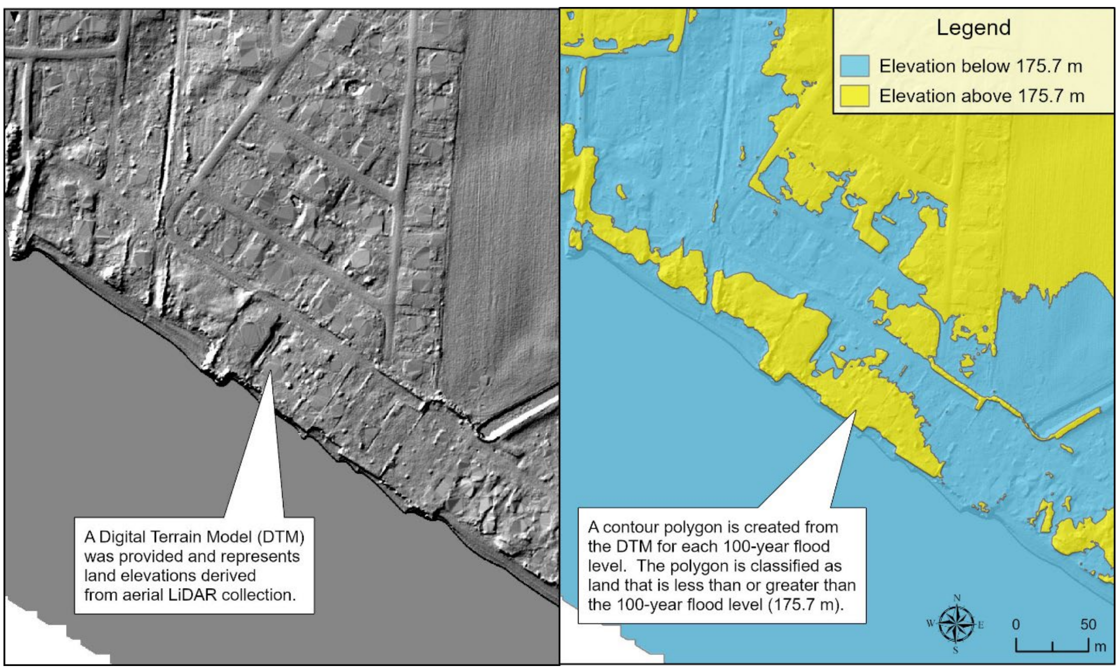


Figure 5.2 Contour polygons extracted from the DTM

An example of the features that were removed is provided in Figure 5.3. Features that were outside of the project study area or lacked a hydraulic connection to the river or lake (such as isolated ponds and land depressions) were also deleted. For the areas where 100-year flood level elevation transitions to another elevation at a reach boundary, the 100-year flood level polygon features were edge-matched together.

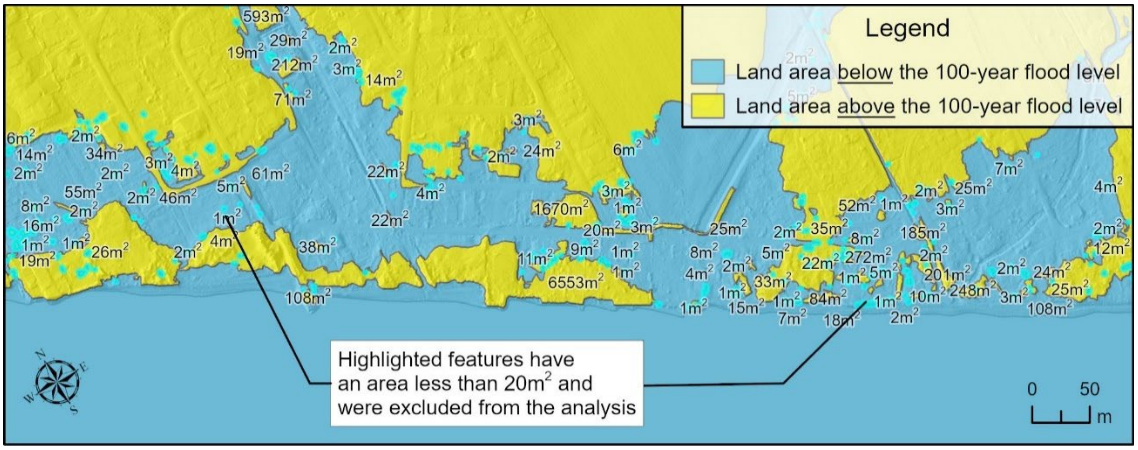


Figure 5.3 Example of 100-year flood level (shaded blue) for lands above the hazard

This process of extracting cleaning contour polygons was repeated for each project reach. Once cleaned, the contour polygon was converted to a line dataset to optimize viewing and integration into the *flooding hazard*. The entire process was repeated for each of the three climate change scenarios. When viewed together in GIS, the differences in the extents of each 100-year flood level scenarios becomes apparent as seen in Figure 5.4.

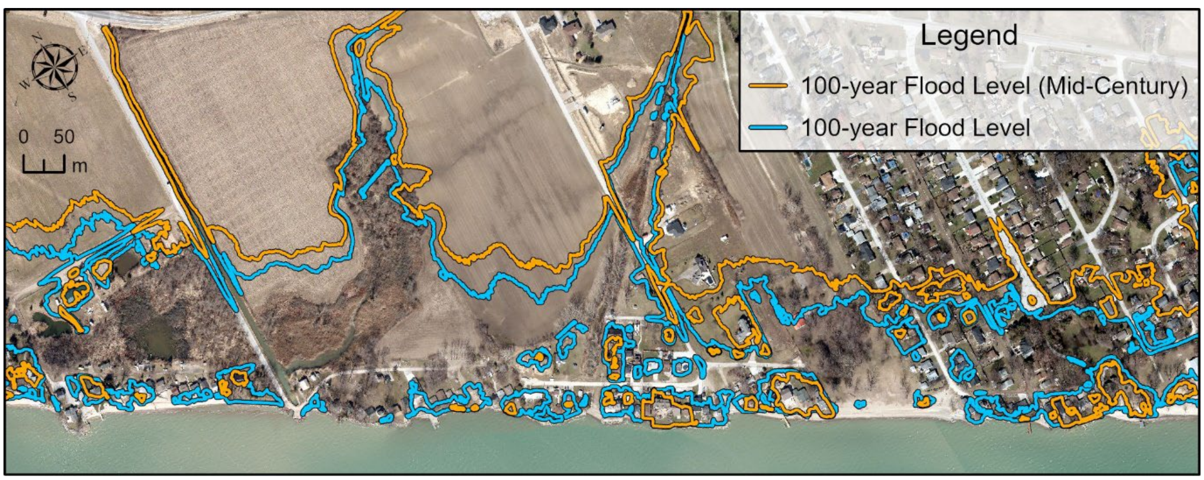
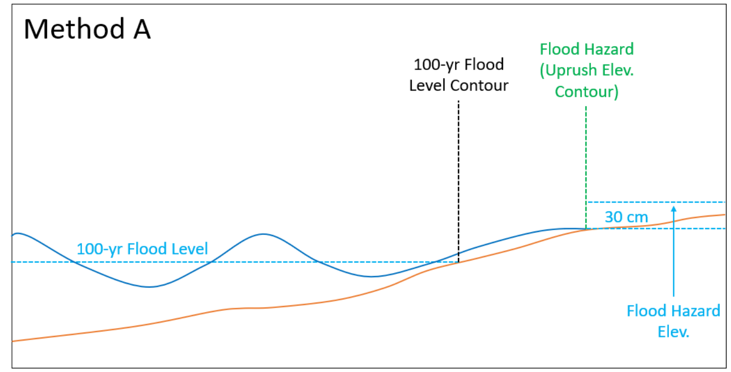
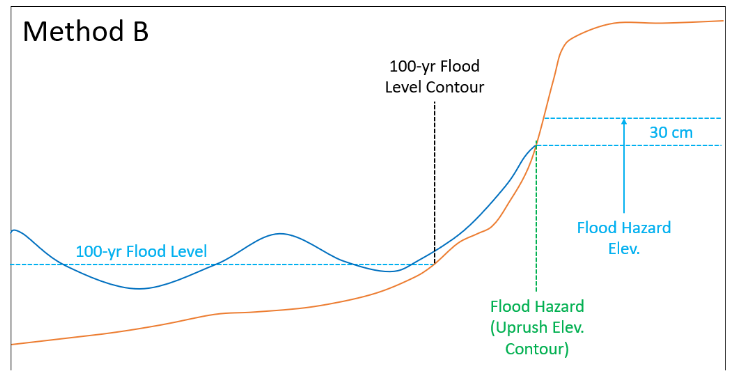
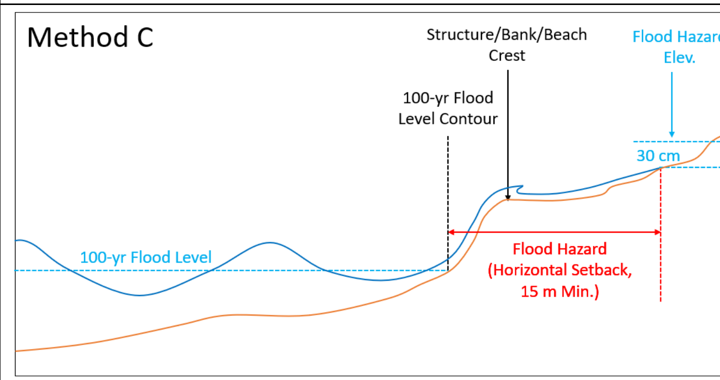
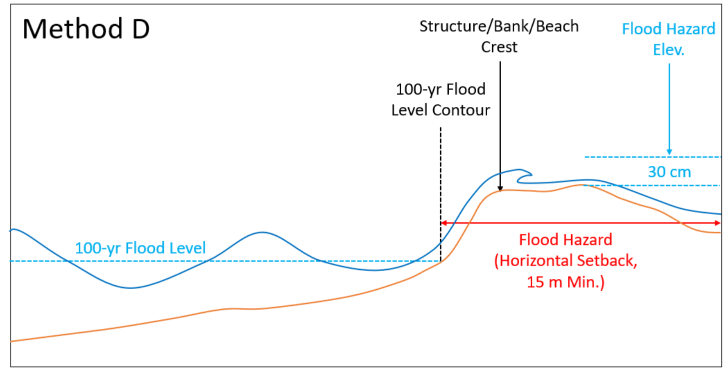
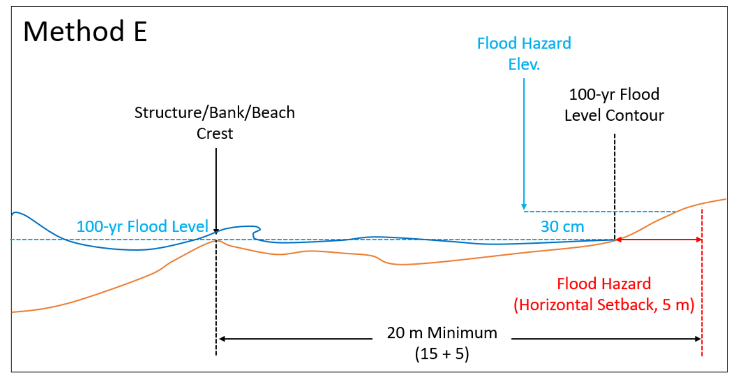
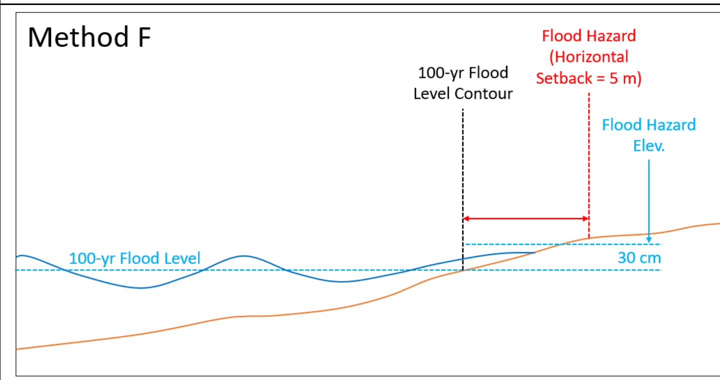


Figure 5.4 Comparison of the historical (Scenario A) and mid-century RCP4.5 100-year (Scenario B) flood levels

5.1.2 Mapping Approach for the Flooding Hazard Limit

The *flooding hazard* limit which extends landward from the 100-year flood level was mapped for Scenarios A (historical) and B (mid-century RCP4.5 climate change). The distance beyond the 100-year flood level to which the *flooding hazard* limit extends is dependent on the evaluated setback for wave effects (uprush and overtopping). This additional setback was applied within each project reach and for mapping scenarios A and B based on the following methodology:

Uprush Mapping Method ID	Description:	Mapping Approach:	Graphic:
A	Gentle sloping beach or shoreline where uprush does not exceed the elevation of the back of beach or beach crest	Map the topographic contour corresponding to the uprush elevation ($R_{2\%}$) from the composite slope method. The recommended *flood elevation* for flood proofing is equal to the uprush elevation plus 30 cm	
B	High bluff/bank shoreline where uprush does not exceed the elevation of the bluff/bank	Map the topographic contour corresponding to the uprush elevation ($R_{2\%}$) from the composite slope method. The recommended *flood elevation* for flood proofing is equal to the uprush elevation plus 30 cm	
C	Low lying beach, bank or armoured shoreline where wave uprush exceeds the beach, bank or structure crest elevation, but is limited by a higher elevation on the profile landward of the bank or structure crest	Adopt a horizontal setback (X_R) from the 100-year flood level based on the average of the Cox-Machemehl and FEMA formulas, with a minimum value of 15 m. The recommended *flood elevation* for flood proofing is the elevation at the predicted limit of uprush using the composite slope method plus 30 cm	

D	Low lying beach, bank or armoured shoreline where wave uprush exceeds the maximum topographic elevation on the profile (e.g. low lying, flat shorelines and barrier beaches)	Adopt a horizontal setback from the 100-year flood level based on the average of the Cox-Machemehl and FEMA formulas, with a minimum value of 15 m. The setback may intersect areas already below the 100-year flood level, in which case the hazard extends to the landward extent of the 100-year flood level contour. In-land flood pathways must be visually inspected. The recommended *flood elevation* for flood proofing is the elevation of the beach crest, top of bank, or the maximum topographic elevation on the profile that is overtopped, plus 30 cm	
E	Low lying beach, bank or armoured shoreline where the 100-year flood level <u>without</u> wave effects exceeds the maximum topographic elevation on the profile (the profile is inundated)	Adopt a horizontal setback of 5 m from the 100-year flood level (which is well inland of the shoreline for this scenario), to account for minor wave effects propagating long distances through shallow depths behind shoreline infrastructure or low banks and into the flooded backshore. The total setback from the shoreline (structure or bank crest) should be a minimum of 20 m. In-land flood pathways should be visually inspected. The recommended *flood elevation* for flood proofing is the 100-year flood level plus 30 cm	
F	Connecting channels (e.g. Detroit River)	Adopt a horizontal setback of 5 m from the 100-year flood level. The recommended *flood elevation* for flood proofing is the elevation of the 100-year flood level plus an additional 30 cm	

The topographic uprush contour ($R_{2\%}$) used in uprush mapping methods A and B and the horizontal setback (X_R) adopted in methods C, D and E was established based on the values listed in Table 4.16 and Table 4.17. If only one uprush profile fell into each mapping method category for a particular shoreline reach, that value was used for all instances of that mapping method being encountered in that reach. If multiple uprush profiles fell into a given mapping method category for a particular shoreline reach, the average plus one standard deviation was used for all instances of that mapping method being encountered in that reach.

For portions of the Essex Region shoreline where the *flooding hazard* extent is based on a topographic uprush contour ($R_{2\%}$) (i.e. uprush methods A and B), the uprush contour was extracted from the topographic LiDAR data (refer to Section 3.3) and used to define the landward extent of the *flooding hazard* (refer to Figure 5.5).

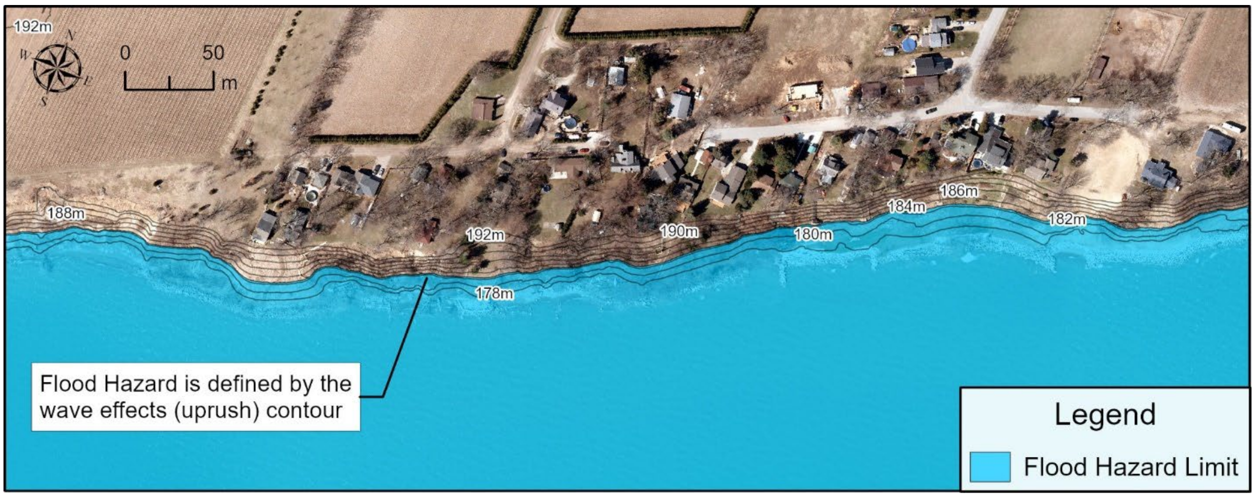


Figure 5.5 Flood hazard based on wave uprush topographic contour

For portions of the shoreline where the *flooding hazard* extent is based on the 100-year flood level plus a horizontal setback (i.e. uprush methods C, D, E and F), a setback was applied to the lakeward edge of the 100-year flood level contour along the shoreline. In many cases such as the examples provided in Figure 5.6 and Figure 5.7, significant inland areas beyond the extent of wave effects were also mapped as *flooding hazard* if they were A) below the 100-year flood level topographic contour, and B) had hydraulic connectivity to the lake(s) or river. For Lakes St. Clair and Erie these inland areas subjected to the *flooding hazard* received no additional setback beyond the 100-year flood level. For inland areas adjacent to the Detroit River, an additional 5 m buffer was added, per discussion with the client. Any inland areas that were lower than the 100-year flood level but hydraulically isolated from the lake(s) or river (e.g. land depression or pond) were excluded from the *flood hazard*.

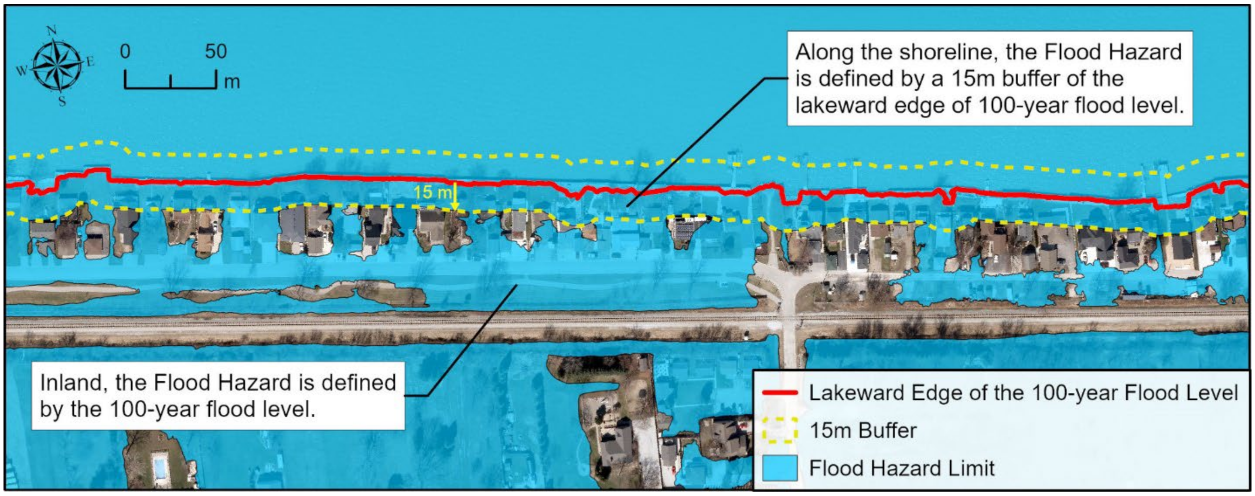


Figure 5.6 Flood hazard limit based a wave uprush horizontal setback

Figure 5.7 Flood hazard limit for Detroit River reaches

Regardless of the mapping method employed to establish the *flooding hazard*, a minimum mapping area was established to define the smallest physical area (polygon) to be mapped. A number of factors influence the minimum mapping area such as data resolution, development potential, project scale and project scope. For this study, the minimum mapping area was defined as 200 m^2. As such, all *flooding hazard* polygons have a minimum size of 200 m^2.

Although the methodology outlined in this section for mapping the 100-year flood level (Scenarios A, B, C and D) and the *flooding hazard* (Scenarios A and B only) was generally followed for the entire Essex Region shoreline, certain localized areas required professional judgement, including where the transitions between the different mapping approaches should occur.

5.2 Hazard Maps and Tile Index

A standard hazard map template was developed for Essex Region at a scale of 1:2,000. To cover the mainland and island shoreline required 413 tiles. Refer to the tile index in Figure 5.8.

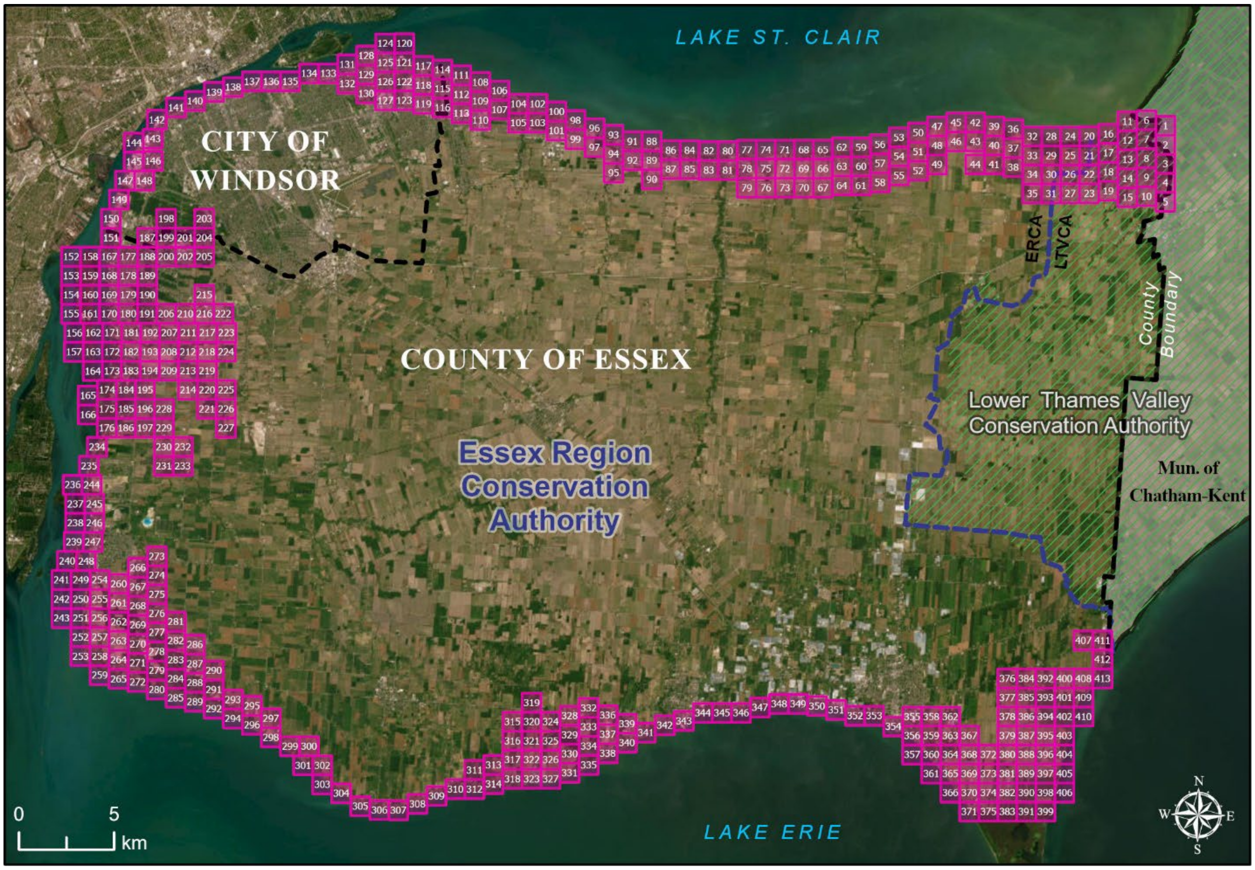


Figure 5.8 Map tile index

A sample map is provided in Figure 5.9 and includes definitions, information on datums, and data sources. They were stamped by the two professionals who supervised the map production (P. Zuzek and S. Logan). Refer to Appendix A for the remaining maps.

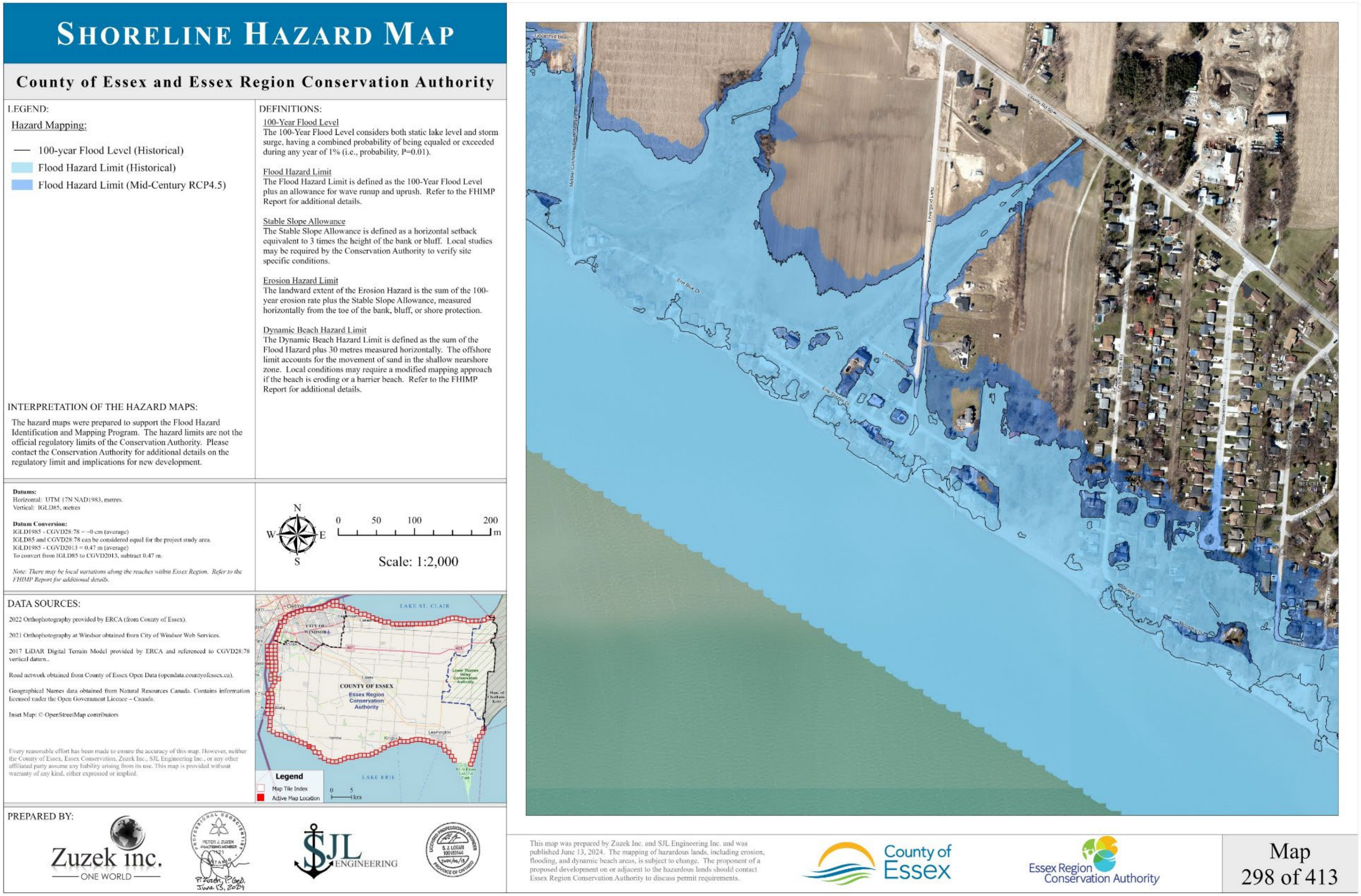


Figure 5.9 Sample Hazard Map

5.3 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 periods of extreme lake levels and storm activity are experienced. This is particularly important for the *erosion hazard* limit, since an eroding shoreline will make the static hazard lines generated in this study 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 of the PPS 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 of Ontario on how climate change impacts should be incorporated into *flooding, erosion* and *dynamic beach hazard* mapping. A draft version of the Technical Guide (Zuzek Inc., 2023) has been prepared and is presently in government review (and thus not published). The methodology followed for inclusion of the projected impacts of climate change in shoreline hazard mapping in this report followed the methodologies outlined in the draft updated Technical Guide.

Notwithstanding the above, the following climate change impacts and potential policy updates should be monitored, with the appropriate updates or actions related to the hazard mapping pursued as necessary in the future:

- Updates to the *Conservation Authorities Act* and the release of the updated *Technical Guide* mandating 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 levels used for this study.

- Ice cover reductions and increased storm activity lead to recession rates higher than those 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 of the *flooding hazard*).

6.0 KNOWLEDGE SHARING WITH COMMUNITY

Section 6.0 summaries the five public open house meetings held in December 2023 to present the draft hazard mapping to the communities of Essex Region.

6.1 County of Essex Webpage

The County of Essex developed a webpage to keep the community informed of the flood hazard mapping update and share the meeting materials. A link to the meeting is provided below.

https://www.countyofessex.ca/en/doing-business/shoreline-natural-hazard-mapping-update.aspx

A recording of the public open house PowerPoint presentation was made available for any stakeholders not able to attend the December open houses.

6.2 Fall 2023 Stakeholder Meetings

Five open house meetings were executed in the study area from December 4th to 7th, 2023 in the communities of Belle River, Lasalle, Harrow, Leamington, and the Town of Essex. When signing in on arrival, all the meeting attendees were given a colour coded dot by date to add to the study area map. Refer to the results in Figure 6.1.

Figure 6.1 Study Area map with dots for attendees

Seven technical posters were developed and used at every meeting. In addition, three sample hazard maps representative of the meeting area were also generated. Refer to Figure 6.2 for a sample of the discussions at the poster displays. Copies are provided in Appendix B.

The draft flood hazard mapping was also available online at an ArcGIS site, which enabled the attendees to observe the new flood mapping their area of interest. The interactive mapping generated a lot of interest from the attendees. The site will remain live for the communities to observe the draft mapping until the completion of the FHIMP study, then the layers will be hosted on the County of Essex and Essex Region Conservation Authority websites.

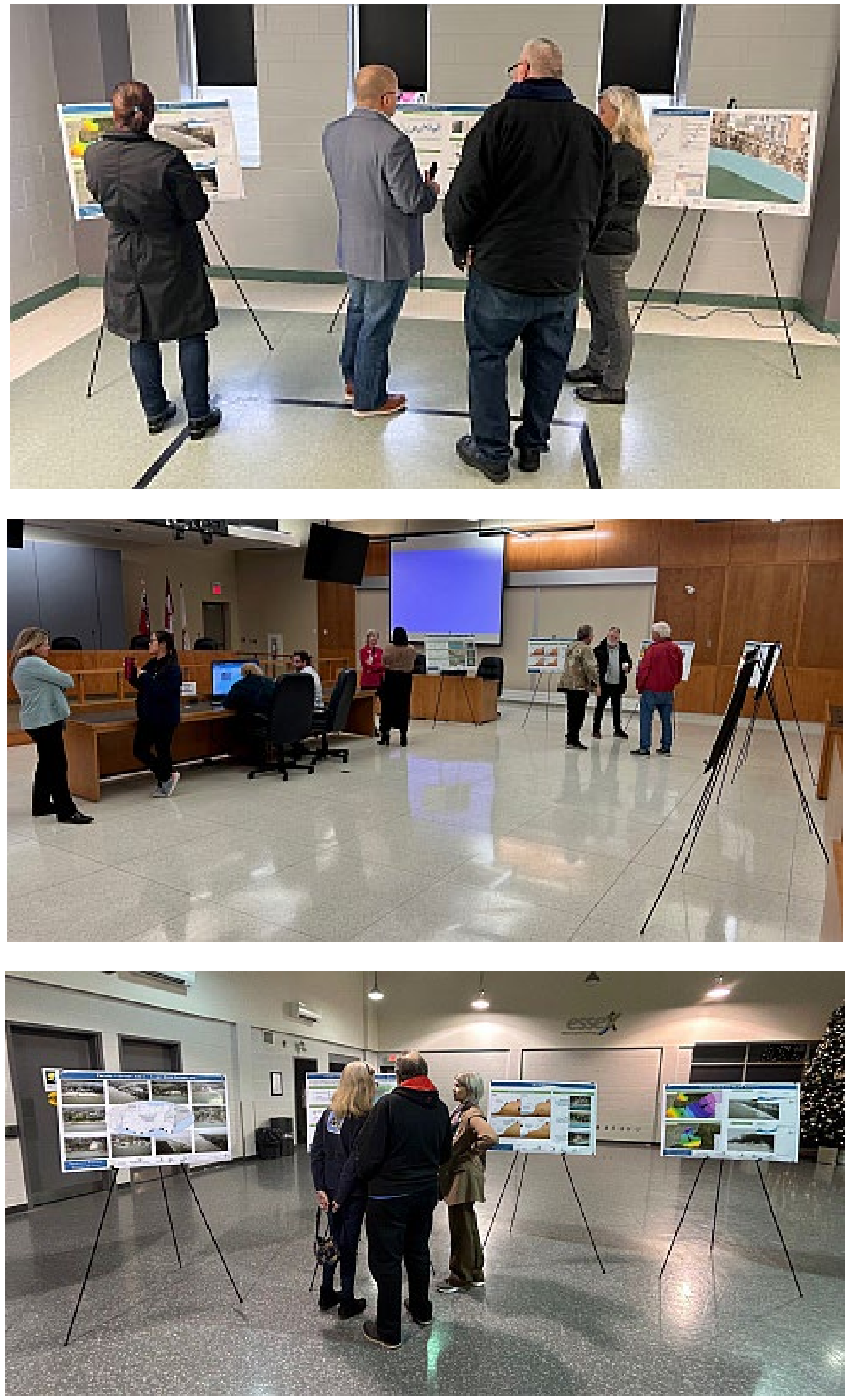


Figure 6.2 Poster displays at public open house meetings (Top: Harrow; Middle: Leamington; Bottom: Town of Essex)

Figure 6.3 Demonstration of interactive online web mapping application

7.0 CONCLUSIONS

The key findings from the *flood hazard* mapping update completed for the Essex Region shoreline on Lake St. Clair, the Detroit River, and Lake Erie are summarized as follows:

- The historical 100-year flood level for the Belle River, Bar Point, and Kingsville water level gauges, originally reported in MNR (1989), were updated with recorded water levels up to 2022. The levels were 176.22 m, 175.71 m, and 175.62 m IGLD'85, respectively.

- Three additional 100-year flood levels were calculated using mid- and late-century climate change projections and two emission scenarios (RCP4.5 and RCP8.5). The 100-year flood level increased by roughly 0.3 m at the three gauges for the mid-century RCP4.5 climate change water levels. When the late century climate change water levels were evaluated for emission scenario RCP8.5, the 100-year lake levels increased roughly 0.6 m over the historical levels with measured data.

- A large hydrodynamic model including the St. Clair River, Lake St. Clair, Detroit River, Lake Erie, and the Niagara River was setup and verified using measured data from the Canadian and United States of America water level gauges. The model was used to estimate gradients in storm surge and ultimately the 100-year flood level between the known values at the water level gauges.

- Spectral wave models were setup for Lake St. Clair and Lake Erie to estimate the 25- and 100-year nearshore wave conditions for the 100-year lake level based on historical extremes and the mid-century RCP4.5 climate change water levels. The wave heights were extracted at the nearshore profiles used for the wave uprush calculations.

- An updated *flood hazard* limit was mapped for the historical 100-year flood level and the mid-century climate change projection for RCP4.5 following the methodology outlined in the draft Technical Guide (Zuzek Inc., 2023). The current PPS (2020) states "Planning authorities shall prepare for the impacts of a changing climate that may increase the risk associated with natural hazards". Adopting the mid-century climate change *flood hazard* limit for the RCP4.5 emission scenario would be consistent with this recommendation in the PPS (2020).

- Municipal officials and stakeholders were engaged in five open house meetings from December 4th to 7th, 2023. The draft hazard mapping was presented in sample hazard map tiles and shared digitally with the online mapping site as outlined in Section 6.0. A pre-recorded PowerPoint presentation was looped throughout the meeting and also made available on the project website, along with the information posters.

- A total of 413 *flood hazard* maps were generated in PDF to cover the study area shoreline of Essex Region. The digital flood mapping was delivered to the County of Essex, the Essex Region Conservation Authority, and the Lower Thames Valley Conservation Authority.

REFERENCES

Clites and Lee (1998). MIDLAKES: A coordinated hydrologic response model for the middle Great Lakes. NOAA Tech. Rep. ERL GLERL-109, 48 pp.

Conservation Authorities Act (1990). Prepared by the Province of Ontario. Last updated October 1, 2021.

Conservation Ontario and Ministry of Natural Resources (2005). Guidelines for Developing Schedules of Regulated Areas. Prepared by Conservation Ontario and the Ontario Ministry of Natural Resources.

Cox, J.C. and Machemehl, J. (1986). Overland bore propagation due to an overtopping wave. Journal of Waterway, Port, Coastal and Ocean Engineering. Vol. 112, No. 1, pp. 161-163.

Dillon (1976). Essex County Shoreline Report on Erosion, Fill, and Flood Line. Prepared for Essex Region Conservation Authority.

Federal Emergency Management Agency (1991). Guidelines for Great Lakes Wave Runup Computations and Mapping. FEMA, Federal Insurance Administration, Washington, D.C.

International Joint Commission (2012). International Upper Great Lakes Study – Lake Superior Regulation: Addressing Uncertainty in Upper Great Lakes Water Levels. Final Report to the International Joint Commission, March 2012.

MNR (1989). Great Lakes System Flood Levels and Water Related Hazards. Prepared by Conservation Authorities and Water Management Branch, Ontario Ministry of Natural Resources.

MNR (2001a). Technical Guide for Great Lakes – St. Lawrence River Shorelines. Prepared by the Province of Ontario.

MNR (2001b). Understanding Natural Hazards: Great Lakes - St. Lawrence River System and large inland lakes, river and stream systems and hazardous sites. Ontario, Canada.

Planning Act (1990). Planning Act of Ontario. Amended 2022.

PPS (2020). Provincial Policy Statement. Available from: https://www.ontario.ca/page/provincial-policy-statement-2020.

Seglenieks and Temgoua (2022). Future Water Levels of the Great Lakes under 1.5 C and 3.0 C Warner Climates. Journal of Great Lakes Research, 48 (865-875).

Stantec (2022). Municipality of Lakeshore Shoreline Management Plan Final Report. Prepared for the Municipality of Lakeshore.

Zuzek Inc. (2021). Southeast Leamington Graduated Risk Floodplain Mapping Project. Prepared for the Municipality of Leamington.

Zuzek Inc. (2022). Town of Tecumseh Coastal Flood Risk Assessment. Prepared for the Town of Tecumseh.

Zuzek Inc. (2023). Updated Great Lakes St. Lawrence River Technical Guide. Prepared for the Ministry of Natural Resources and Forestry.

APPENDIX A – Hazard Maps

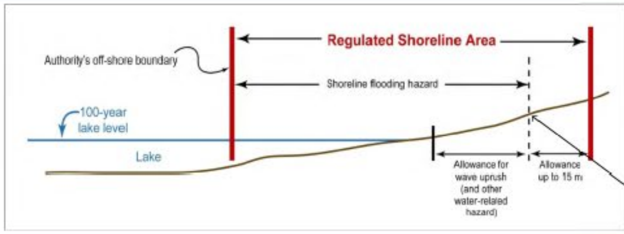
(*not included with this version of the report*)

APPENDIX B - Posters

Shoreline Natural Hazard Mapping Definitions

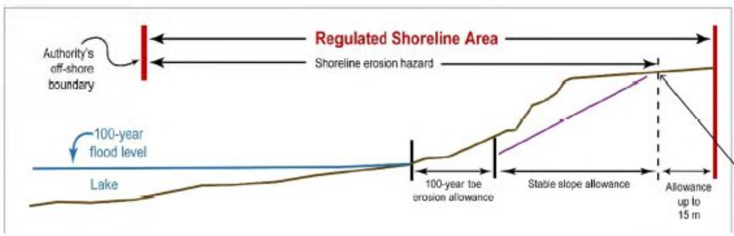
Natural hazards affecting Great Lakes shorelines are defined in the Technical Guidelines for Great Lakes – St. Lawrence River Shorelines (MNR, 2001) and the Guidelines for Developing Schedules in Regulated Areas (CO and MNR, 2005).
The *Regulated Area* is determined by the greatest landward extend of the hazardous lands plus an additional allowance determined by the Authority (maximum 15 m).

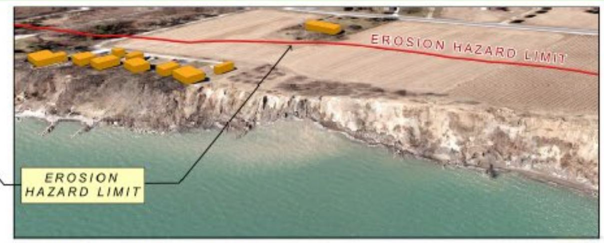
Flooding Hazard




Flooding in Essex County (Photo obtained from windsornewstoday.ca)

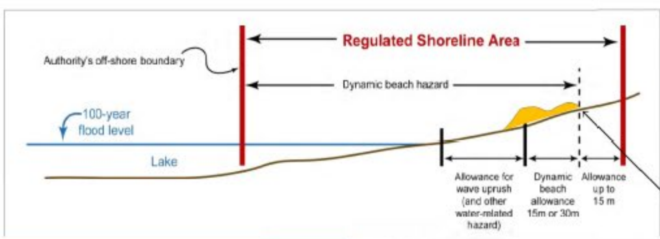
Erosion Hazard






Bluff erosion east of Colchester

Dynamic Beach Hazard



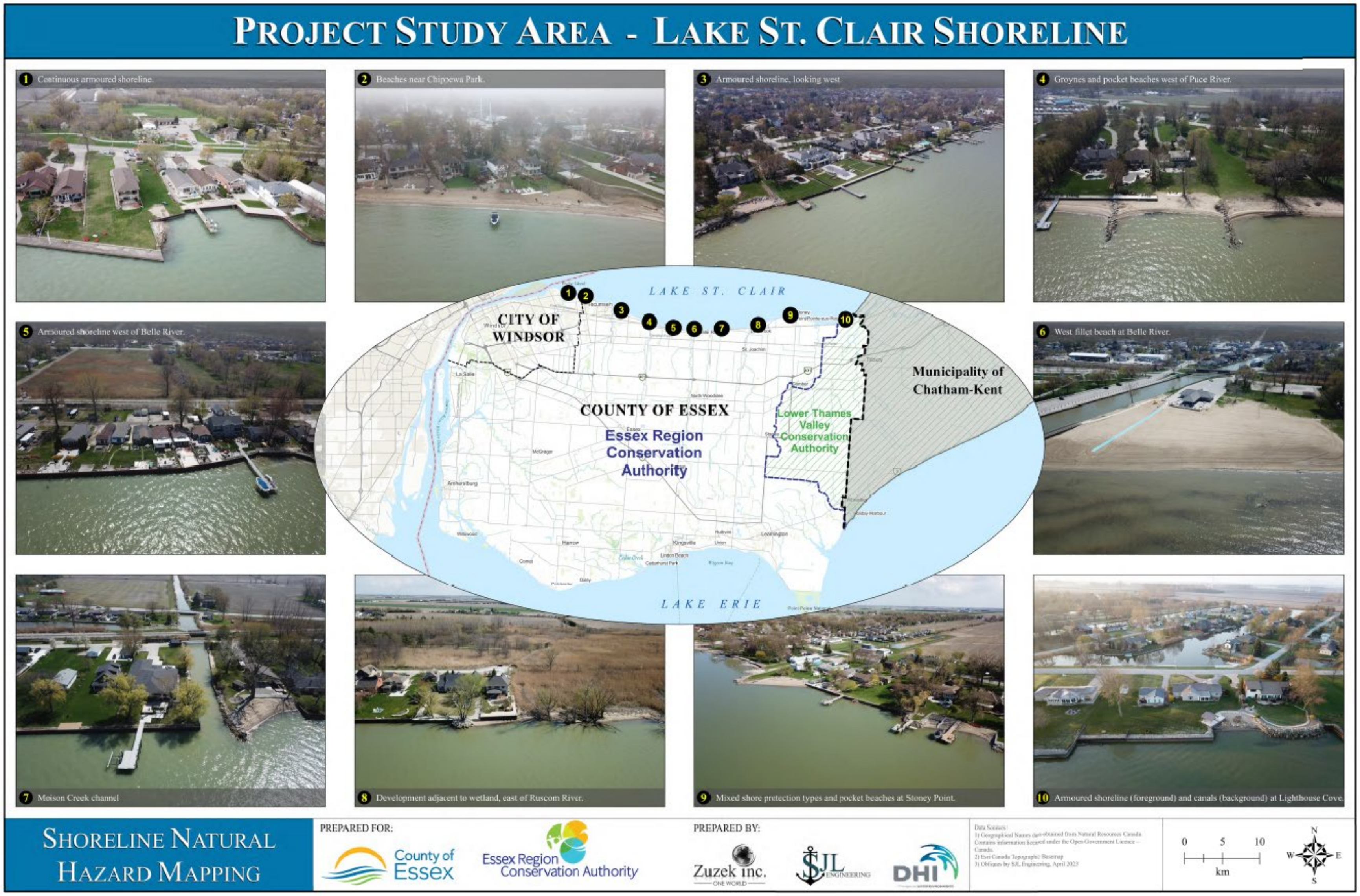

Dynamic beach environment at Belle River

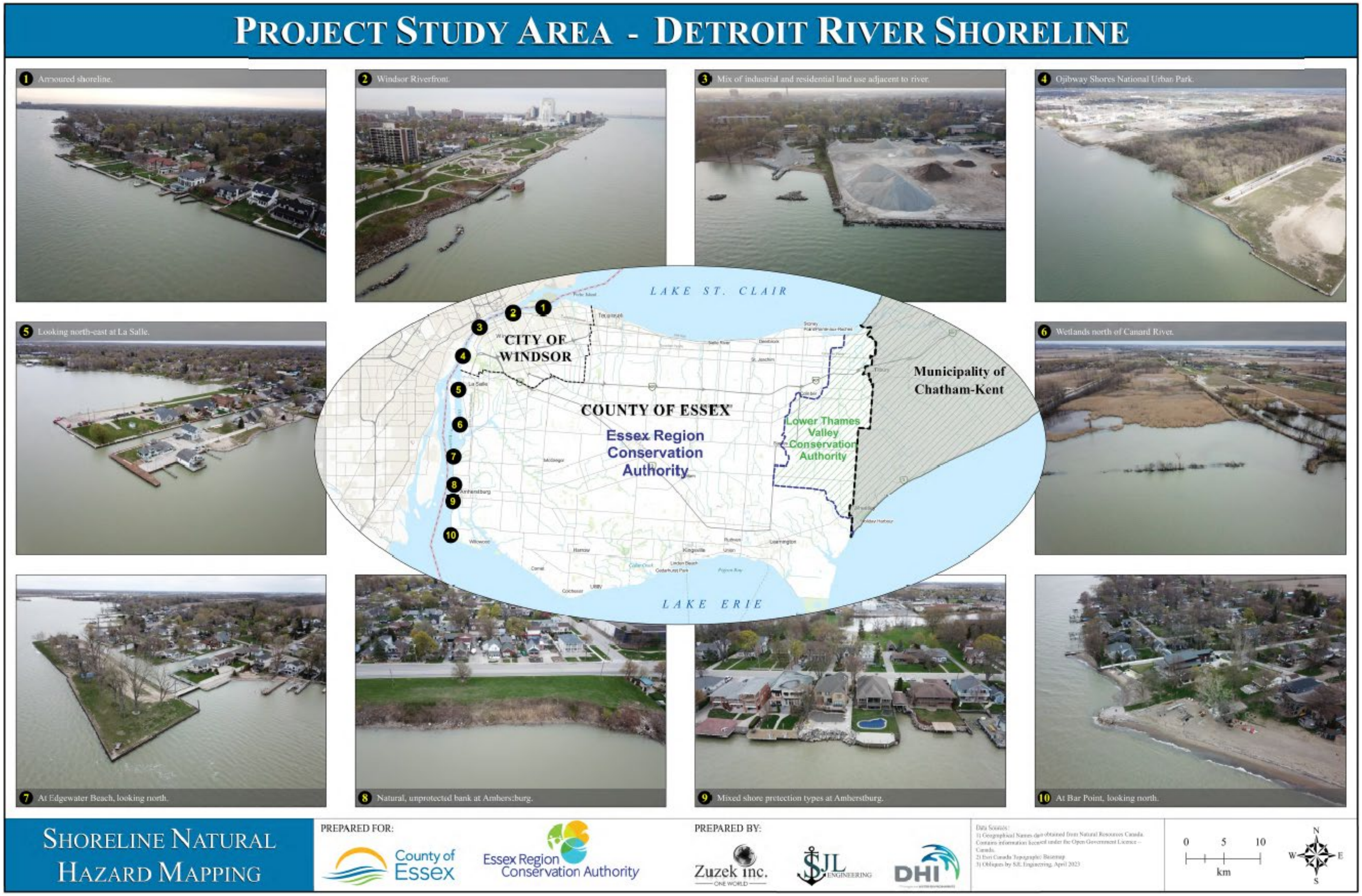
Shoreline Natural Hazard Mapping

PREPARED FOR: County of Essex; Essex Region Conservation Authority

PREPARED BY: Zuzek Inc.; SJL Engineering; DHI

Note: Hazard definitions from 'Guidelines for Developing Schedules of Regulated Areas (Conservation Ontario and Ministry of Natural Resources, October 2005)'.

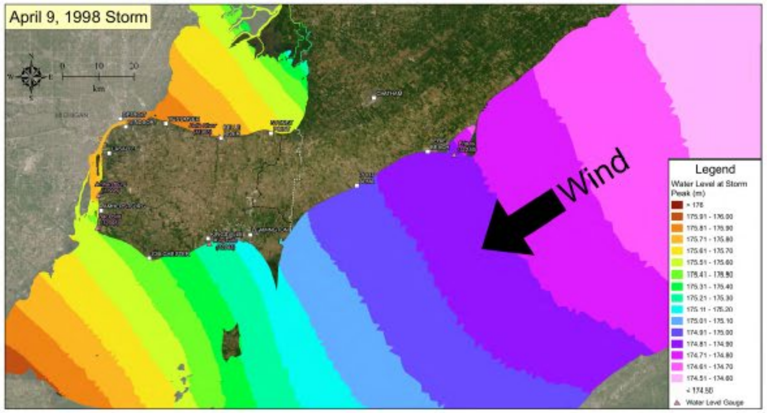

PROJECT STUDY AREA - LAKE ST. CLAIR SHORELINE
1 Continuous armoured shoreline.
2 Beaches near Chippewa Park.
3 Armoured shoreline, looking west
4 Groynes and pocket beaches west of Puce River.
5 Armoured shoreline west of Belle River.
6 West fillet beach at Belle River.
7 Moison Creek channel
8 Development adjacent to wetland, east of Ruscom River.
9 Mixed shore protection types and pocket beaches at Stoney Point.
10 Armoured shoreline (foreground) and canals (background) at Lighthouse Cove.
LAKE ST. CLAIR
CITY OF WINDSOR
COUNTY OF ESSEX
Essex Region Conservation Authority
Lower Thames Valley Conservation Authority
Municipality of Chatham-Kent
LAKE ERIE
SHORELINE NATURAL HAZARD MAPPING
PREPARED FOR:
County of Essex
Essex Region Conservation Authority
PREPARED BY:
Zuzek Inc.
SJL ENGINEERING
DHI
Data Sources:
1) Geographical Names data obtained from Natural Resources Canada. Contains information licensed under the Open Government Licence – Canada.
2) Esri Canada Topographic Basemap
3) Obliques by SJL Engineering, April 2023
0 5 10
km
N
W E
S


PROJECT STUDY AREA - DETROIT RIVER SHORELINE
1 Armoured shoreline.
2 Windsor Riverfront.
3 Mix of industrial and residential land use adjacent to river.
4 Ojibway Shores National Urban Park.
5 Looking north-east at La Salle.
6 Wetlands north of Canard River.
7 At Edgewater Beach, looking north.
8 Natural, unprotected bank at Amherstburg.
9 Mixed shore protection types at Amherstburg.
10 At Bar Point, looking north.
LAKE ST. CLAIR
CITY OF WINDSOR
COUNTY OF ESSEX
Essex Region Conservation Authority
Lower Thames Valley Conservation Authority
Municipality of Chatham-Kent
LAKE ERIE
SHORELINE NATURAL HAZARD MAPPING
PREPARED FOR:
County of Essex
Essex Region Conservation Authority
PREPARED BY:
Zuzek Inc.
SJL ENGINEERING
DHI
0 5 10
km

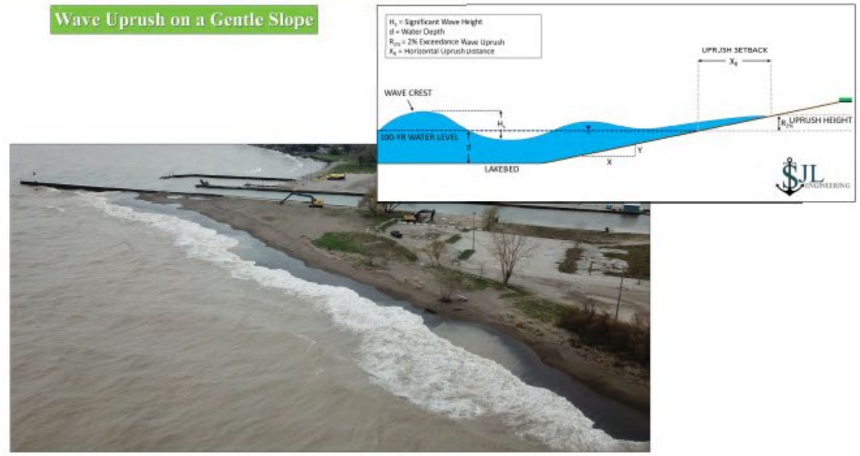

PROJECT STUDY AREA - LAKE ERIE SHORELINE
1 Houses on the barrier beach at Big Creek.
2 Vertical sea wall shore protection.
3 Naturally eroding bluff east of Colchester.
4 Wide fillet beaches at Cedar Creek.
5 Low plain shoreline west of Kingsville.
6 High vegetated bluff west of Leamington.
7 Toe protection and regrading of steep bluff.
8 Ad-hoc armour stone revetment spanning several properties.
9 Looking north-east from Marentette Drain.
10 Near Wheatley Harbour, looking south-west.
LAKE ST. CLAIR
CITY OF WINDSOR
COUNTY OF ESSEX
Essex Region Conservation Authority
Lower Thames Valley Conservation Authority
Municipality of Chatham-Kent
LAKE ERIE
SHORELINE NATURAL HAZARD MAPPING
PREPARED FOR:
County of Essex
Essex Region Conservation Authority
PREPARED BY:
Zuzek inc.
SJL ENGINEERING
DHI
Data Sources:
1) Geographical Names data obtained from Natural Resources Canada
Contains information licensed under the Open Government Licence – Canada.
2) Esri Canada Topographic Basemap
3) Obliques by SJL Engineering, April 2023
0 5 10
km
N
W E
S

Storm Surge and Wave Effects

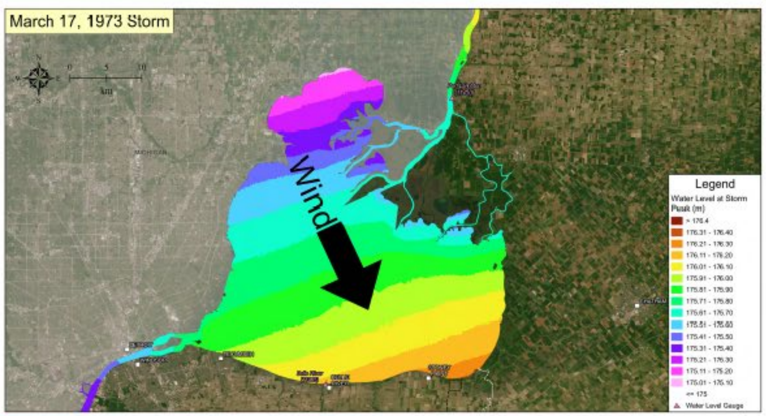
Strong Winds from the Northeast Push Water Southwest Resulting in Storm Surge



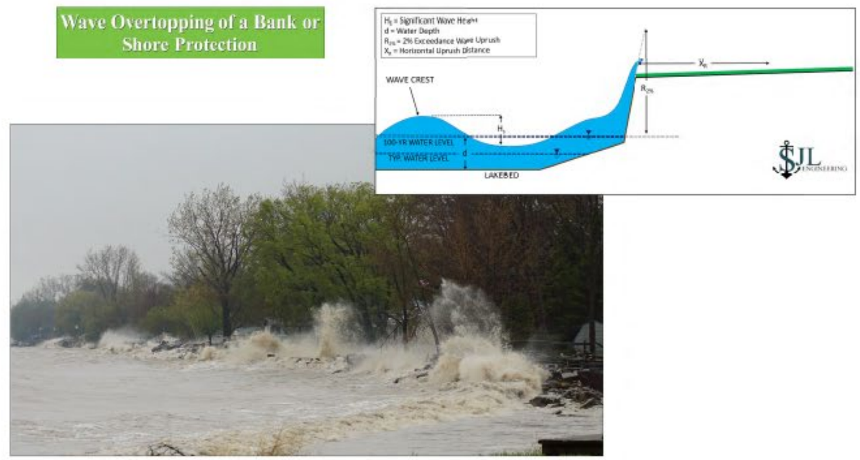
Wave Uprush on a Gentle Slope



Strong Winds from the Northwest Push Water Southeast Resulting in Storm Surge



Wave Overtopping of a Bank or Shore Protection



Shoreline Natural Hazard Mapping

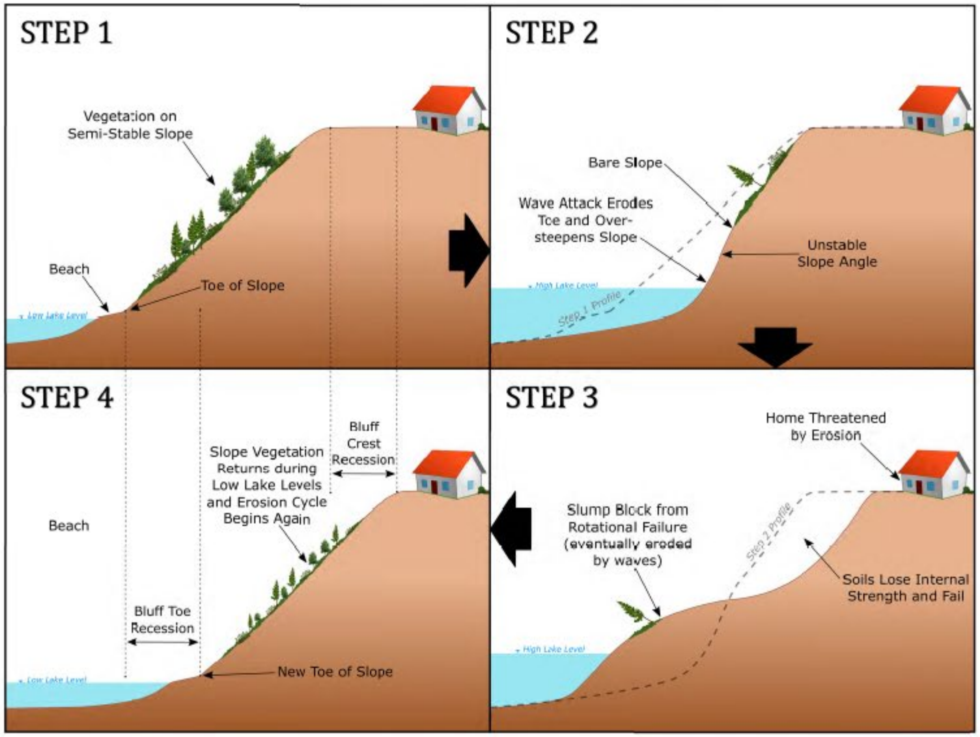
PREPARED FOR: County of Essex; Essex Region Conservation Authority

PREPARED BY: Zuzek Inc.; SJL Engineering; DHI

Data Sources:
1) Storm surge modelling results provided by DHI.
2) Oblique image provided by SJL Engineering Inc.
2) Uprush and overtopping graphics provided by SJL Engineering Inc.

BLUFF EROSION

The Bluff Erosion Process:



Example from Lake Huron:

Onset of Step 2
Wave attack has eroded the bluff toe and some stairs are damaged


April 2016

Step 2
Bluff slope is over-steepened and stairs to beach were lost


July 2021

Step 3
Bluff slope failed and homes threatened


May 2022

SHORELINE NATURAL HAZARD MAPPING

PREPARED FOR: County of Essex; Essex Region Conservation Authority

PREPARED BY: Zuzek Inc.; SJL Engineering; DHI

Data Sources:
1) 2016 and 2021 oblique imagery provided by Maitland Conservation.
2) 2022 oblique imagery provided by SJL Engineering Inc.

Note - houses have been intentionally masked to provide anonymity to homeowners.

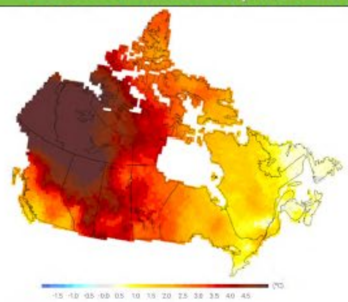
CLIMATE CHANGE IMPACTS

2020 PROVINCIAL POLICY STATEMENT

3.1 Natural Hazards:

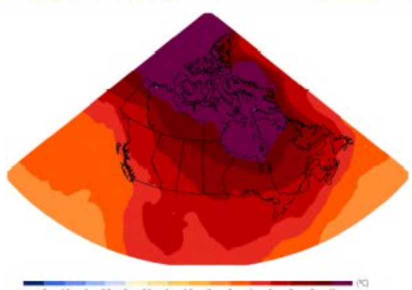
3.1.3 Planning authorities shall prepare for the impacts of a changing climate that may increase the risk associated with natural hazards.

1948 to 2012 Winter Air Temperature Increase



Source: Vincent et al. 2015. In 'Zhang, X., Flato, G., Kirchmeier-Young, M., Vincent, L., Wan, H., Wang, X., Rong, R., Fyfe, J., Li, G., Kharin, V.V. (2019): Changes in Temperature and Precipitation Across Canada; Chapter 4 in Bush, E. and Lemmen, D.S. (Eds.) Canada's Changing Climate Report. Government of Canada, Ottawa, Ontario, pp 112-193'.

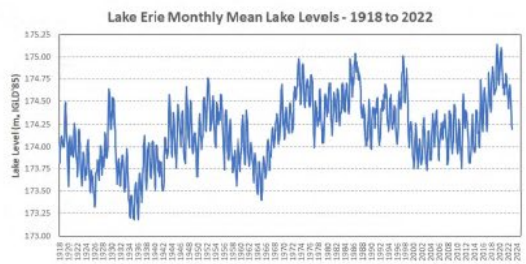
Late Century (2081-2100) Projected Winter Air Temperature Increase



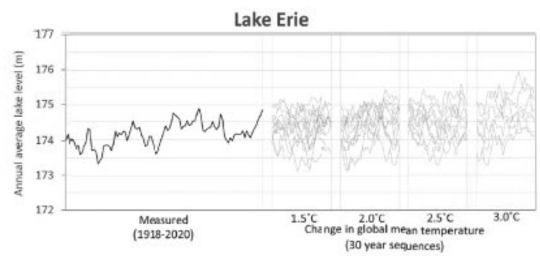
Note: Projection for RCP8.5 Emission Scenario

Source: Climate Research Division, Environment and Climate Change Canada. In 'Zhang, X., Flato, G., Kirchmeier-Young M., Vincent, L., Wan, H., Wang, X., Rong, R., Fyfe, J., Li, G., Kharin, V.V. (2019): Changes in Temperature and Precipitation Across Canada; Chapter 4 in Bush, E. and Lemmen, D.S. (Eds.) Canada's Changing Climate Report. Government of Canada, Ottawa, Ontario, pp 112-193'.

Historical Measured Lake Levels

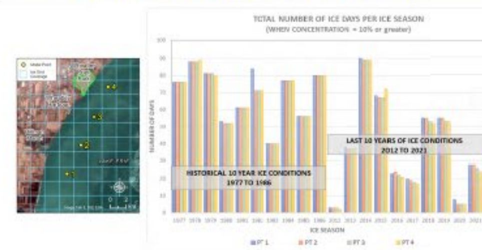


Future Climate Change Lake Level Projections

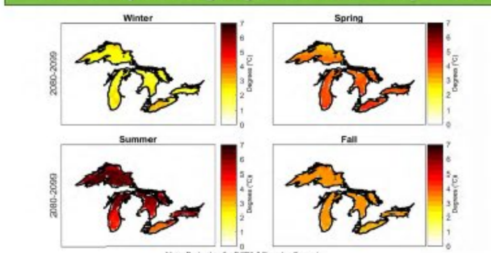


Source: Seglenieks and Temgoua (2022). Future water levels of the Great Lakes under 1.5 C and 3 C warmer climates. Journal of Great Lakes Research

Example of Ice Loss with a Warming Winter



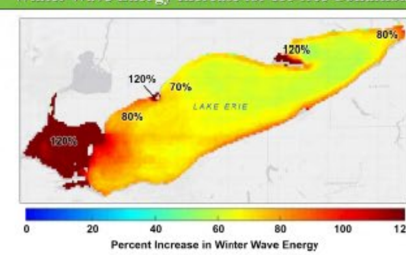
Late Century Warming Projections for Lake Temperature



Note: Projection for RCP8.5 Emission Scenario

Source: Seglenieks and Temgoua (2021). Future hydroclimate variables and lake levels for the Great Lakes using data from the Coupled Model Intercomparison Project Phase 5 (draft). Environment and Climate Change Canada.

Winter Wave Energy Increase for Ice-free Conditions



SHORELINE NATURAL HAZARD MAPPING

PREPARED FOR: County of Essex, Essex Region Conservation Authority

PREPARED BY: Zuzek inc., SJL Engineering, DHI