Lake Simcoe Shoreline Hazard Mapping

Final Report

April 4, 2024 | 13671.101.R1.Rev2

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13671.101.R1.Rev2

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Revision	Date	Status	Comments	Prepared	Reviewed	Approved
RevA	2023/02/21	Draft	For client review	DCW/SES	FJLD/MD	DCW
Rev0	2024/03/11	Final	Responding to comments	DCW	SES	DCW
Rev1	2024/03/25	Final	Minor edits	DCW	SL	DCW
Rev2	2024/04/04	Final	AODA compliance adjust.	DCW	AD/EP	DCW

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Executive Summary

Baird & Associates was retained by the Lake Simcoe Region Conservation Authority (LSRCA) to provide updated mapping for erosion and flooding hazards around the shore of Lake Simcoe. Hazards were assessed for the entire lake, and regions with similar conditions were grouped into reaches. A total of 29 reaches were identified around the perimeter of the lake, with an additional nine reaches identified for islands (38 reaches total).

The flood hazard assessment included assessing regional historical recorded water levels and the water level management scheme for the lake. Based on this assessment, a 100-year still water level of 219.50 m CGVD28 was selected for the lake. The impacts of storm surge and waves are then considered for a storm that occurs at this lake level.

Waves and storm surge on Lake Simcoe were assessed using the numerical model MIKE21 with available bathymetric data, including Canadian Hydrographic Service multi-beam bathymetry and satellite derived bathymetry in the shallower regions of the lake. Wave heights were assessed with the MIKE21 Spectral Wave model using a sustained 20-year wind speed generating waves on the lake. The MIKE21 Flexible Mesh Hydrodynamic model was used to assess storm surge on the lake during similar conditions. This combination of the 100 year water level and the 20 year wave/surge condition were used to define the flood hazard around the lake. The results of this model were extracted, and a representative wave height and surge level was determined for each of the 38 reaches.

The final phase of flooding at the shoreline is undertaken through an assessment of wave runup and overtopping. This is applied using a representative cross section of the shoreline and a combination of the models “CSHORE” (for gently sloped areas) and “EurOtop” (for areas with structures). In most areas that may be flood-prone, the nearshore part of the lake is fairly flat and shallow, and the surrounding land is also typically at a low slope. In many of these areas, the limit of inland wave action is defined by a combination of wave runup height along the shore, and the extent to which a wave may propagate inland over relatively flat land (for example across a residential lawn fronted by a riprap revetment).

In most cases, the extent of inland wave propagation above the 100 year water level was relatively small, and the recommended minimum of a 5 m flood allowance was a conservative estimate of the inland wave propagation. Only in limited areas was the inland flooding greater than this 5 m default minimum allowance.

The shoreline erosion hazard was also assessed based on historical shoreline positions along undeveloped shorelines. After identifying regions of natural shoreline, aerial photographs were reviewed from the 1960’s and from recent data (2018 to 2021) and shoreline recession rates were found to average about 0.07 m/yr, with one site at 0.135 m/yr. These sites are all less than the 0.15 m/yr minimum value recommended by the Technical Guide (MNR, 1996). Consequently, a 100 year erosion allowance of 15 m (0.15 m/yr for 100 years) was applied around the lake. A stable slope allowance was also applied based on a 3:1 (H:V) slope from the shore of the lake.

Another hazard that was assessed for the study area was the dynamic beach hazard. Dynamic beaches are features that can shift or realign rapidly in response to higher wave events and can cause rapid erosion in some areas. Dynamic beaches are characterized as being more than 100 m in length, more than 10 m in width (above water), and more than 0.3 m thick. Furthermore, these beaches are located in regions that have fetches greater than 5 km. The Lake Simcoe shoreline was reviewed and was found to have no natural beaches that met these criteria. Consequently, the dynamic beach hazard is not mapped for Lake Simcoe.

The impacts of climate change were also reviewed with respect to the potential impacts on flooding and erosion. The largest impact is expected to be a future reduction in ice cover, which would result in more wave action in the winter, when the water levels are typically lower. Furthermore, the management of water levels on the Trent Severn system provides some ability to respond to changes in the climatic conditions. There is little evidence that anticipated climate change impacts will have any significant influence on the flooding or erosion hazard on Lake Simcoe.

Shapefiles that represent the erosion and flooding hazards were delivered to the LSRCA as part of this study, and these shapefiles will be used to update the mapping for the region. The revised hazard lines are generally similar to the lines represented in past mapping (1978 and 1981).

When applying these results to sites around Lake Simcoe, it is important to consider that these values are all developed on a reach basis, and site specific conditions could result in variation from the regional recommendations. Furthermore, topographic and bathymetric details were limited in their resolution, which will need to be considered in site-specific assessments.

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1. Introduction

The purpose of the Lake Simcoe Shoreline Hazard Mapping Project is to update the Lake Simcoe flood and erosion hazard mapping to current mapping and technical standards. The study area covers over 300 linear kilometres of shoreline inclusive of the islands of Lake Simcoe. Current and accurate hazard mapping will enhance risk characterization to inform land use, emergency management, and infrastructure planning. This project will help to create a more resilient and safer shoreline community in the face of changing climate conditions.

1.1 Background

The existing hazard mapping for Lake Simcoe was completed in 1978 by Marshall Macklin Monaghan (MMM, 1978). The MMM study focused on the southern shores of Lake Simcoe. The remainder of Lake Simcoe was addressed in the 1981 study by the same group using similar methods.

These earlier studies used different approaches from those used in this study. Effective fetches were computed along with representative depths; however, the study did not appear to consider the impacts of the shallow, depth-limited wave conditions along the shoreline. It is unclear what topographic data were used in the past study; however, we believe it was an earlier and more approximate (coarse) elevation dataset.

When a development application is submitted, development that falls within the hazard limit, or within the 15 m buffer extension inland of the hazard limit, is identified for further review.

1.2 Study Approach

Hazard mapping is used to delineate the regions where flooding and erosion could be an issue for development. This hazard mapping study made use of numerical modeling to better predict the wave conditions and storm surge on Lake Simcoe. The study area was divided into 29 reaches along the lake shore, and nine more reaches along island shorelines. Since the analyses are not being completed on a property by property basis, it is necessary to have some conservatism in the hazard zone delineation. This conservatism was applied in two ways:

- by using slightly conservative assumptions for each reach; and
- by including a 15 m buffer along the landward extent of the hazards to define a regulation limit that is broader than the approximately defined hazard limit.

For the flood hazard mapping, wave height and surge values were then combined with numerical techniques to assess wave runup for steeper slopes and structures (EurOtop) or for more gently sloped beach areas (CSHORE).

The erosion hazard limit was defined by determining an appropriate shoreline recession rate along the lakeshore, and then considering a stable slope of 3:1 from the newly eroded toe position.

The topography data around the lake varied significantly in its level of detail; in some regions there is detailed LiDAR-derived topography, while in other regions coarser photogrammetry based data are available from earlier studies. The variable density of the data and variable conditions within many reaches led to an approach where the mapping focused more on the inland extent of the wave action from a high water line, rather than using a wave runup elevation. This reduced the extent to which unrealistic inland wave propagation was predicted. The same topographic information was used for the erosion hazard mapping.

The result from this process is a set of revised hazard limits for both erosion and flooding. The landward extent of these limits was then offset by 15 m inland to define the regulation limit along the shoreline.

Section 2 of this report provides an overview of the available data. Sections 3 describes the numerical modeling completed to develop the flood hazard mapping and Section 4 describes the erosion hazard limit. Section 5 discusses the dynamic beach hazard in the area. Details of the reach delineation and the hazard mapping approach are provided in Sections 6 and 7 respectively. An assessment of the impacts of climate change are presented in Section 8 and a discussion of the impacts of shoreline development are provided in Section 9.

2. Data Overview

2.1 Vertical Datums

Data provided by the LSRCA and other agencies were provided in CGVD28. This includes topographic elevation data, and water level data. The only data that were obtained in a different vertical datum were the field data, which were collected in CGVD 2013 and then adjusted to CGVD28. Unless otherwise stated, all elevations in this report are in CGVD28.

2.2 Water Level Data

2.2.1 Daily Data

Daily mean water level data for Lake Simcoe are available from Parks Canada for the period 1960 to February 2022 and are defined in Canadian Geodetic Vertical Datum 1928 (CGVD28). Gauging locations vary over the period of record and include Jackson's Point (1960 – 2022) and Atherley (1998 – 2022) (Figure 2.1). When readings were available from both gauges, the water level was defined as the average of the two. The advantage of having two locations is that there are minimal gaps in the data.

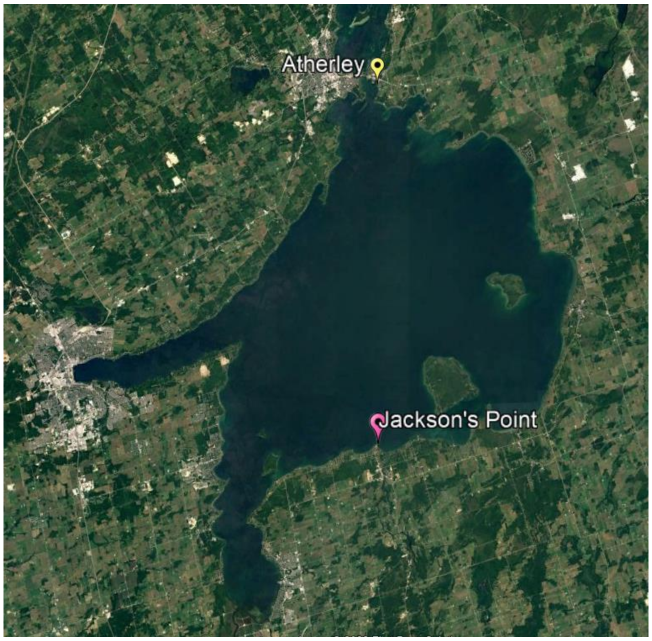

Figure 2.1: Water Level Gauges on Lake Simcoe

Water levels were not available at a more frequent time interval, and therefore it was not possible to assess fluctuations in the water level (such as storm surge) with these data.

Water levels in Lake Simcoe are a result of inflow, outflow, precipitation and evaporation. Lake Simcoe is part of the Trent-Severn Waterway system and water levels are managed. Water level management generally follows a "Rule Curve", as shown in Figure 2.2. The rapid rise in water levels in March/April is associated with melting snowpack and the spring freshet from the inflowing tributaries. The target level is about 35 cm above

Chart Datum (CD), which is defined as 218.72 m CGVD28. The gradual decline in the target water level throughout the summer is associated with the supply of water to the Trent Severn system to support navigation.

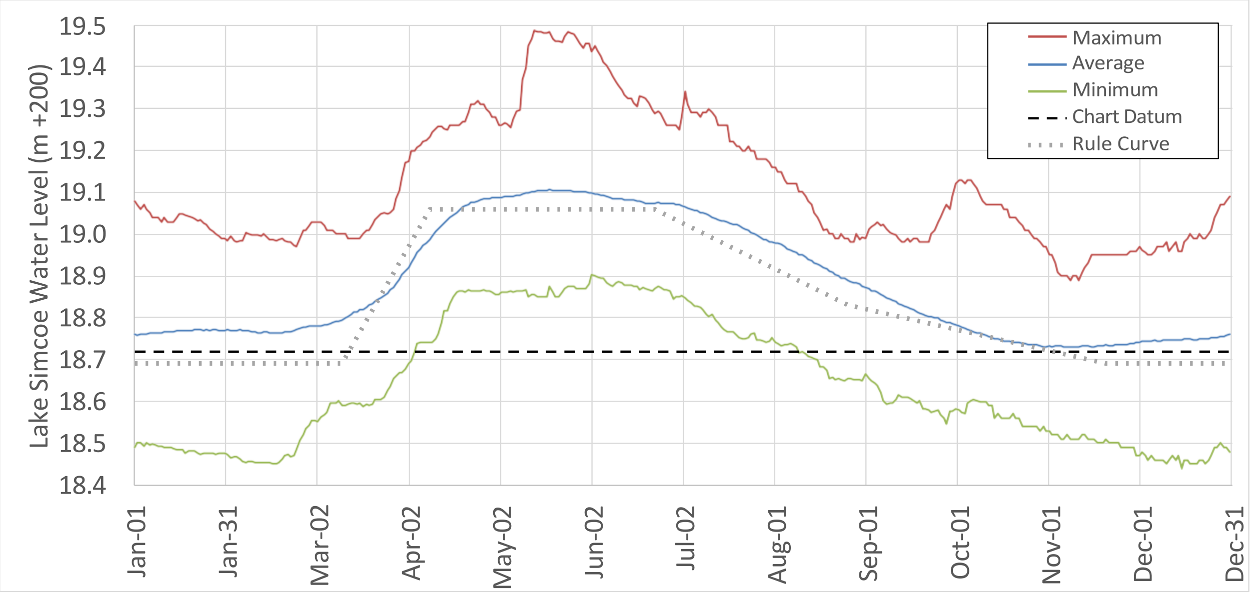

Figure 2.2: Water Level Patterns on Lake Simcoe

One interesting feature of Lake Simcoe water levels is that the highest water levels (April through August) typically occur during some of the least stormy months of the year. This can be compared to the wind data, which indicates that the most severe storm events occur during the fall and winter months when the water levels are the lowest.

2.2.2 Annual Extremes

Annual extreme water levels were also provided from 1912 to 2021 (Figure 2.3). Note that water level management as part of the Trent Severn started in 1916. Therefore 1912 to 1915 was removed for the statistical analysis of the extreme water levels. A review of the data suggests that the extreme high levels are less prevalent in recent years (1970 onwards) perhaps as a result of better management of water levels.

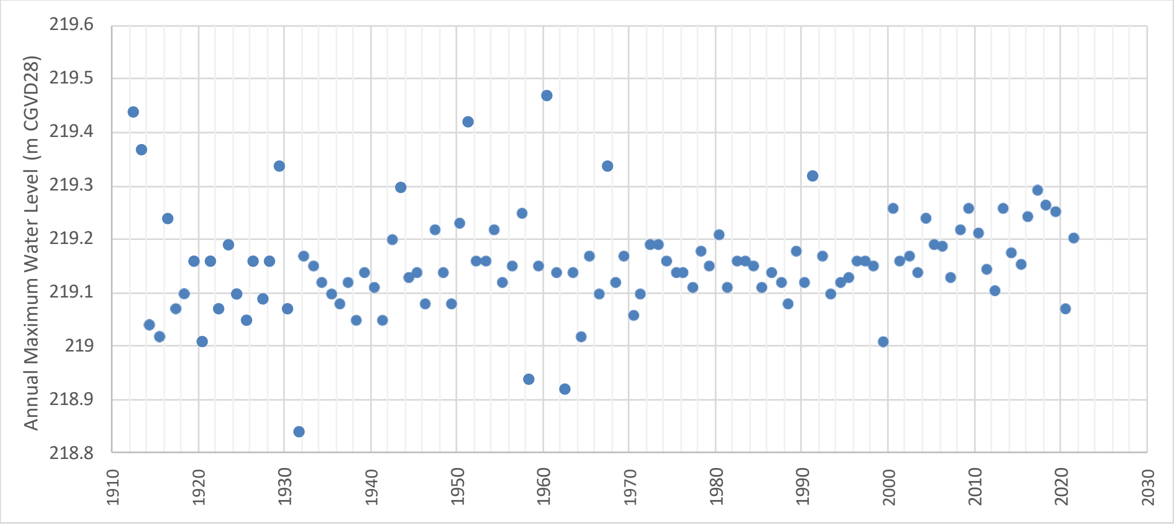

Figure 2.3: Lake Simcoe Annual Extreme Water Levels

An extreme value analysis of these data suggests a 100-year water level of 219.45 m CGVD28. Despite the visual difference in the water level extremes, a similar 100-year water level is obtained from assessing water levels from 1917 to 2021, as well as 1960 to 2021.

This assessment of water levels suggests that a lake-wide 100-year water level (without the influence of wind or waves) of 219.50 m is appropriate.

2.3 Ice Cover

Ice cover is important as it impacts the time of year over which wind-waves will be generated. Futter (2003) presents the ice cover of numerous lakes in southern Ontario, based on historical records from volunteer observers. . The dates of ice break-up on three lakes including Lake Simcoe are shown in Figure 2.4. Based on these records, ice break-up on Lake Simcoe typically occurs in April. However, these data end in 2003 and there is the potential that break-up dates may be shifting as a result of climate change impacts. A review of 2022 MODIS satellite imagery shows that ice break-up occurred around April 8, as seen in Figure 2.5. In this image Kempenfelt Bay is still ice covered (grey in colour) as is Lake Couchiching. The 2021 imagery shows a somewhat earlier ice break-up in late March (cloud obscured the actual date when reviewing satellite imagery). For this study, we have assumed that ice break-up occurs in early April.

The duration of the open water (ice-free) season is shown in Figure 2.6 (from Futter, 2003). A visual estimate through the more recent data (grey bar) suggests approximately 265 days per year of open water. This aligns with a freeze-up date of December 30th.

Therefore, for this study we have assumed that the lake is frozen from January 1 until March 31. This means that wind/wave storms within this time frame were not considered in the extreme wave analysis.

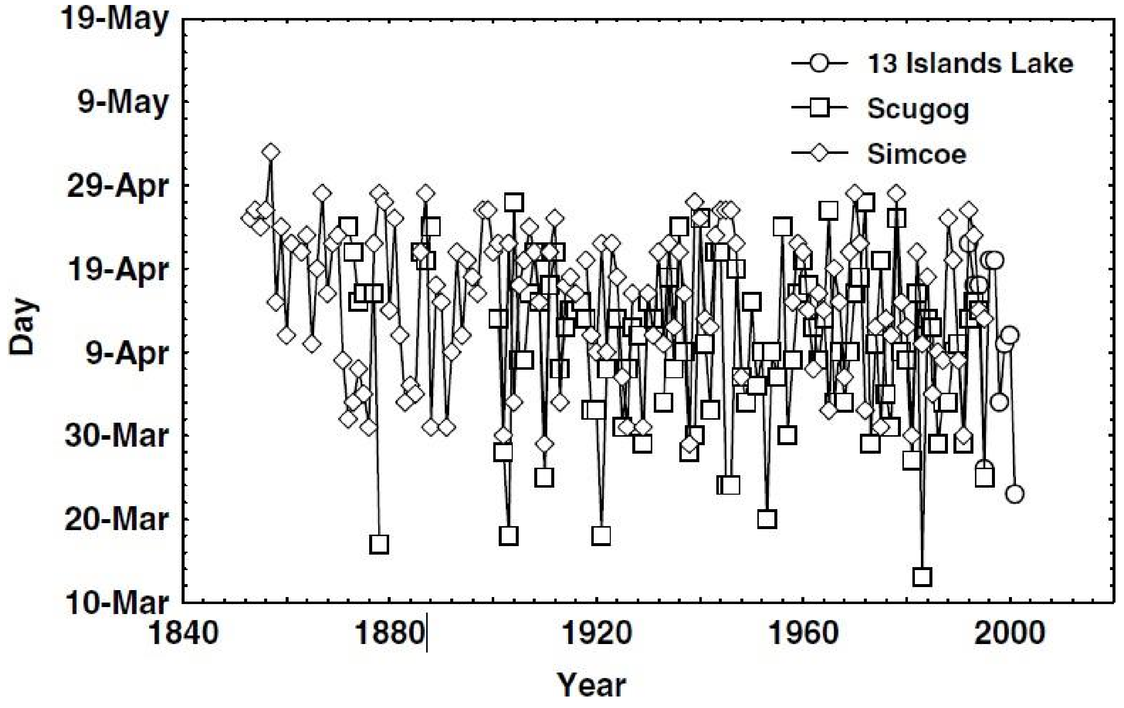

Figure 2.4: Ice Break-up Dates on Lake Simcoe (Futter, 2003)

Figure 2.5: MODIS Satellite Imagery of Lake Simcoe, April 9, 2022

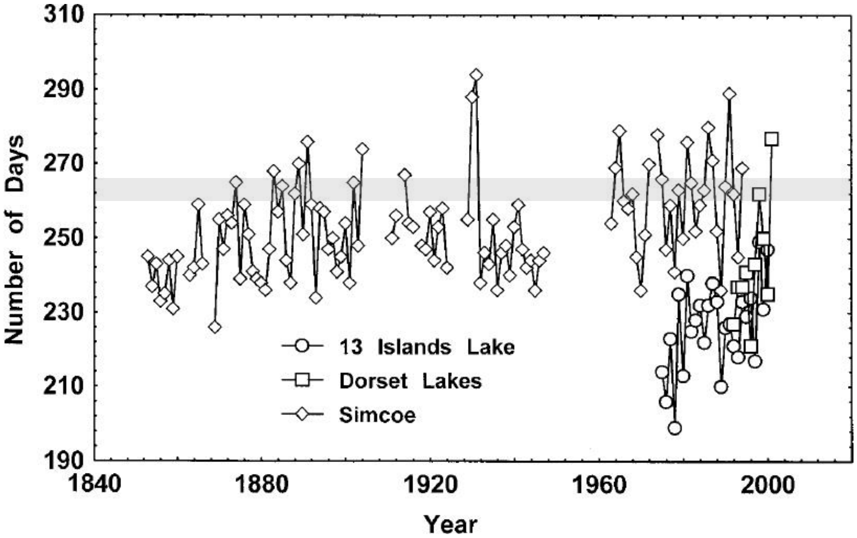

Figure 2.6: Duration of Open Water Season on Lake Simcoe (Futter, 2003)

2.4 Wind Data

Wind data are available from two nearby land stations and one buoy on Lake Simcoe. The wind stations at Barrie and Lagoon City were selected due to their proximity to the lake. The Barrie airport is located about 5.5 km from the NW shore of Lake Simcoe and has one east/west runway and reports winds since 2004. The Lagoon City anemometer has been active since 1994 and is located on the tower at the end of the south entrance jetty to Lagoon City. It is about 350 m from shore in a predominantly over-water location.

Wind data from buoy C45151 are available from 1999 until 2021. The buoy is deployed in early April to early May, and the retrieval date is early November to early December. With the strongest storms typically occurring in the fall, winter and spring, many of these events were not measured at C45151.

For wave hindcasting on Lake Simcoe, we need to know the winds over the lake; over-land and over-water winds can be quite different. Differences occur due to the increased wind friction over land (trees, buildings, etc.) as well as topographic effects. Air/lake temperature differences can also impact the over water winds. Cold water conditions (colder than the air) can result in less vertical mixing and weaker winds closer to the surface of the lake (common in the spring). Warm water conditions (warmer than the air) can increase the vertical air mixing over the lake and create stronger over-water winds than those measured on land.

A series of comparisons were completed to better understand the winds at different sites around Lake Simcoe. The conclusions were:

- The winds at Barrie are of shorter duration and were often quite different from Buoy 45151 and Lagoon City. This is probably due to the distance from the lake and local topographic effects. Barrie winds were determined to be less preferred than other locations.
- Buoy 45151 provided reasonable over-water winds but had less coverage during critical spring/fall periods.
- Lagoon City appeared to provide the most reliable wind data, although some directional discrepancies were noted compared to Buoy 45151

Data comparison were completed to determine if any scaling relationships were required to correct the wind data at Lagoon City. These comparisons showed that when winds were blowing in an onshore direction (SW quadrant) the Lagoon City winds were slightly higher than the C45151 buoy winds. This is consistent with typical differences due to anemometer heights. The standard for most land stations is to measure winds at 10 m elevation, while the standard on large buoys is 5 or 6 m elevation. Wind profiles vary with temperature (lake versus air temperature); however, a correction of 15% (buoy wind speed times 1.15) is appropriate and results were in good agreement between the buoy and Lagoon City.

When winds were blowing in an offshore direction, Lagoon City showed much lower wind speeds than the buoy, suggesting that sheltering from nearby land was reducing the wind speeds at the anemometer. To correct for this sheltering effect, it was necessary to increase the wind speeds at Lagoon City for winds blowing offshore. This scaling was used to adjust the Lagoon City winds to be equivalent to the buoy winds after increasing the buoy winds by 15% to account for the anemometer elevation.

2.5 Wave Data

Recorded wave data on Lake Simcoe are available through the Environment Canada buoy 45151, which only collects data during the ice-free season. This buoy records both wind and wave data and therefore provides the opportunity to validate the wave model, while driving the model with winds that should be reliable.

Data buoys such as 45151 on Lake Simcoe are installed by Environment Canada primarily for the purpose of monitoring meteorological parameters. Based on the selection of equipment, the buoy was not installed for the primary purpose of measuring waves and consequently the waves are variable in quality over the data record. Figure 2.7 shows some data quality related parameters from buoy 45151. The data quality assessment focused on removing wave data that were not physically possible, such as wave heights over 5 m or wave periods longer than 9 seconds (these are generous criteria). Zero values were also removed.

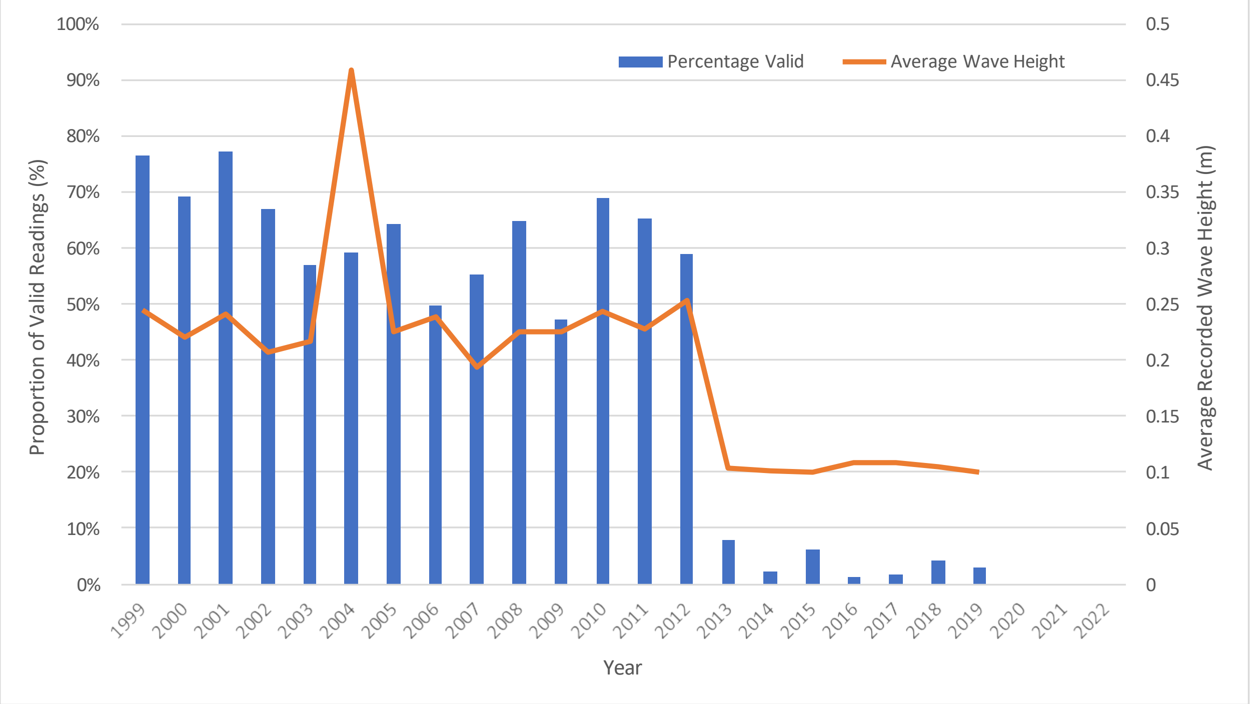

Figure 2.7: Data Quality from Buoy 45151

The average wave height was similar from 1999 until 2012, other than 2004 when waves were unexpectedly higher. The percentage of valid readings dropped significantly in 2013. This initial assessment suggests that wave data are more reliable from 1999 until 2012 (except 2004); these data were used to assess the accuracy of the wave model.

2.6 Topographic Data

Topographic elevation data were supplied by LSRCA in the form of gridded/raster Digital Elevation Models (DEMs) that cover the study area with a 1 metre spacing. The underlying data that were used to create the 1 m DEM were obtained by LSRCA from the various municipalities in the study area and consequently have different data collection dates and used different methodologies, resulting in 5 distinctly separate datasets used for analysis. In York Region and the City of Barrie, LiDAR data were available and were used as the basis for the DEM. Other regions relied on photogrammetry to derive elevations and the underlying data are much coarser. Therefore, despite the consistent 1 metre gridded data sets that were used to define elevations in the area, there are regional differences in the level of detail. Figure 2.8 shows the data sources that were used to create the 1 m DEM. In regions where there is overlap in the data (such as the City of Barrie), the higher resolution data (typically LiDAR) were used wherever possible. Table 2.1 provides additional information on the data sources.

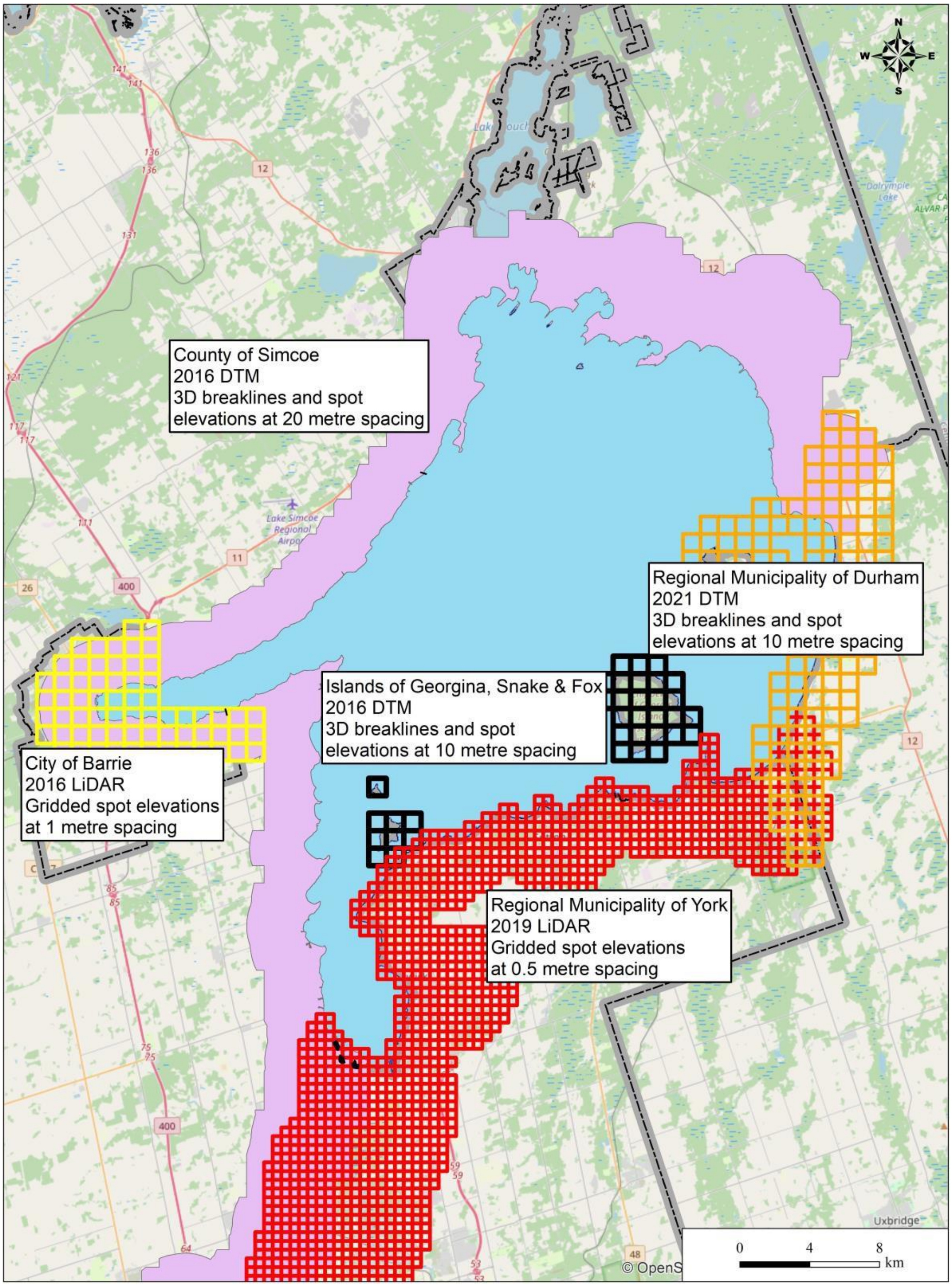

Figure 2.8: Source Digital Elevation Model Coverage Map

Table 2.1: Topographic Data

Region	Data Type	Resolution	Comments
City of Barrie	LiDAR	1.0 m	2016
York Region	LiDAR	1.0 m	Not used in favour of OMNR data
York Region from OMNR	LiDAR	0.5 m	2019
York Region Islands (Georgina, Snake & Fox)	Photogrammetry DTM points and 3D breaklines	Points at 10 m	2016
Durham Region	Photogrammetry DTM points and 3D breaklines	Points at 10 m	2021
Simcoe	Photogrammetry DTM points and 3D breaklines	Points at 20 m	2016

One of the challenges was that elevation data from these surveys were often clipped at an elevation close to lake level. This meant that details such as beach faces and revetment slopes were not included in the DEM. In the regions where LiDAR data were available, there were more detailed near-lake elevation data.

2.7 Bathymetric Data

Bathymetric data for Lake Simcoe were obtained from the Canadian Hydrographic Service (CHS) and included data from an older lake-wide data set (coarser in coverage, about 11,000 spot depths) as well as selected areas where more recent multi-beam data were available. A map of the data coverage is shown in Figure 2.9.

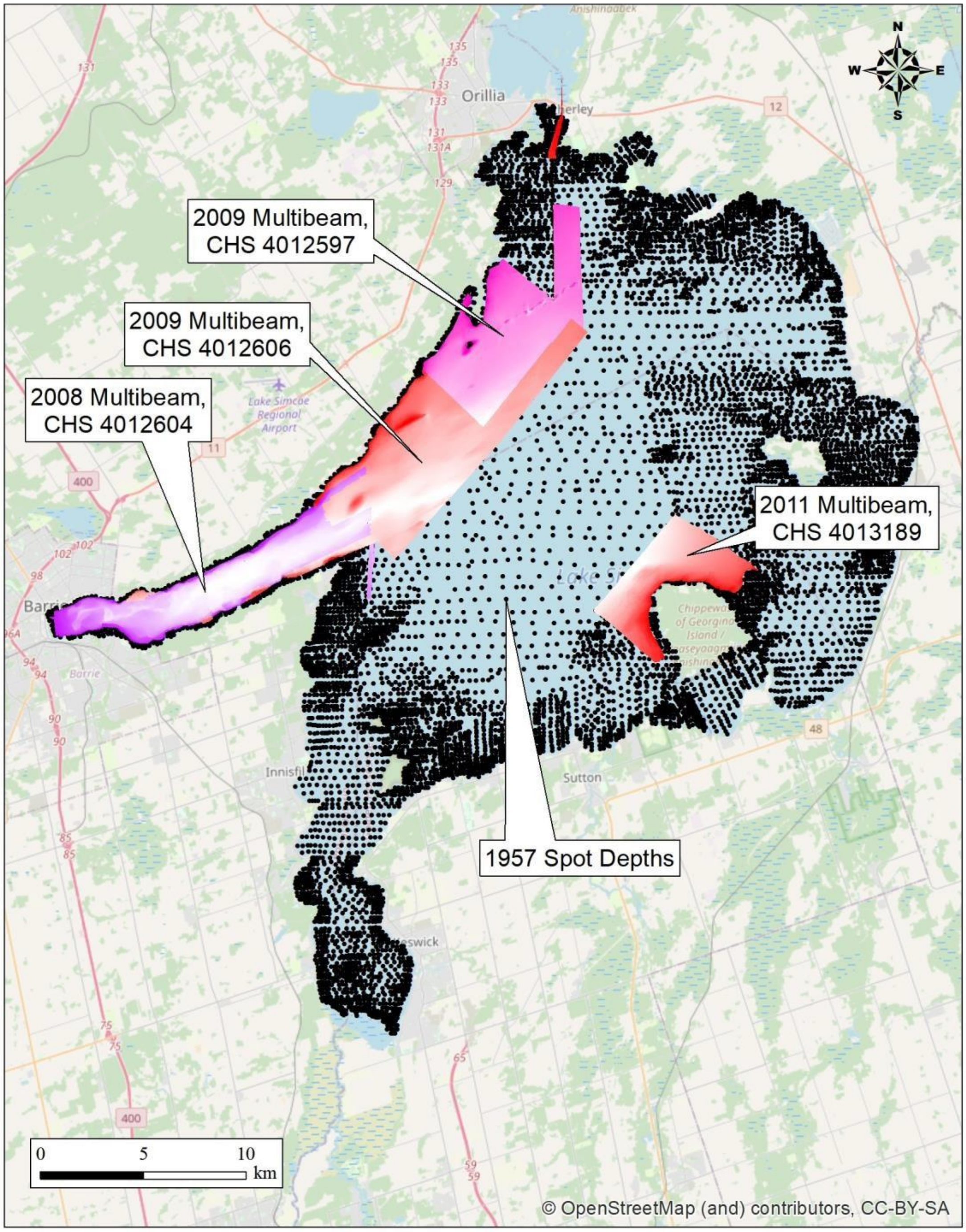

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Figure 2.9: Lake Simcoe Bathymetric Data Coverage (Canadian Hydrographic Service)

For assessing wave and surge processes near the shoreline, bathymetry data were also sourced using Satellite Derived Bathymetry (SDB) methods. SDB relies on multispectral imaging and then analyses the difference in light penetration of different wavelengths to obtain an estimate of water depth. The process is limited by water clarity and is only suitable for shallower regions of the lake. However, it does provide much needed data in shallow regions where CHS data are sparse. The region covered by SDB is shown in Figure 2.10.

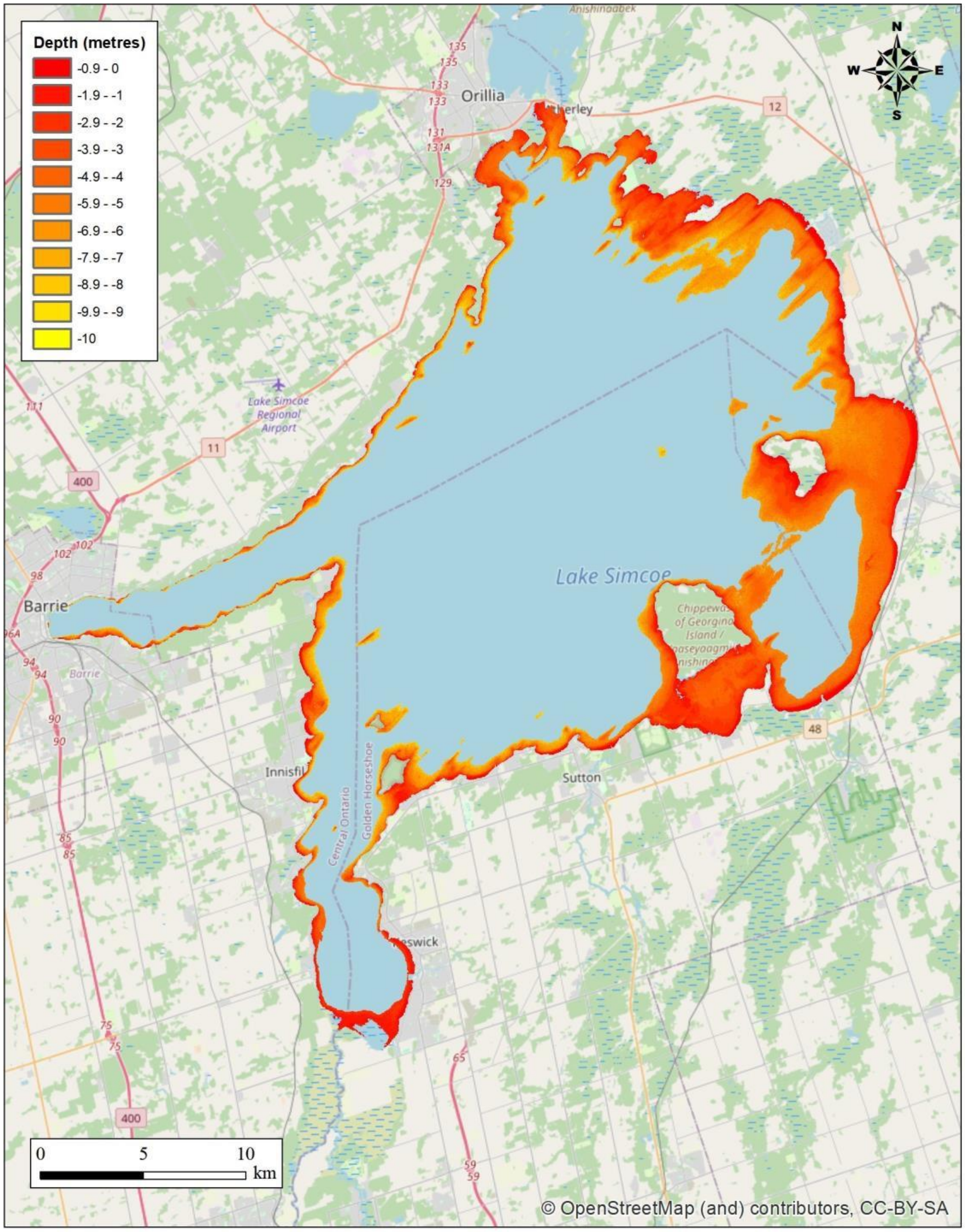


Figure 2.10: Lake Simcoe Satellite Derived Bathymetry Coverage

2.8 Validation of Bathymetric Data

SDB data have a reported accuracy of about ±0.5 m, plus 10% of the water depth. This is not as reliable as a boat-based survey; however, the coverage area and the cost make this an attractive alternative. It also allows for data collection in regions that might be too shallow for most boats.

Cross sections were cut through regions where there was intersection of the CHS multi-beam data and the SDB. In most locations, the availability of the two data sets were more complimentary than redundant, with only small regions of duplicate coverage. An example cross section with the bathymetry data sets is shown in Figure 2.11. Further comparisons of the bathymetric data and the profile locations are provided in Appendix A. These plots show generally good agreement between the SDB, the older CHS data and the newer multibeam CHS data.

Figure 2.11: Comparison of CHS Multi-beam, CHS Point Data and SDB Bathymetric Data at Profile 1

To obtain an additional validation of the SDB data in shallower water, a series of transects were undertaken from a small boat in the NE region of Lake Simcoe on September 8, 2022. The goal of measuring these transects was to overlap with a significant range in SDB water depths, as the CHS multibeam data was limited to deeper areas and did not enter shallower water. The survey was completed with a Syqwest Hydrobox single beam echosounder; an overview of the region that was surveyed is shown in Figure 2.12.

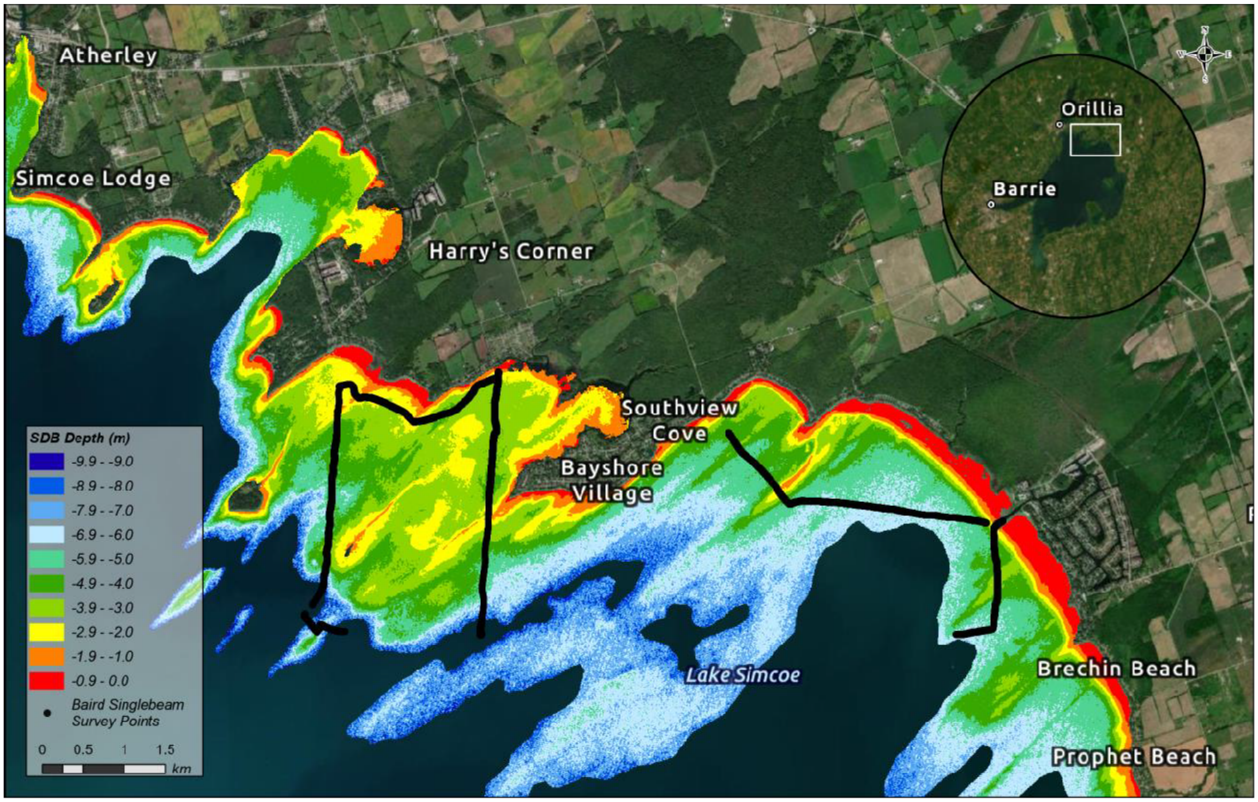


Figure 2.12: Map Showing Survey Lines Measured in September 2022 and SDB Bathymetry Data

The general conclusion from these surveys was that the SDB provided a good representation of the bathymetric depths; however, there was some variability that seemed to be somewhat regional. Deeper water depths were often under-reported in the SDB (reported as shallower than they were), while in shallow regions the SDB tended to report deeper water depths. This can be seen in the comparison in Figure 2.13 for profile SB_000_1310.

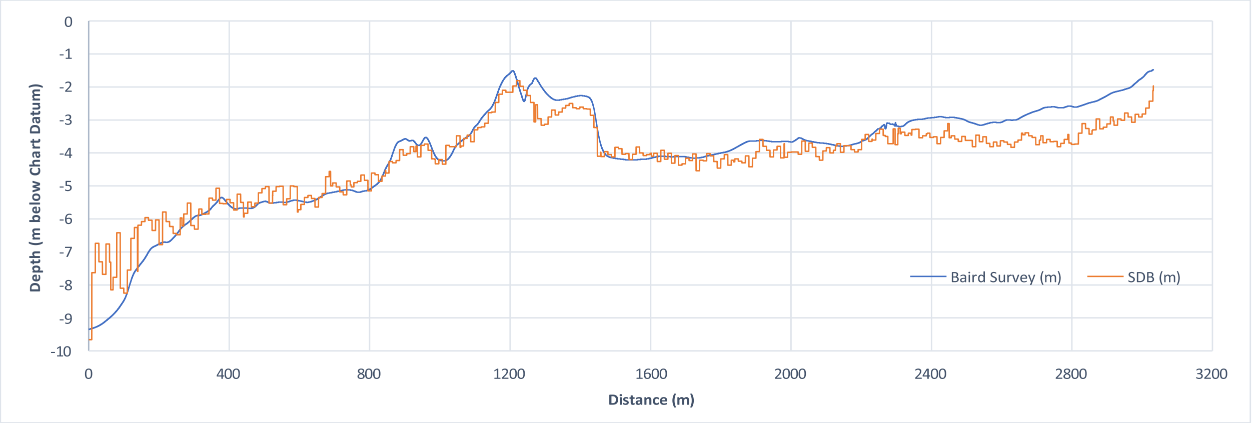


Figure 2.13: Comparison of SDB and Verification Boat Survey Data Measured in September 2022

The differences in the data are also demonstrated through a comparison of Baird's boat-measured survey points (Sept 8, 2022) and the SDB extracted at the same location (Figure 2.14). With perfect agreement of the two data sets, all of the points would plot along the red 1:1 line. In terms of predicting wave heights, the deviation from the 1:1 line in shallower water with the SDB reporting slightly deeper depths will be conservative, as a model with deeper water depths could allow slightly larger waves to reach the shoreline. The deviation from the 1:1 line in the 6 to 7 m water depth is of little consequence to the processes that reach the shoreline, as these depths are located a significant distance offshore.

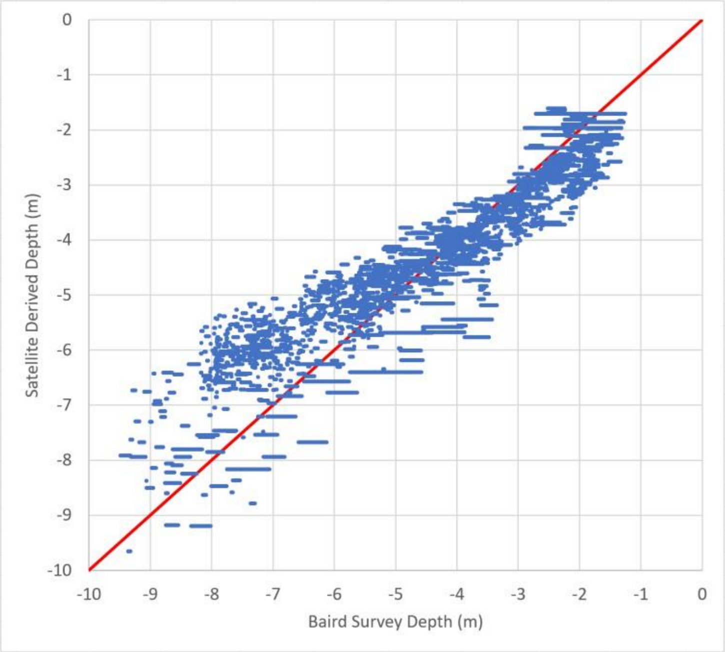


Figure 2.14: Depth versus Depth Plot for SDB and Boat Survey

2.9 Validation of Nearshore Elevations

After assessing the available topographic and bathymetric data, it was concluded that the region with the least data coverage was typically at the shoreline. In regions where the topographic data were based on photogrammetry, there was rarely data below 219.5 m. Bathymetric data typically started at least 1 m below this elevation. Nearshore bathymetric data were also derived from satellite imagery and have a greater level of uncertainty than direct measurements.

Completing a survey of the entire lakeshore was not within the scope and schedule for this study; however, some basic validation of elevations was undertaken. The survey also assisted in understanding the transition of the profile from the bathymetric data to the topographic data. Some of the key questions that needed to be answered included:

- What is a typical profile of a beach in the area?
- What are the typical land elevations adjacent to revetments and vertical walls along the shoreline?

A topographic survey was completed at selected locations on August 26, 2022, to fill in the data gap between the existing topographic and bathymetric data. Survey locations focused on areas that were publicly accessible, and had the characteristics that were of interest (e.g. a natural beach, or a nearby revetment or wall). Data were collected using a GPS with a median horizontal and vertical accuracy of about 2 cm (95% of the samples under 5 cm estimated error); data were collected by wading into the water and by walking on public shoreline areas. The locations where data were collected are shown in Figure 2.15.

Figure 2.15: Nearshore GPS Survey Locations

The general observation from these data was that elevations for developed areas adjacent to the lake were quite variable even within one reach.

Nearshore slopes were shallow in most areas and there was a general linear trend through the waterline into the beach area. At some locations, the SDB showed a slight deepening near the shoreline, which was not supported by the transect surveys.

It was concluded that flood hazard mapping must consider the case where there is minimal freeboard above the 100-year water level and waves may propagate inland.

2.10 Regional Recession Rates

Approximately 20 sites were initially identified (an arbitrarily lettered for reference) for assessing shoreline recession. From this list, six sites were identified where the shoreline remained in a more natural state and assessment of the recession rate was possible from historical and recent photographs. These locations

(Figure 2.16) were typically park areas, or areas where farming had continued until recently and no development had occurred along the shoreline.

Figure 2.16: Selected Locations for Shoreline Recession Assessment

Historical aerial images that covered the area of interest were obtained from the National Air Photo Library. The historical imagery were from 1965 and 1967. Recent aerial images from 2018 to 2021 were then compared, resulting in a time span of about 53 to 57 years at the selected sites. An example of the shoreline positions from historical and recent imagery at “Site M” is shown in Figure 2.17. The green lines represent the difference in the shoreline position along transects spaced at 2 m. At this site, the average rate of recession was determined to be about 0.09 m/yr.

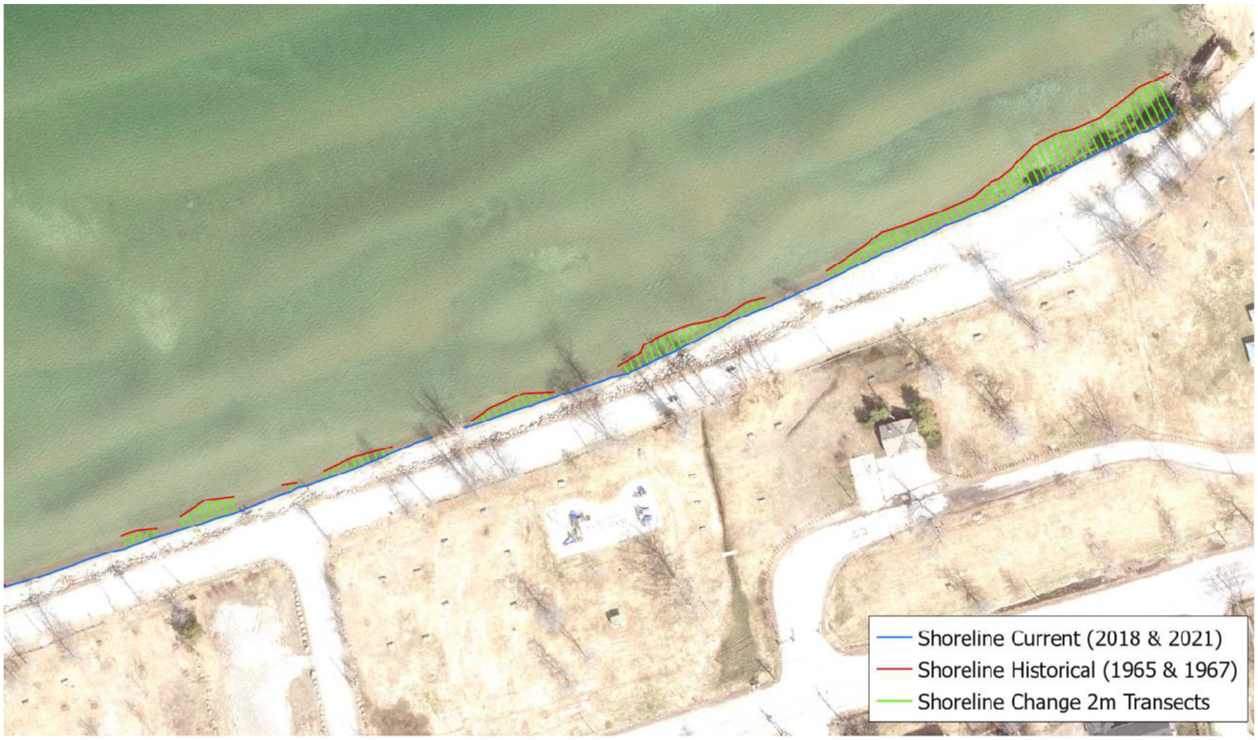


Figure 2.17: Recent Aerial Photograph and Historical Shorelines Showing Shoreline Change

The results of these comparisons provided an estimate of the shoreline recession rate over a total of 576 m of shoreline. Compared to the total length of shoreline being mapped (~300 km) this is a very small fraction of the study area and extrapolating these results to other sites needs to be done cautiously. The results of the shoreline recession analyses are summarized in Table 2.2.

Table 2.2: Shoreline Erosion Rates in Undeveloped Locations

Site	Reach ID	Site Length (m)	Average Annual Recession Rate			
			Average (m/yr)	St. Dev (m/yr)	Max (m/yr)	Ave + 1 St Dev
M	19	226	0.086	0.048	0.204	0.135
O	25	82	0.064	0.019	0.097	0.082
C	3	100	0.035	0.020	0.072	0.055
F	7	40	0.113	0.015	0.143	0.128
G	10&11	116	0.035	0.018	0.079	0.053
I	15	12	0.105	0.012	0.116	0.117
All Sites Combined		**576**	**0.066**	**0.043**	**0.204**	**0.109**

Rather than using an average value, it is common practice to use a value that is somewhat above the average. Using the average results in higher risks, as the recession rate will be underestimated 50% of the time. It is recommended to use the mean value plus one standard deviation to define the erosion allowance; this value is provided in the last column of Table 2.2.

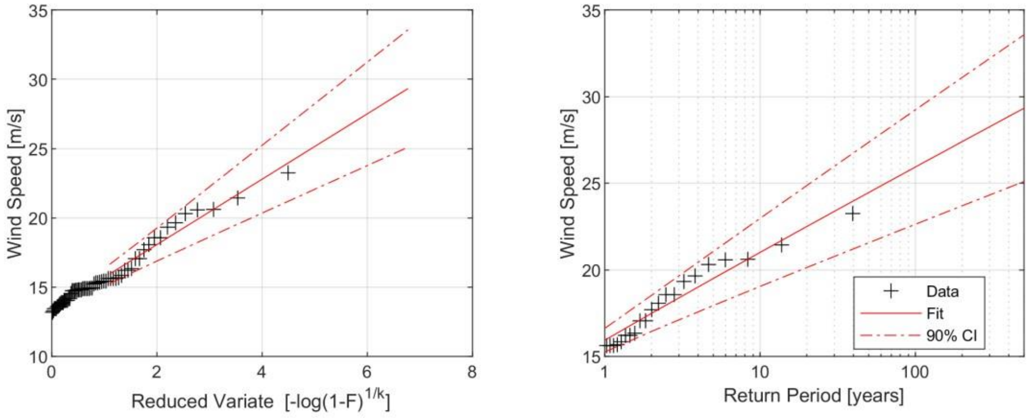
The calculated recession rates from the six different sites range from 0.053 m/yr to 0.135 m/yr, compared to the default value for a large inland lake of 0.15 m/yr (MNR, 1996). With a significant range in values from the six study sites, it is challenging to differentiate where a lower or higher rate of erosion may occur around the lake in regions that have had shore protection installed for decades.

Given the challenge in defining a natural erosion rate, it is recommended that the default erosion rate for large inland lakes of 0.15 m/yr be applied throughout the study area. This is expected to be slightly conservative based on the values in Table 2.2; however, some areas that were protected long ago could have a natural rate of erosion that is higher than 0.15 m/yr. This recommended approach is consistent with the Technical Guide (MNR, 1996) which states that any deviation from the 15 metre erosion allowance standard is to be undertaken only in accordance with accepted scientific and geotechnical engineering principles.

3. Wave & Surge Modelling for Flooding Hazard

3.1 Extreme Wind Speeds

Winds are important as the driving force behind storm surge and wave generation on Lake Simcoe. An extreme value analysis was completed for the adjusted Lagoon City winds (adjustments described in Section 2.4). As a result of the seasonal differences in water levels, two assessments were completed: one for the ice-free high water period of April to July, and another for the lower water period of July to December. A Weibull distribution was fit to 21 years of data, with the results from the top 60 windstorm events during April to July shown in Figure 3.1.



Extreme Value Series:
Peak OVer Threshold

Data summary:
Years of data = 21
Number of events = 63
Events per year = 3.00

Sample statistics:
Mean = 15.67
Max = 23.25
Min = 13.19
Std = 2.20
Skew = 1.53

Distribution parameters:
Fit = least squares
Scale = 2.36
Location = 13.36
Shape = 1.04
Correlation = 0.987

AEP	Return Period	Wind Speed [m/s]	Lower Estimate	Upper Estimate
99%	1.01	15.96	15.27	16.65
50%	2	17.49	16.45	18.53
20%	5	19.50	17.94	21.06
10%	10	21.01	19.05	22.97
5%	20	22.50	20.14	24.87
4%	25	22.98	20.49	25.48
2%	50	24.46	21.56	27.36
1%	100	25.94	22.63	29.24
0.5%	200	27.40	23.70	31.11
0.2%	500	29.33	25.10	33.57

Figure 3.1: Extreme Value Analysis for Winds on Lake Simcoe

This assessment shows that the 20-year wind speed is approximately 22.5 m/s. The assessment for the lower water ice-free season (August to December) shows only marginally different wind speeds with a 20-year value of 22.59 m/s. For the purposes of defining the extreme worst wave conditions that would coincide with a high water level, a wind speed of 22.5 m/s was selected.

3.2 Storm Surge

With managed water levels on Lake Simcoe, it presents a condition where the water levels would not be expected to conform to typical extreme value patterns. The lake levels are a product of the hydrologic process and also how the lake is managed. Over the years, more knowledge on lake levels and management is accumulated; however, policy changes and/or individual decisions can also impact the lake levels. Therefore, the level of complexity in undertaking the analysis should be commensurate with the processes that are being considered. Section 2.2.2 outlines the extreme water levels and a selected 100-year level of 219.5 m.

Storm surge on an enclosed water body such as Lake Simcoe is related to strong winds blowing across the lake surface. Surge due to changes in atmospheric pressure can be ignored as the entire lake will experience similar atmospheric pressure over the surface. Any differences will be small and transient, and the lake will not respond to these in any significant manner.

Wind setup is most pronounced in broad shallow bays when wind stress pushes the surface water towards the shore. Shallow conditions then limit how water may flow back into the deeper parts of the lake. This can be illustrated by comparing Cooks Bay to Kempenfelt Bay, with Cooks Bay being very shallow in comparison to Kempenfelt Bay. Wind setup from a north wind blowing into Cooks Bay will be much more pronounced than wind setup from a strong easterly wind blowing into Kempenfelt Bay.

Simulations were completed using the MIKE21 Flexible Mesh model. The grid used for these simulations is shown in Figure 3.2. Lake Simcoe is a small enough lake that the important processes for assessing flooding (surge and waves) will develop over a period of about two hours or less. This means that extreme events can be assessed based on steady-state conditions, rather than requiring lengthy storm simulations of complex time series.

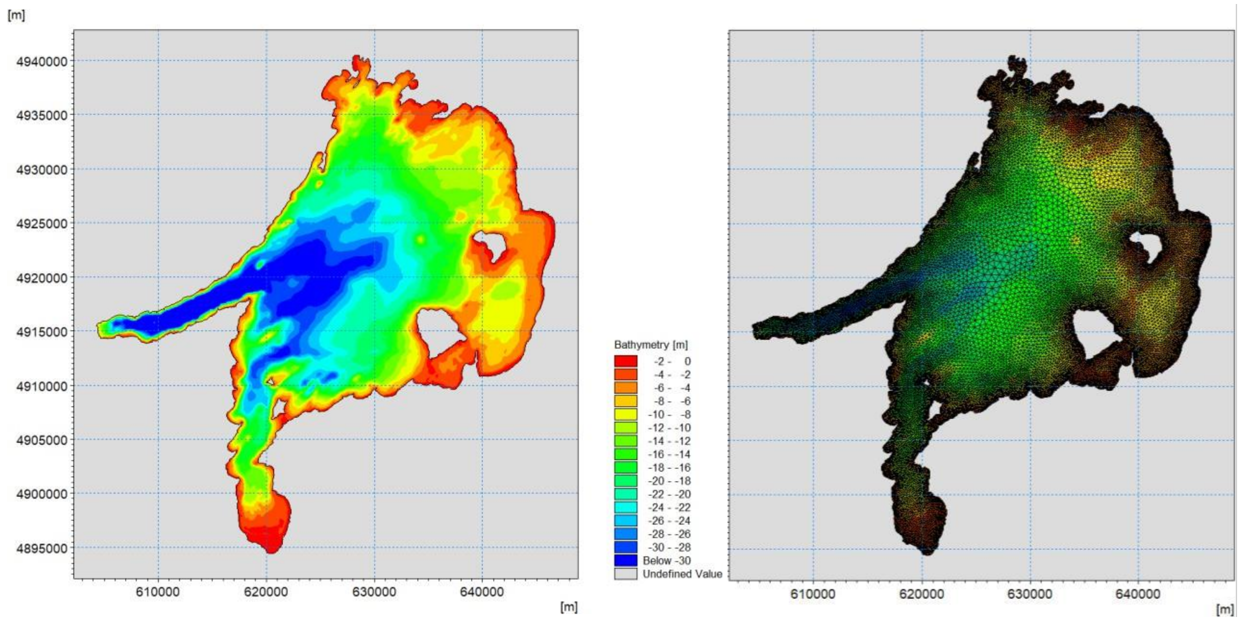


Figure 3.2: MIKE21 Bathymetry and Mesh for Storm Surge and Wave Simulations

Simulations were undertaken by gradually increasing the wind speed across the lake at the 20-year return period speed (22.5 m/s) and recording the resulting change in water level. Without any reported water levels at an hourly timestep (only daily averages were available) it was not possible to validate any large surge events. Instead, this assessment used default parameters for wind friction. With relatively modest storm surge values over most of the study area, adjustments to the wind friction only influence the wind setup by a few centimetres or less in most areas.

Wave setup modeling was completed for 36 directions around the compass, and the maximum surge level from each direction was recorded at each node in the model. The resulting map of the 20-year surge level is shown in Figure 3.3. These simulations were completed for a mean water level of 219.5 m, which is 0.78 m above chart datum (218.72 m). A surge value of 0.5 m would reach 220.00 m and would show as 0.50+0.78= 1.28 m above chart datum in this figure.

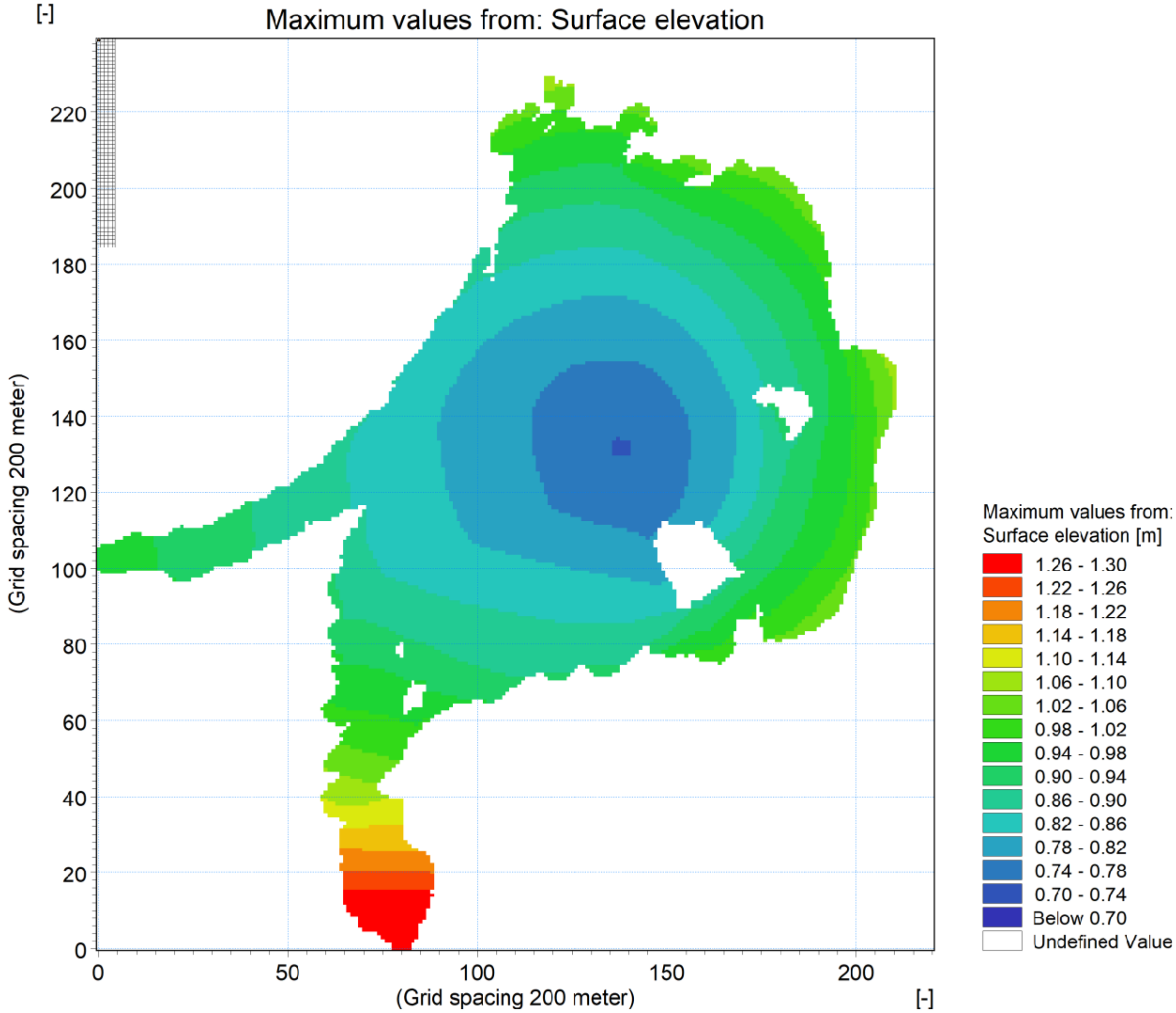


Figure 3.3: 20-year Storm Surge on Lake Simcoe (height above CD)

The regions with the greatest surge are shallow bays, while more open/deeper areas of the lake and the shorelines around islands (other than those close to the main lake shoreline) have minimal wind setup. The region with the greatest surge is Cooks Bay, where the shallow shoreline adjacent to the Holland River can have a surge value of about 0.62 m during a 20-year wind speed from the north.

3.3 Wave Conditions

The MIKE21 Spectral Wave (M21SW) model was used to predict waves on Lake Simcoe; the same numerical mesh was used as that shown in Figure 3.2. Initial simulations were undertaken for storm conditions that were recorded on wave buoy 45151 during the years with more valid data (see Section 2.5).

Storm events with higher wind and wave conditions sustained over consecutive hours were identified. Simulations were then completed in M21SW for approximately 12 hours around the peak of the storm. The model used the buoy-measured winds, which were applied over the full model domain. Adjustments to the buoy-measured winds were completed to better represent the wind speeds at a 10 m elevation, which is the standard used for wind-wave modeling.

A comparison of the modeled and measured wave conditions is presented in Figure 3.4. This simulation shows acceptable agreement between the modeled and measured data for the purposes of this analysis and provides confidence in the performance of the model.

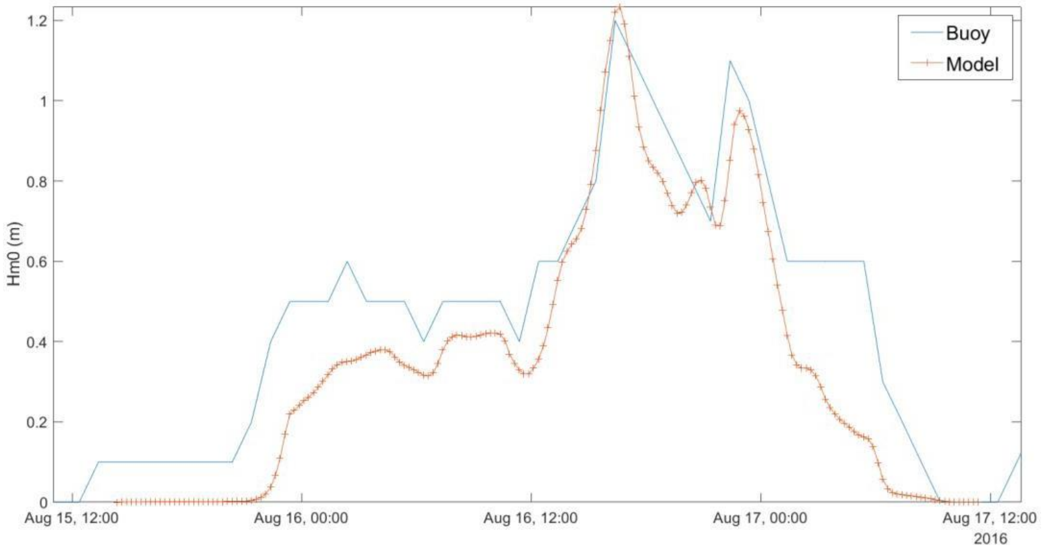


Figure 3.4: Comparison of Modeled and Measured Wave Conditions at Buoy 45151

Wave conditions throughout Lake Simcoe were developed using a similar approach to that used for storm surge modeling. The 20-year wind speed of 22.5 m/s was applied from 36 directions around the compass in separate simulations. The maximum wave condition in the lake from all of these simulations was mapped. These simulations were completed at a water level of 219.5 m; however, surge was not applied. The impact from locally adjusting the lake level to account for surge is considered in the final stage of modeling at the shoreline.

The maximum significant wave height from these simulations of varied wind directions is shown in Figure 3.5. This figure shows the sheltering effect from islands, and the decrease in wave height as shallow water is encountered close to the shoreline. Wave conditions from these simulations are the input to the final stage of modeling, which involves simulating runup and overtopping at the shoreline using a profile model.

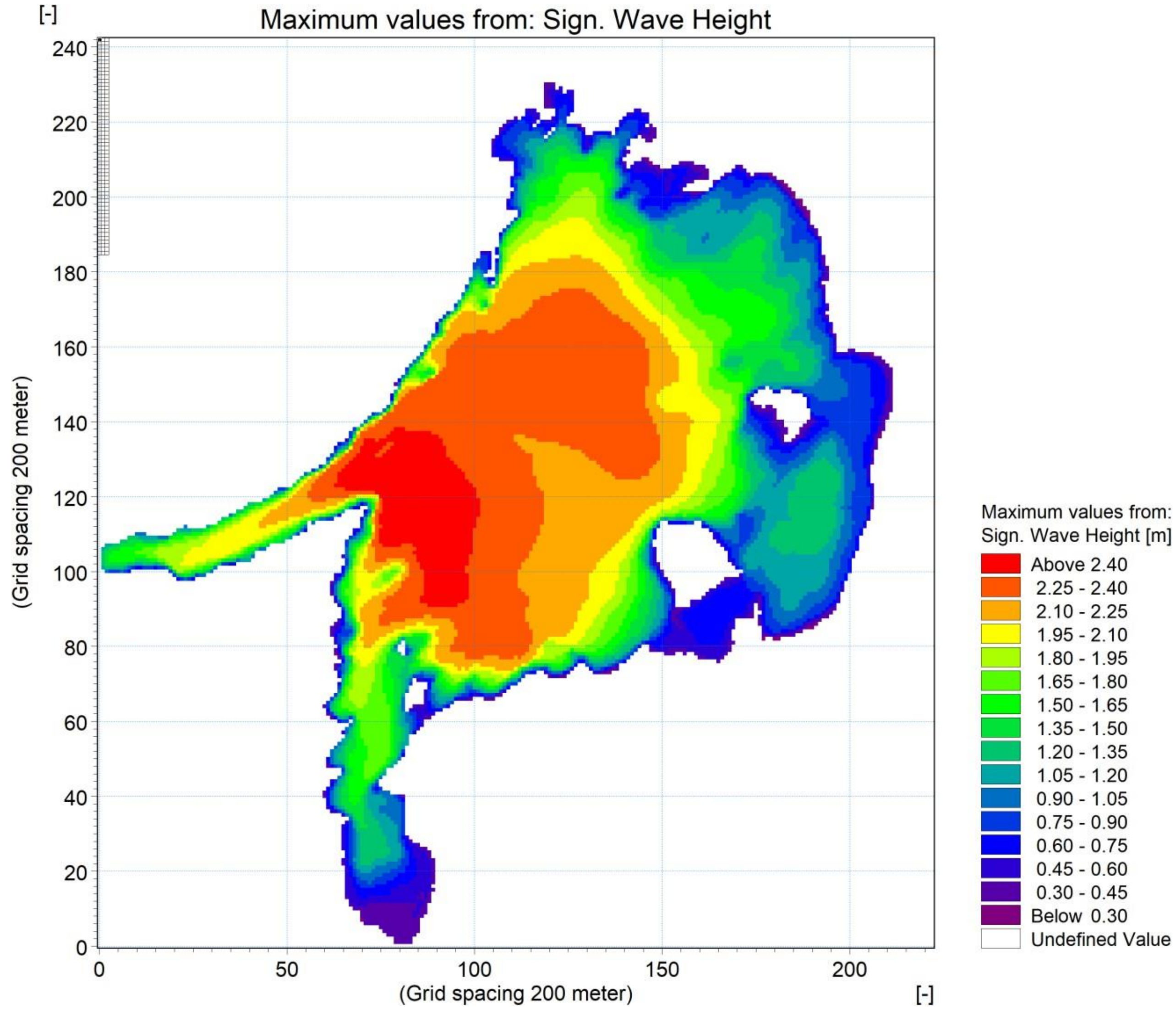


Figure 3.5: Wave Conditions from 20-year Wind Storm (maximum from all directions)

3.4 Wave Uprush

The final stage of modeling involves simulating wave breaking in shallow water close to the shore, and wave runup on the shoreline. This modeling uses a profile model that depicts the processes along a line that is perpendicular to the shoreline. The model starts in about 5 m of water (sometimes less in very flat/shallow areas) and extends to the shoreline and some distance inland above/beyond where wave processes stop.

Two models were used in this study:

- EurOtop is a tool that was developed to assess runup and overtopping of dyke structures along the European coastline. This tool is best suited to artificial shorelines where revetments and vertical walls may be present and is typically applied on steeper structures/shorelines rather than gentle beaches. EurOtop predicts the maximum wave runup height on the shore.

- CSHORE is a model that was developed for more natural beach shorelines. This model is used in regions where there is no significant artificial structure and runup occurs on a beach with slopes gentler than 10:1.

Wave runup was calculated for each of the shoreline reaches using a representative shoreline profile for each reach. The wave runup was estimated at the 2% exceedance level, which represents the 1 in 50 highest wave crest runup, but not the absolute maximum runup that might be expected within a storm. The 2% exceedance level for runup is defined based on individual wave crests within a storm. If an observer watched the runup of 100 consecutive waves (within 10 or 15 minutes typically) the 2% level would be at approximately the height of the second highest runup. A maximum runup value within a storm is not used as it is statistically challenging to estimate.

The 100-year flood level with the 20-year wave condition were used in the analysis as per MNR (1996). The definition sketch for wave runup or uprush is shown in Figure 3.6, where SWL is the still water level, excluding wave runup. In this figure, “R” is the wave uprush height for threshold extension of slope, “F” is the freeboard height; and “Ls” is the maximum distance that an overtopping wave is predicted to travel inland from the crest of the profile. The distance “Ls” is proportional to the excess uprush (R minus F) and the wave period. The wave uprush allowance is equal to the vertical extent of the wave uprush on the slope, for cases where the uprush is below the profile crest. When uprush exceeds the crest of the profile, the wave uprush allowance is defined based on the horizontal distance “Ls” from the profile crest.

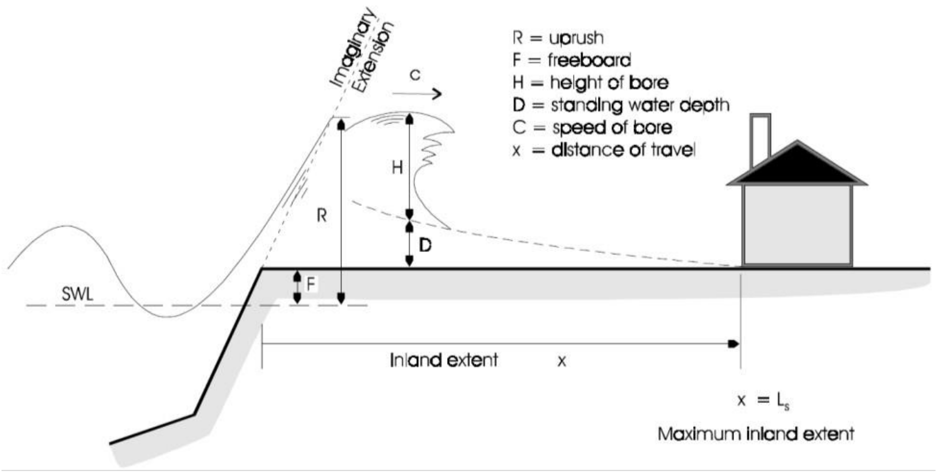


Figure 3.6: Definition sketch of wave uprush over low bluff (from MNR, 2001a)

When wave runup exceeds the crest of the structure, the inland extent of wave propagation is then calculated according to the Cox-Machemehl equation (Eq. 1), as presented in MNR (2001a) and shown in Figure 3.6.

$$L_s = \frac{T\sqrt{g}}{5}(R-F)^{1/2} \qquad \text{(Eq. 1)}$$

where:

Ls = horizontal extent of wave uprush measured from the slope crest
T = wave period
g = acceleration due to gravity

R = wave runup
F = freeboard

On Lake Simcoe, waves are smaller near the shoreline (compared to the Great Lakes for example) due to the size of the lake and the gentle/shallow slopes around the perimeter of the lake. This means that theoretical runup levels are relatively small, with values typically in the range of 0.5 to 1.5 m above the water line. Of the 45 profiles simulated, runup exceeded 1.5 m on only five profiles.

With sparse data for the elevation of land around the perimeter of the lake, and considering the variability of the shoreline slopes within a reach, it is not appropriate to select a runup contour and use this to define the inland extent of wave runup. In areas where the land is very flat (perhaps some isolated areas within a reach), the runup will not reach the prescribed contour but will be limited by the extent of wave propagation inland.

Inland wave propagation was assessed through a sensitivity assessment using typical wave runup values and different assumptions about the elevation of the land adjacent to the shoreline. The worst conditions occur when the land is very flat just above the flood level, and the toe is relatively deep in the foreshore area. This approach involving using the inland propagation distance is further discussed in Section 7.3.

4. Erosion Hazard Analysis

4.1 Overview of Shoreline Hazards

The Provincial Policy Statement (PPS) provides policy direction on matters of provincial interest related to land use planning and development. Hazardous lands are defined in the PPS, (MMAH, 2014) as “property or lands that could be unsafe for development due to naturally occurring processes.” Along shorelines of the Great Lakes – St. Lawrence River System, this means the land, including that covered by water between the international boundary where applicable, and the furthest landward extent of the flooding hazard, erosion hazard, or dynamic beach hazard limits.

The technical basis and methodologies for defining and applying the hazard limits for flooding, erosion, and dynamic beaches are provided by the Technical Guide for Flooding, Erosion and Dynamic Beaches, Great Lakes – St. Lawrence River System and Large Inland Lakes (MNR, 2001a). The basic procedures outlined in the Technical Guide (MNR, 2001a) with some modifications have been included in subsequent documents, such as Ontario Regulation 97/04 (“Generic Regulation”) and Guidelines for Developing Schedules of Regulated Areas (Conservation Ontario, 2005). The methodologies outlined in MNR (2001a) have been used on this project.

It is important to note, as outlined in the Technical Guide (MNR, 2001a), that the regulated hazard limits are generally to be mapped based on the assumption of no shoreline protection works in place. The clearly stated intent is that the mapped flooding, erosion, and dynamic beach hazard limits are to represent the underlying ambient nature of the natural shoreline hazard and should not be modified by the presence of existing or proposed shoreline protection. The most landward limit of the Flooding, Erosion and Dynamic Beach hazards is utilized in determining the regulated area along the Lake Simcoe shoreline.

4.2 Flooding Hazard

The flooding hazard limit is defined as the 100-year flood level plus an allowance for wave uprush and other water-related hazards. The 100-year flood level is the sum of the static water level plus storm surge with a combined 1% probability of being equalled or exceeded in a given year. This means that on average it has a one percent probability of occurring in any given year.

When shorelines are exposed to wave action, wave uprush and overtopping occur driving water above the 100-year water level. Site specific studies may be used to assess the allowance for wave uprush and water related hazards. For large inland lakes, the Technical Guide (MNR, 2001a) requires a flooding allowance of 5 m, measured horizontally from the location of the 100-year flood level if a study using accepted engineering, and scientific principles is not undertaken (Figure 4.1).

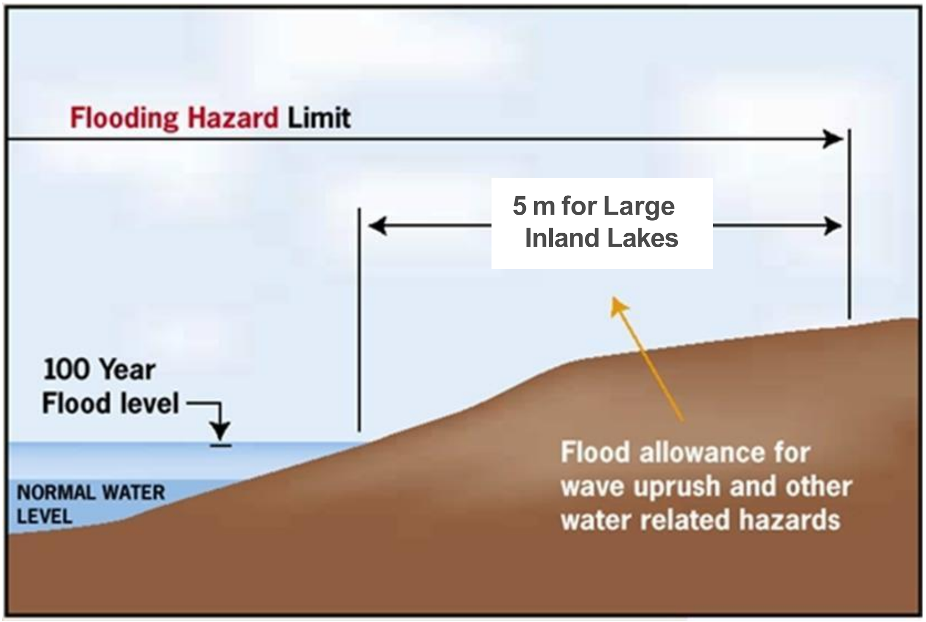


Figure 4.1: Flooding Hazard Limit for the Large Inland Lakes (from MNR, 2001a)

4.3 Erosion Hazard

The erosion hazard limit is calculated as the sum of the stable slope allowance, plus the 100-year erosion allowance. Figure 4.2 shows the erosion hazard limit as defined in the Technical Guide (MNR, 2001a) and Understanding Natural Hazards (MNR, 2001b).

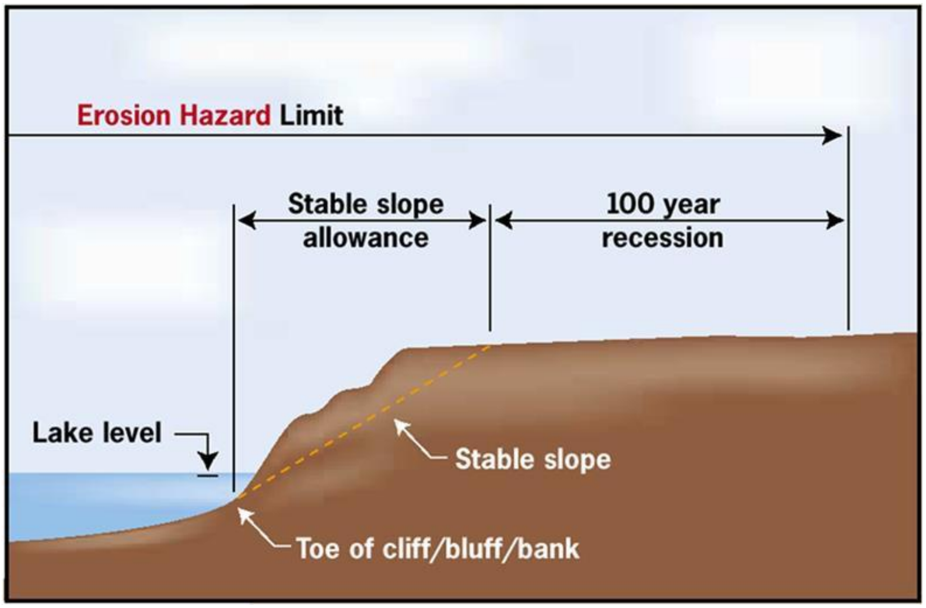


Figure 4.2: Erosion Hazard Limit Defined with Reliable Recession Data (from MNR, 2001a)

The approach used in Ontario Regulation 97/04 is similar, but the recession allowance is applied first and then the stable slope allowance is applied.

The stable slope allowance is a horizontal allowance measured landward from the toe of the bluff or bank. It is dependent on soil characteristics and groundwater conditions. In the absence of a site-specific study, a stable slope allowance of three times the bluff height may be used. The bluff heights are calculated as the vertical change in elevation from the toe of bluff to the top of bluff.

The erosion allowance is the distance the shoreline would erode in 100 years from present. It is calculated as 100 times the average annual recession rate (AARR) as shown in Figure 4.2.

4.4 Methodology

The Technical Guide (MNR, 1996) provides a recommended approach for assessing the erosion hazard limit on large inland lakes. The erosion hazard is comprised of an erosion allowance and a stable slope allowance.

The Technical Guide recommends a default value for the average annual recession rate (AARR) for locations where there is insufficient data to determine the AARR. The default erosion allowance 15 m over a 100-year planning horizon (AARR = 0.15 m/yr). Variation from this 0.15 m/yr value is accepted when an appropriate engineering study can define a more accurate value. The default value for a stable slope is 3 horizontal:1 vertical, unless otherwise defined by a geotechnical engineer.

The standard approach for assessing shoreline recession on a lake-wide basis is through a comparison of shoreline position using historical aerial imagery. Several requirements must be fulfilled to complete an accurate assessment:

- High quality aerial photographs that are separated by a minimum 35 years between photos.
- A visible shoreline must be present in the aerial photographs, ideally at a known water level.
- Positioning (geo-registering) of the photographs must be appropriate for the situation. In areas with lower erosion, much more precise photograph positioning is required in order to make an accurate assessment of small changes in the shoreline. With older photographs the landmarks for positioning may have changed, making this a challenging task.
- Locations where the shoreline is in its natural state, without groynes, revetments, breakwaters and other significant shoreline protection or modification.

Lake Simcoe has a highly developed shoreline, with homes, cottages, marinas, public beaches, launch ramps and road/rail along the shore in many areas. Much of the development took place in past decades, with upgrades continuing today. This makes it difficult to find photographs that are sufficiently spaced in time and show a shoreline in a natural condition. Furthermore, the relatively low erosion rates make the use of poorer quality photos from the 1940s or 1950s impractical, since accurate shoreline positioning is not possible in these photographs and position errors may be large relative to the recession distance.

The recession rate is determined through a process of comparing the position of two shorelines that are digitized from aerial photographs. The distance between the two shorelines will vary and this distance is tabulated at a regular interval in the comparison region. From these comparisons, a mean shoreline change is calculated, as well as a standard deviation.

4.5 Stable Slope Allowance

The stable slope allowance is defined as the horizontal setback distance from the toe of a coastal bluff to where the stable slope intersects the tablelands. Shoreline slopes around Lake Simcoe are typically in the range of 0 to 10 m.

In low-lying areas where there is no bank or bluff at the shoreline, the stable slope is irrelevant as there is no risk of slope failure. In these areas the erosion hazard is equal to the erosion allowance (stable slope allowance is zero).

Around the Lake Simcoe shoreline, there are some higher hills, but many of these features are not coastal bluffs, they are simply slopes close to the lake. For a slope to be considered a coastal bluff and for a stable slope allowance to be defined, the toe of the bluff must be within the erosion allowance, which is typically 15 m landward from the high water mark (based on 0.15 m/yr of shoreline recession).

With a range of soil conditions in the area and limited slope stability information, the stable slope allowance was defined by a 3 Horizontal:1 Vertical slope from the anticipated toe of the bluff (following recession of the shoreline).

5. Dynamic Beaches

Dynamic beaches are defined in the technical guide as a beach that is more than 100 m in length, more than 10 m in width (above water) and more than 0.3 m thick. Furthermore, these beaches are located in regions that have fetches greater than 5 km.

In some areas of the Great Lakes and other large inland lakes, beach systems may respond to seasonal wind/wave patterns and significantly realign. This can cause the shoreline to quickly vary from whatever may be shown on a map and in recognition of this the dynamic beach hazard was defined.

The existing guidance from the LSRCA is that dynamic beaches are generally not present on Lake Simcoe. This guidance was verified by completing the following tasks:

- Locations of potential beaches were identified. This was done by reviewing:
  - The shapefile of beach locations provided by LSRCA,
  - MNR classification of surficial geology and shoreline type.
  - Aerial imagery that showed the presence of offshore bar formations, which are often indicative of large beach deposits
  - Other visible signs of sufficiently large beaches along the shoreline
- Oblique aerial imagery was reviewed in target areas
- Beach dimensions were obtained from Google Earth imagery and other images

A table of potential beaches was developed, with only a very small number of beaches meeting the preliminary criteria of a dynamic beach. In many cases, these appear to be beaches that were constructed, likely with fill placed lakeward of the original shoreline. Typically, these beaches are in bays where very oblique wave action is limited, or they have a large groyne on one or both sides. None of these beaches would be expected to display significant erosion/accretion or planform realignment in a storm due to the geometric properties of the beach, the surround structures and the wave directions.

After reviewing the beaches in Lake Simcoe and considering the points listed above, we concur with the opinion of the LSRCA that there are no beaches in Lake Simcoe that have the properties of a dynamic beach and warrant special shoreline hazard designation.

6. Shoreline Reach Identification

6.1 General Approach

Shoreline hazards are assessed on a reach basis, where a reach is defined as a section of shoreline with similar hazard characteristics. Mapping is not undertaken at a parcel level and does not consider the shoreline treatment of individual properties. Therefore, the hazard limits defined in this study should be considered appropriate for broad planning level considerations but may not be appropriate for decisions at a specific property. More detailed analysis may be required to support development on specific properties.

The previous hazard mapping completed in 1989 used 34 reaches. Some of these were very small, localized reaches while others were larger and encompassed a range of conditions. New reaches have been developed with some similarities to the previous reaches; however significant differences also exist.

The primary considerations in developing the shoreline reaches were as follows:

- Nearshore water depths and slopes: This was assessed based on the nearshore satellite derived bathymetry. Nearshore water depths influence the maximum wave height that will reach the shoreline and impact the flooding hazard.
- Wave exposure: Based on the multidirectional wind/wave simulations on Lake Simcoe, reaches were defined with generally consistent wave exposures.
- Storm surge: Wind setup from strong onshore winds results in some areas having greater flooding potential. Large shallow bays, such as Cooks Bay were separated from other areas due the higher surge levels.
- Shoreline elevation: The flooding hazard may be limited to a narrow region of runup on a steep shoreline or could extend further inland in very flat areas. Reaches were defined with generally similar topography. However, in the final analysis, landside slopes and elevations were less critical than expected due to the relatively low wave runup values in many areas.

Nearshore substrate was not considered a primary delineator of the reaches. The wave exposure and nearshore underwater slope often resulted in logical breaks in the reaches that aligned with the substrate maps. For example, steeper bathymetry/topography regions with higher wave exposure were typically not classified as “mud” but were typically gravel or cobble.

The average annual recession rate was not used to delineate the reaches as there was insufficient data to define reach-specific shoreline recession rates. However, environmental forces such as wave exposure and the slopes along the shoreline are typically linked to erosion potential.

Islands were typically categorized as a separate reach, and multiple reaches were delineated on larger islands. It is common for islands to have less storm surge as the water can more easily pass around the island during strong wind events rather than building up against the shore.

6.2 Reach Summary

An overview of the reaches is shown in Figure 6.1. A total of 29 reaches were delineated around the perimeter of the lake. An additional 9 reaches were delineated along island shorelines. A list of the reaches, their name and length are provided in Table 6.1. These shorelines total to 266.4 km of the main shoreline, and 37.1 km of island shorelines (303.5 km total).

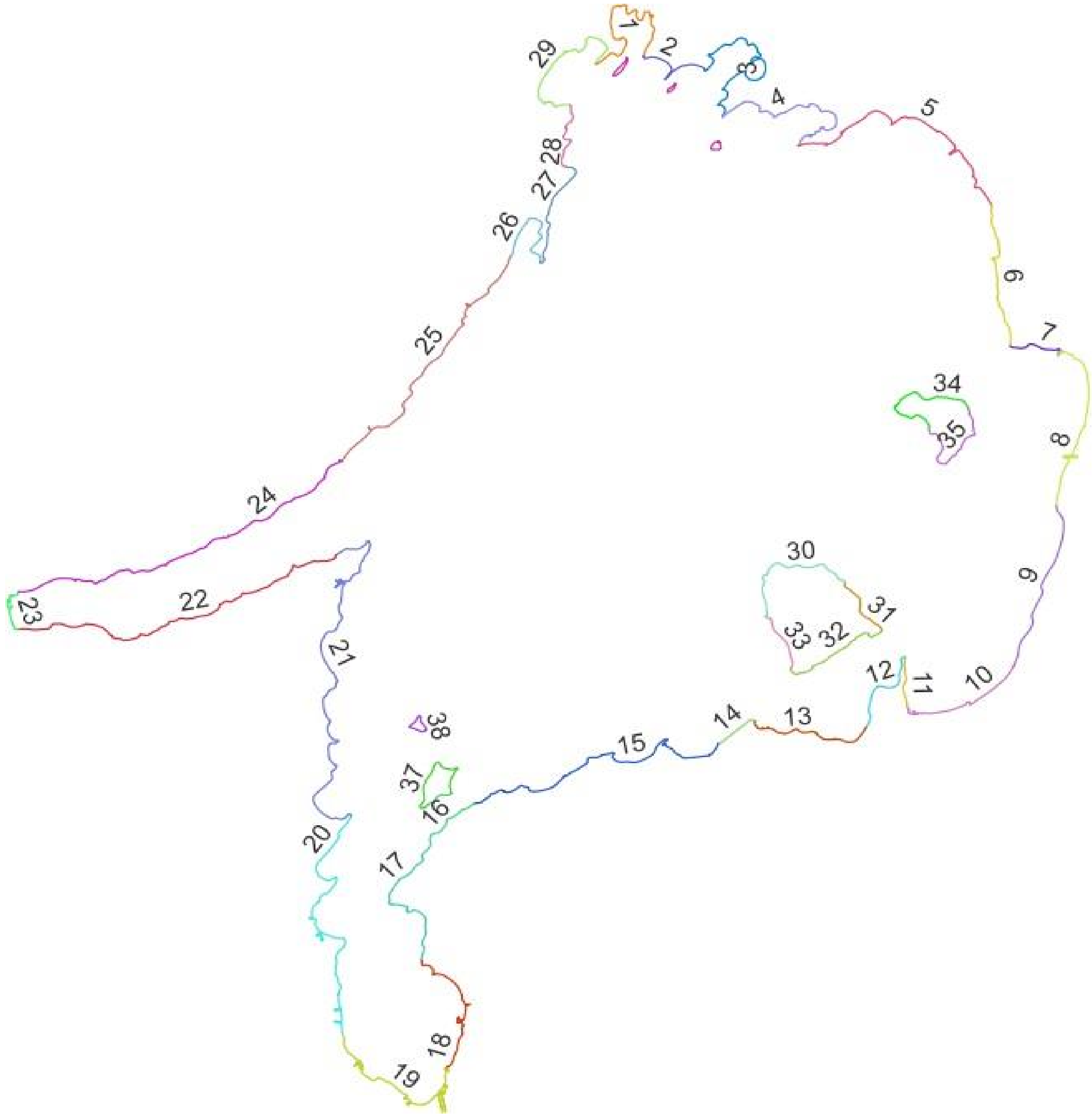


Figure 6.1: Map of Lake Simcoe Shoreline Reaches

Table 6.1: Summary of Lake Simcoe Reaches

Reach	Name	Length (m)	Location
1	Smith's Bay, Atherley, Victoria Point to Champlain Point	9,969	Main shoreline
2	Champlain Point to Cedar Point to Black Point	4,004	Main shoreline
3	McPhee Bay, Black Point to McRae Point	10,597	Main shoreline
4	Banstable Bay, McRae Point to McGinnis Point	9,275	Main shoreline
5	Lagoon City, St. Ives Bay, McGinnis Point to Prophet Point	13,333	Main shoreline
6	Prophet Point to Mara Point	7,518	Main shoreline
7	Mara Point to Canal Waterway	2,589	Main shoreline
8	Canal Waterway to McLennan's Beach	10,996	Main shoreline
9	McLennan's Beach to Thorah Beach Port Bolster	7,803	Main shoreline
10	Thorah Beach to Duclos Point Prov. Nature Reserve	7,005	Main shoreline
11	Duclos Point East	2,679	Main shoreline
12	Duclos Point West	4,446	Main shoreline
13	Sunset Beach to Sibbald Point	6,823	Main shoreline
14	Sibbald Point to almost Black River	2,017	Main shoreline
15	Black River Jacksons Pt Mossington Pt Willow Beach to Island Grove	15,630	Main shoreline
16	Island Grove to Eastbourne	3,446	Main shoreline
17	Eastbourne to Ferguson Point	8,835	Main shoreline
18	Ferguson Point to marina at Miami Beach	9,609	Main shoreline
19	Holland Marsh	16,636	Main shoreline
20	Gilford Beach to DeGrassi Point to Big Cedar Point	18,507	Main shoreline
21	Big Cedar Point to Big Bay Point	21,596	Main shoreline
22	Kempenfelt Bay South Shore Big Bay Point to Barrie	15,263	Main shoreline
23	Barrie urban waterfront	3,788	Main shoreline
24	Kempenfelt Bay North Shore	16,807	Main shoreline
25	Oro to Carthew Bay	15,362	Main shoreline
26	Carthew Bay	4,981	Main shoreline
27	Eight Mile Point to Cedarmont Beach	5,315	Main shoreline
28	Moons Beach to Four Mile Point	3,660	Main shoreline
29	Shingle Bay	7,932	Main shoreline
30	Georgina Island Northwest shoreline	6,099	Georgina Island
31	Georgina Island East shoreline	2,844	Georgina Island

Reach	Name	Length (m)	Location
32	Georgina Island South shoreline	5,475	Georgina Island
33	Georgina Island Southwest shoreline	2,737	Georgina Island
34	Thorah Island Northwest shoreline	5,667	Thorah Island
35	Thorah Island Southeast shoreline	5,437	Thorah Island
36	Snake Island South shoreline	1,600	Snake Island
37	Snake Island West-North-East shorelines	5,067	Snake Island
38	Fox Island	2,180	Fox Island

7. Hazard Mapping

7.1 Overview

Hazard mapping tasks for this study involve defining the erosion hazard and the flooding hazard for the reaches around Lake Simcoe (Figure 6.1). No dynamic beaches were identified and the dynamic beach hazard is therefore not applicable. Mapping was completed on a reach-by-reach basis using parameters for flood level and wave conditions that were consistent within each reach. The erosion hazard was addressed by using consistent parameters throughout the study area.

7.2 Erosion Hazard Mapping

Erosion hazard mapping is intended to account for long term recession of the shoreline as well as the natural stabilization of shoreline slopes to a stable angle. The recession rate is intended to represent the recession of an unprotected shoreline, rather than one where protection has been added. The evolution of the shoreline slope to the natural stable angle can take many years to develop; the stable slope allowance defines a long term setback to accommodate this stabilization process.

The Technical Guide (MNR, 1996) shows an approach where the stable slope angle is applied first, from the existing water level, after which a recession rate representing a 100 year planning horizon is applied at the top of the slope. This is an appropriate method where there are steep bluffs and a house close to the top of the bluff. This approach can highlight how some structures are at imminent risk, even without ongoing shoreline recession.

On many shorelines (such as Lake Simcoe) there are few buildings close to the edge of an eroding coastal bluff. Also, there is often a flatter area adjacent to the shore, after which there is a slope/bluff that slopes upwards. In these instances, it is more appropriate to apply the erosion to the shoreline first, and then assess how a stable slope would evolve based on the bluff/slope that is then being impacted by the shoreline erosion. This is a more appropriate method for Lake Simcoe, and is shown in Figure 7.1

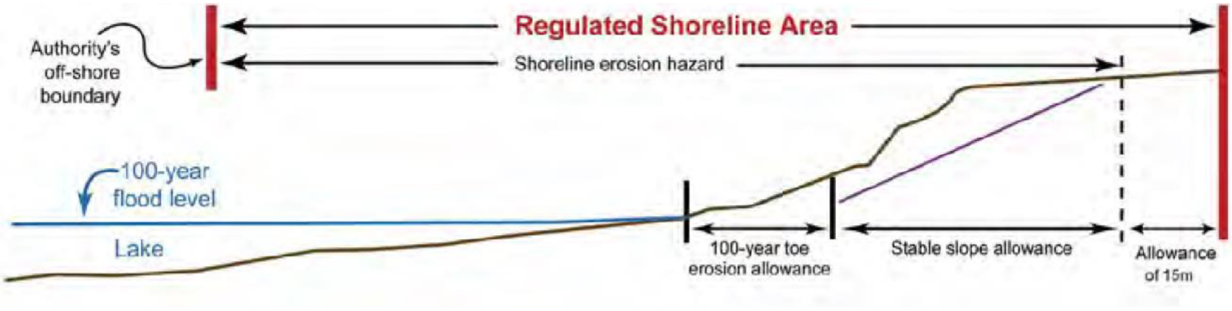


Figure 7.1: Ontario Regulation 97/04 Approach to Shoreline Erosion Hazard Mapping

The first step in defining the erosion hazard is to define an erosion allowance based on 100 years of erosion with a rate of 0.15 m/yr. This results in a 15 m erosion allowance along all shorelines of the lake. This erosion allowance is defined from the typical water line on Lake Simcoe, which is estimated to be approximately the normal early summer water level.

The stable slope allowance is then applied based on a 3H:1V stable slope. Insufficient data were available to define a steeper or locally varied stable slope.

To complete the shoreline erosion mapping the first step was to revise the shoreline of Lake Simcoe. This was accomplished by manually editing the existing shapefile to better match the recent aerial imagery (see Table 7.1). Changes were mostly minor but did reflect some additional works along the shore of the lake. This shoreline was used as the starting point for the erosion hazard mapping.

Table 7.1: Aerial Imagery Dates for Shoreline Definition

Location	Year
York	2021
Durham	2021
Simcoe (small section near Oro)	2016

The 15 m offset, which represents the erosion allowance, was defined by a 15 m offset from the shoreline. The stable slope allowance varies with topography within a reach. With the range in nearshore elevations that can occur close to the lake, the stable slope allowance was determined by using the elevation of the 15 m offset line and then applying a 3H:1V slope from an assumed shoreline elevation of 219.0 m. For example, if the 15 m offset line was at an elevation of 221 m, this implies an elevation change of 2.0 m and therefore a stable slope allowance of 6 m beyond the 15 m erosion offset.

An example of the product of this approach in a region with topographic variability is shown in Figure 7.2. In this figure the lower lying areas have minimal stable slope allowance (e.g., on the point with green colours), while the higher regions have an increased offset (e.g., in the yellow/orange colour).

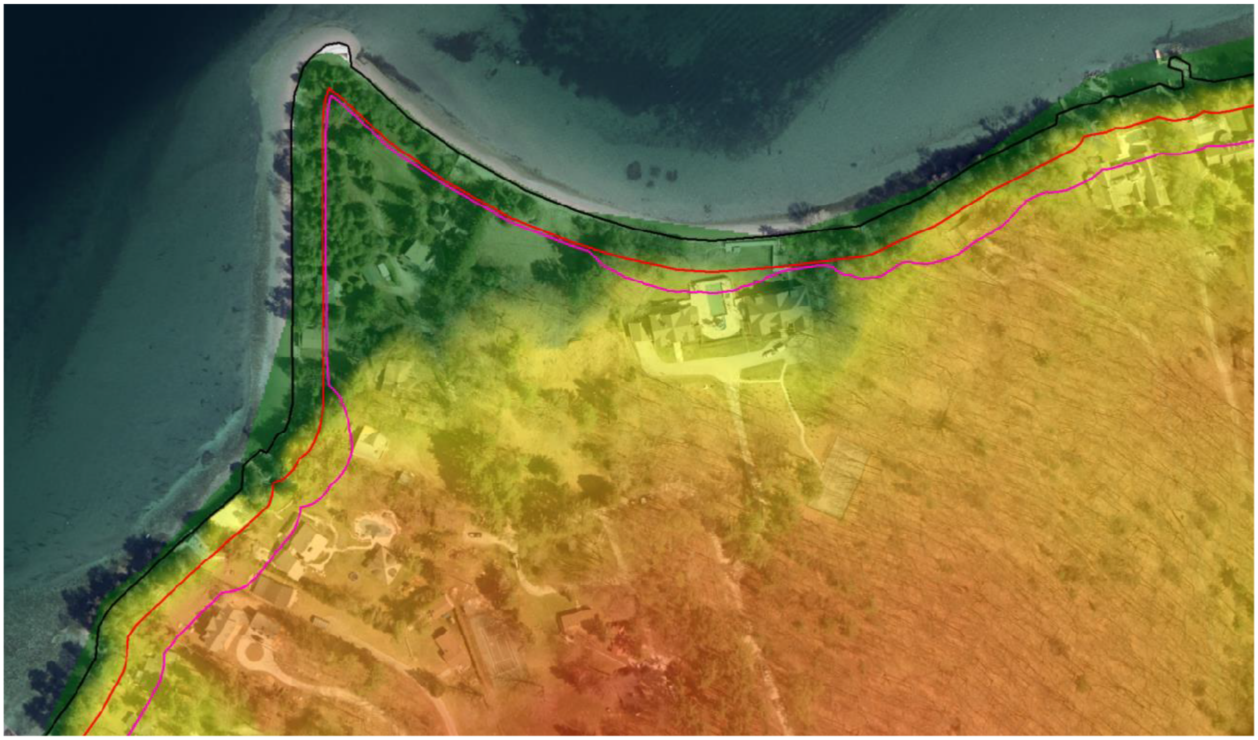


Figure 7.2: Example of Stable Slope Allowance in Variable Topography

The resulting erosion hazard limit assumes no shore protection and the shoreline erodes 15 m over the 100-year planning horizon, with no intervention by property owners. Most of the slopes near the shoreline of Lake Simcoe are also steeper than 3:1 and although these slopes may not be stable in the long term, there is significant time required for a slope to develop to a final 3:1 slope through normal erosion processes. Therefore, the mapped 100 year erosion allowance is generally a conservative assessment of the erosion processes with no future human interaction and with no recognition of existing shoreline protection.

When defining erosion lines around the lake, an erosion buffer was not applied on adjacent water bodies such as marinas or creeks as these features are not subject to the same erosion forces as the main part of the lake. Setbacks along rivers or creeks are defined through an independent study and are not part of this assessment.

The resulting erosion hazard areas are defined for use in GIS by polygons that cover the region between the shoreline and the inland erosion allowance. With breaks at numerous connecting water bodies, the result is a set of many polygons that define the erosion hazard zone.

7.3 Flood Hazard Mapping

Flood hazard mapping is based on the combined impact of high water level, wind surge and waves impacting the shoreline. The wind surge and wave conditions are linked, in that the same forces that cause wind setup will also cause waves to develop. The mapping outlines the impact of a 20-year storm event that occurs concurrently with the 100-year still water level. Mapping of the flood levels followed the processes outlined below:

- High lake-wide water levels, with a storm condition superimposed. This results in a water level of 219.5 m plus a wind surge allowance for a 20-year storm event, which varies by reach from about 0.2 to 0.6 m.
- Wave runup on the shoreline. This is typically defined based on the contour of the runup level. For example, a 219.5 still water level plus 0.25 m of surge might then have a runup level of 0.5 m. This would result in a flood level of 219.75 m and a runup elevation of 220.25 m.
- Assess the extent of inland wave propagation. This is an alternative approach from mapping the runup elevation. It is used in low lying areas to avoid over-predicting the inland propagation on very flat areas just above the waterline.

The Large Inland Lake Technical Guide (MRN, 1996) outlines that in the absence of an appropriate engineering study, a 5 m minimum flooding allowance is applied inland from the 100-year regulatory flood level. For this study the 5 m offset was applied as a minimum, and engineering analysis sometimes dictated an allowance for wave uprush that exceeds the 5 m minimum. This typically occurred in regions with deeper water near the shore, where the waves impacting the shore may be higher.

With significant variability of the shoreline conditions within most reaches, it was necessary to use an approach that was different from the standard Technical Guide approach to defining the inland flooding extent from wave action. Rather than defining a runup elevation and following that contour, a horizontal allowance from the flood level was found to provide more consistent results.

Variation within a reach means that the conditions in some parts of the reach may not agree well with the profile(s) that were used to determine the runup level for that reach. For example, a shoreline might be mostly steep (e.g., 3:1 slope) revetment but have isolated regions where the slope is very flat, such as near marshes or creek mouths. In these very flat areas, it is inappropriate to define a flood elevation based on a calculation from a single (perhaps not representative) shoreline profile at a revetment.

If we assume that the land becomes very flat, just a few centimetres above the 100-year regulatory flood level, then this provides a worst-case scenario in terms of how far inland the wave would travel (see Eq. 1). This maximum inland wave propagation was computed for each reach and defines the inland extent of the flooding allowance. Using this approach avoids a condition where a wave that has a runup elevation of, for example, 0.5 m above the waterline is depicted as surging 50 m or more inland. The horizontal propagation approach more effectively limits the practical extent of inland wave propagation.

There are some areas within a reach where the waterline at the 100-year flood level is far inland (100's of metres) from the normal waterline. This implies that the land is very flat, and it is therefore not appropriate to include significant wave runup in these areas since wave action would dissipate over a wide shallow area (typically vegetated). With typical 100-year regulatory flood levels around Lake Simcoe of 219.7 m this represents a level that is about 0.6 m above the monthly average water level in June (219.1 m). If we assume that the standard shoreline delineated in the maps is a typical June water level, then in regions where the 219.7 contour is more than 60 m inland from the normal shoreline we can conclude that the nearshore land slopes are 100:1 or flatter. With these very flat flooded areas, waves at the 219.7 water line will be very small, and a 5 m buffer from this line will be more than adequate. Calculations that indicated a larger inland bore propagation (greater than 5 m) will be ignored in these flat and shallow areas.

In summary, the 100-year regulatory flood level contour was produced around the lake, according to the flood level in each reach. A 5 m allowance was then applied in all reaches, except for those reaches where the modeling indicated that 5 m was insufficient; in some reaches the allowance is as high as 10 m. If there was evidence that the land is very flat in the flooded areas, then the allowance reverted to the standard 5 m distance.

The wave runup elevation was produced for each reach but was not used for the reach-based mapping due to limited data accuracy and irregular slopes and topography within a reach. The values used for this mapping are included in Appendix B and could be applicable to site-specific assessments where more accurate topographic data are available.

The flood allowance was delivered as a series of polygons in a GIS format that cover the region from the shoreline to the inland limit of the flooding allowance. The definition of the flood allowance adjacent to river mouths was applied in a manner consistent with Figure 5.12 of the Technical Guide (MNR, 1996). The polder area in the central part of the Holland Marsh is not regulated by the LSRCA and therefore this region was clipped from the spatial definition of the flood hazard.

8. Climate Change Analysis

8.1 Focus of Climate Change Assessment

Climate change assessments that are specific to Lake Simcoe are limited. The most relevant reports were prepared by the LSRCA and include the Climate Change Adaptation Strategy (LSRCA, 2020a) and the Climate Change Mitigation Strategy (LSRCA, 2020b). These documents address many different aspects of climate change including physical and environmental aspects.

The intent of this summary is to provide comment on the climate change implications towards the hazard mapping goals. The details of climate change variables are addressed in large scale atmospheric models, while specific impacts for Lake Simcoe are determined from an understanding of the processes that are specific to Lake Simcoe.

The impacts of projected climate change on the erosion hazard could be manifested through increased erosive forces, either through higher water levels or more severe/frequent wave events. For the flooding hazard, similar forces could cause a change to the flooding extent. Therefore, we can look at the impacts from projected climate change on flooding and erosion with a consistent approach.

8.2 Variables of Concern

Climate change could have an impact on many different aspects of the natural environment; however, very few of these aspects are expected to have direct impacts on the flooding potential on Lake Simcoe. The variables that may be impacted by climate change can be classified as either primary or secondary variables. For example, water level is an important variable, but it is determined by many other factors, which makes it a secondary or dependent variable. An independent variable would be something like temperature, which may change as a result of broad scale climate patterns that are not directly tied to Lake Simcoe. This is a slight oversimplification because most variables are dynamically linked; however, the primary independent variables are mostly independent of the conditions of Lake Simcoe, while the dependent variables are defined by one or many independent variables. An overview of relevant variables is provided below.

Primary Independent Variables:

- Temperature: Temperature has no direct impact on flooding, although it can impact precipitation, evaporation, water levels and ice conditions. Temperature could have an indirect impact as discussed later (see ice cover section below).
- Precipitation: Precipitation could have a significant impact on water levels, either through increased or decreased precipitation levels. Within limits, it may not directly link to water levels because the water levels are managed and management activities can overcome smaller changes to precipitation. However, water level management activities may not be able to accommodate large changes in precipitation.
- Wind Speeds: Wind speeds could cause an increase in the wave conditions on the lake; however, these differences are probably minimal in most areas of the lake since the waves are depth-limited near the shoreline. An increase in winds could increase the surge, which would increase the depth limited waves. Wind speeds are not expected to significantly change, and therefore impacts on flooding should be minimal.

Dependent Variables

- Water Level: Water level on Lake Simcoe is related to many factors and not directly addressed through climate models. Climate models provide data for temperature, precipitation, evaporation, etc., which are all factors in determining the water level. However, the outlet control of Lake Simcoe will be vital to understanding future Lake Simcoe water levels.

- Ice Cover: The main function of ice cover in this context, is to prevent the development of waves on the lake and also reduce the extent to which strong winds may produce wind setup on downwind shorelines. Increased future temperatures could reduce the duration of ice cover, resulting in more wind/surge events on the lake. However, periods such as December through March that may see more open water are not typically periods of higher water levels. Overall, we do not expect changing ice cover to increase flooding potential, although it could impact erosion.
- Wave Conditions: Waves are most closely related to the wind conditions and an increase or decrease in winds will affect waves similarly. Wave conditions are also related to ice cover. Changes to waves are particularly relevant if they occur at higher water levels, since most shoreline areas have depth-limited wave conditions.

8.3 Projected Climate Change Impacts

The Ontario Climate Consortium and Ontario Ministry of Natural Resources and Forestry published a climate change synthesis report for the Great Lakes basin in 2015 (McDermid et al., 2015). The report draws on over 70 scientific studies published since 2010 for the Great Lakes basin. The report outlines the anticipated climate change impacts, evidence, uncertainty, and agreement between studies in language that this accessible to the general public. Findings from the synthesis report will be referred to throughout this section as it reflects the current state of climate change science for the Great Lakes basin.

The terms, “confidence” and “uncertainty” are used extensively in climate change literature. In general, confidence relates to the amount, quality, and agreement of the evidence, and uncertainty relates to the magnitude of the unknowns. In McDermid et al. (2015) the various studies were reviewed by a cross-section of climate change researchers and information on each topic was evaluated and ranked as low, medium or high confidence based on the agreement among available studies; type, amount, and quality of the evidence; and limitations of the research.

Uncertainty in future projections is also related to the challenges of predicting future human behaviour related to future green house gas levels (scenario uncertainty), and model imperfection. Climate models use mathematical equations to represent complex processes between the atmosphere, earth surface, and human and natural systems. Model uncertainty is related to our understanding of those systems and the accuracy of the model processes and results.

A summary of projected climate change impacts on factors affecting Lake Simcoe is provided in Table 8.1. The various factors are discussed in detail in the following sections.

Table 8.1: Projected impacts of climate change in the Great Lakes Basin (adapted from McDermid et al., 2015)

Theme	General Projections	Trend	Confidence
Air Temperature	• 1.5 to 7 °C increase by the 2080s depending on climate scenario model used. • Greater increases in the winter.	Increase	High evidence High agreement
Precipitation	• 20% increase in annual precipitation across the Great Lakes Basin by 2080s under the highest emission scenario. • Increases in rainfall, decreases in snowfall.	Increase	High evidence Medium agreement

Theme	General Projections	Trend	Confidence
	• Increased spring precipitation, decreased summer precipitation. • More frequent extreme rain events.		
Drought	• Increases in frequency and extent of drought.	Increase	Low evidence High agreement
Wind	• Increased wind gust events.	Increase	Low evidence Low agreement
Water Temperature	• 0.9 to 6.7 °C increase in surface water temperature by the 2080s.	Increase	High evidence Low agreement
Ice	• Projected decreases in ice cover duration, ice thickness, and ice extent. • Increased mid-winter thaws, changing river ice dynamics.	Decrease	Medium evidence High agreement
Flood	• Increases in flood severity and frequency.	Increase	Medium evidence Medium agreement

8.4 Water Level Implications for Lake Simcoe

There is medium to high confidence that the Great Lakes basin (including the Lake Simcoe region) is in a period of slightly wetter weather. Future projections indicate that annual precipitation will increase by up to 20% across the Great Lakes basin (Lofgren et al., 2002; McKenney et al., 2011).

Rising air temperatures are expected to result in a higher percentage of precipitation falling as rain, and less as snow. Snowfall losses of up to 48% are projected for the Great Lakes basin by the end of the century (Notaro et al., 2014). The projected increase in winter rainfall and decline in snowpack is expected to affect the timing and magnitude of the spring freshet. Rainfall amounts are projected to increase in the spring and decline in the summer (Kling et al., 2003; Hayhoe et al., 2010).

Heavy rainfalls are twice as frequent as a century ago and are projected to become more frequent in the future (Changnon and Kunkel, 2006; Kling et al., 2003).

The greatest threat to having high water levels on Lake Simcoe relates to the spring freshet period. The highest water levels historically have been in May and into the start of June, with historical maximum values in May about 20 cm higher than other periods. One of the key ingredients to a large freshet is having an abundant and late snowpack that melts rapidly with rainfall. With higher temperatures, especially in the winter, there is a greater chance of having regular runoff and therefore less chance of an abundant snowpack and a late thaw.

The period of 2017 through 2019 saw flooding in many parts of Eastern Ontario, including Lake Ontario and other large rivers such as the Ottawa River. Lake Simcoe did not appear to be unusually high during this period. Some of this may be attributed to the higher flows in the Severn River from late February to the middle of March in 2017 (Figure 8.1). This type of flow increase in a managed system is consistent with planning for the freshet and perhaps more aggressively lowering the lake in advance of a stronger freshet. The strong outflow in early March of 2017 lowered Lake Simcoe and probably mitigated what may have been a year with higher water levels.

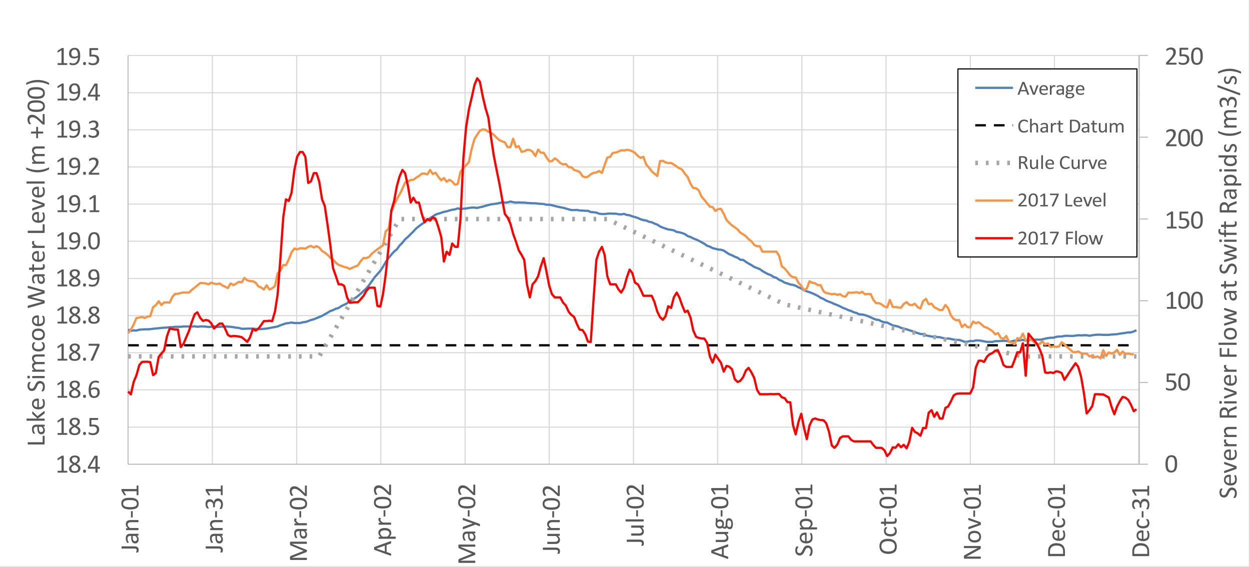


Figure 8.1: Lake Simcoe Levels and Severn River Flows in 2017

The knowledge and skill of those operating dams along the Trent-Severn system appears to have improved over time as evidenced by the greater variability in water levels in the early part of the historical water level record (see Figure 2.3). Better weather forecasting and measurement of current conditions may play a role in this and it is also possible that physical changes along the system improved the water level management. It appears that Severn River has the capacity to move adequate water to mitigate flooding, especially when proper forecasting is in place. The flow patterns in 2017 showed an active effort to plan ahead to mitigate flooding potential in the spring of 2017.

The ability to manage the system and make a material difference to water levels on Lake Simcoe will provide some protection from hydrologic changes related to climate change. The expected change in temperatures, which would contribute to more winter rains and a reduced snowpack, would mitigate the severity of the spring freshet. It will become less likely that a large snowpack will melt late and rapidly.

Overall, the implications of climate change are not expected to have a significant impact on water levels on Lake Simcoe due to the ability to manage the lake's water levels. It does not appear that the lake has seen more severe water levels in recent years; the opposite is generally true.

8.5 Ice

Ice cover was discussed in Section 2.3, with a focus on historical data, which appears to be variable but with no significant long term trend. The trend into the future could be more pronounced, which would involve later freeze-up and earlier thaws. This would result in more open water in early to mid January and in March, and the potential for waves to be generated during this longer open water season. There is also the potential for more mid-winter thaws, although these would typically be in isolated sections of the lake (such as river outlets) and would not be broad enough to generate lake-wide wave action.

With an increased open water season, there is the potential for more wave action along the shoreline. This is addressed in the following section.

8.6 Winds & Waves

There is low confidence in projections of future wind speeds and wind patterns. It is believed that warmer air and water temperatures in the Great Lakes region may increase atmospheric turbulence, resulting in higher wind speeds in the lower atmosphere (Austin and Colman, 2007; Desai et al., 2009; Huff et al., 2014). However, other studies such as Yao et al. (2012), project a decrease in wind speeds in the Great Lakes Basin by the year 2100. Cheng et al. (2012) projected that wind gusts will become at least 10% more frequent by the end of the century.

With significant uncertainty in the change to winds, we can make no conclusion about changes to the severity of waves and surge on the lake. A reasonable estimate is that the severity of the waves and surge on the lake will be generally similar in the foreseeable future. However, with changes to the ice cover, there is the potential for storms in January or March to generate waves on the lake in future years.

From a flooding or erosion hazard perspective, the greatest threat is waves that occur at a high water level. With the water level management scheme on Lake Simcoe, there have historically (1960 to present) never been water levels above about 219.1 m during the period of January and March (Figure 2.2); typical water levels are at about 218.8 m. The normal summer operating water level is 219.1 m, so these increased open water periods would occur during below normal summer water levels.

With lower water levels, the potential for more severe erosion or flooding is extremely small. While it is true that more waves, even at lower water levels, will increase the rate of erosion, we have already established that the average rate of shoreline recession is about 0.07 m/yr (Table 2.2) for the unprotected sections of the shoreline. Some areas may have higher recession rates; however, much of the shoreline is already protected and exhibits minimal erosion in recent years. If the normal open water season of about 265 days increased by two weeks in the fall and two weeks in the spring, then we might expect the erosion rate to increase by 10% (if we ignore the important water level part of the process). This would increase the documented erosion rate (Table 2.2) to about 0.08 m/yr and well below the adopted default average rate of 0.15 m/yr that was used for the mapping.

8.7 Summary

There is little evidence that anticipated climate change impacts will have any significant influence on the flooding or erosion hazard on Lake Simcoe. This can be attributed to the ability to manage the water levels on Lake Simcoe as well as the lower water levels that are achieved during the winter months when some additional open water and waves may occur. Based on observed actions at the dams in recent years, it appears that it would require a significant change in precipitation before the capacity to regular the water level was seriously impacted. An increase in the open water season could lead to increased erosion; however it is not anticipated that this would be significant, considering the current low erosion rates.

The manner in which the climate may change in the future has significant uncertainty and these conclusions related to erosion and flood hazards should be revisited in the future as anticipated climate changes do, or do not, take place.

9. Shoreline Development Impacts

9.1 Discussion of Sediment Transport

Erosion of the shoreline is a natural process that takes place intermittently on almost all shorelines. Accretion of sediment along the shoreline and erosion of the shoreline are both likely to occur intermittently, with the balance between the two of these impacting the long term evolution of the shoreline.

Erosion on Lake Simcoe has two main elements: the removal of material from a lakebed or nearshore area by moving water, and the breakdown of larger material into smaller material through erosive effects. Both of these processes are occurring on a regular basis, with the former being the most apparent along the shoreline. These processes also result in natural sorting of the materials along the lakeshore.

When shorelines are eroded, the fate of the material is largely related to the grain size of the sediment. Large material such as boulders and cobbles are often fairly static and remain close to their original location for a long time (possibly many years) until extreme waves and/or ice process move the material. At the other end of the spectrum, silt and clay fractions become suspended in the water column and remain so until calmer conditions allow this material to settle to the lakebed. This process will repeat many times until the finest fractions have been deposited well away from the shore in deeper water, where they remain mostly undisturbed.

Intermediate fractions of sediment, such as sand and gravel, will move in the nearshore area and form beach and bar deposits. These materials are prone to reworking by wave action, with wave direction, wave height/period and water level all playing a role in the post-storm stable position of these sediments. Regular motion also causes the slow but persistent breakdown of the material into smaller fractions.

The shores of Lake Simcoe are almost entirely cohesive soils, as shown in Figure 9.1 from the Ministry of Northern Development, Mines, Natural Resources and Forestry database. Only isolated areas are bedrock or organic deposits. This map depicts the soils along the land adjacent to the shoreline but does not necessarily align with the nearshore sediments that have been distributed in the nearshore region of the lake. Observations along the lake shore and review of aerial imagery shows that sediment is present over most of the nearshore area, with some regions that are shown as “organic deposits” in the surface geology map having sand present in the nearshore (at least on the surface) as a result of the ongoing sorting of sediments.

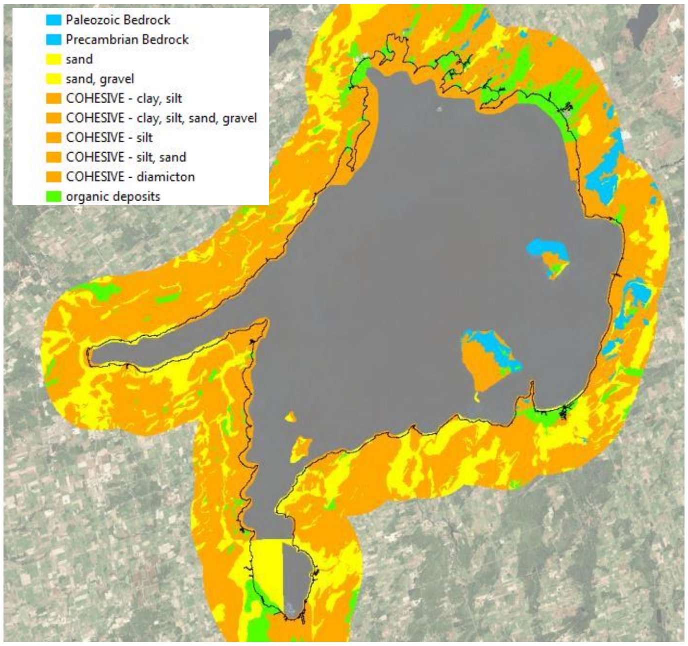


Figure 9.1: Soil Types Around Lake Simcoe

The shape of Lake Simcoe has resulted in a condition with many small beaches in the natural bays around the shoreline. Other than very fine material, coarser sediment transport on Lake Simcoe is typically limited to within a bay or beach cell and does not travel over long uninterrupted distances due to the many natural headlands. Oblique wave attack will happen in some areas where the shoreline has steeper slopes and the potential for oblique wave attack (such as along the NW shore); however, most of these regions have gravel or cobble substrate with limited sand to be moved along the shoreline.

9.2 Shore Perpendicular Structures

Shore protection structures that protrude from the shore, such as groynes, often provide a clear indication of the direction and approximate magnitude of alongshore sediment transport. An example of this can be seen at Great Lakes locations such as Port Stanley, shown in Figure 9.2, where strong west to east sediment movement has been interrupted by coastal development. These types of disruptions are also created by natural headlands and can result in gradually accreting beaches over thousands of years.

Figure 9.2: Disturbance in Alongshore Sediment Transport at Port Stanley, Lake Erie

The processes around Lake Simcoe are somewhat different, with limited evidence of large volumes of sediment accumulating adjacent to shore-perpendicular structures. There are some examples of moderate to smaller accumulation at locations such as Beaverton Harbour, where a sand fillet has developed on the south side of the harbour in response to southwesterly winds and waves (Figure 9.3). A smaller and less obvious sand accumulation also exists on the north side of the structure. A few smaller structures south of Beaverton Harbour also show similar patterns of sediment accumulation.

Figure 9.3: Sediment Accumulation Adjacent to Beaverton Harbour

Figure 9.3 also shows the bar formations that exist in the Beaverton area; these bars are an indication that there is active sediment transport during larger wave events. There is a clear difference between the impact of the large structures protecting the harbour, and the small structure further south. Structures that reach a small distance into the lake will only have limited impact on sediment transport, while the larger structures have the potential to be much more disruptive. The Beaverton Harbour structures extend past the visible limit of the sediment bar formations, indicating that the movement of sand is mostly stopped by these structures.

Despite the severe blockage of the sediment transport from the larger structures at Beaverton, the size of the sand fillet that has developed is relatively small. These larger structures may have had some detrimental impacts on adjacent shores by disrupting alongshore sediment movement, but also by trapping sand adjacent to the structures. Once sediment is pushed into a corner, the mechanism to move the sediment out of the corner is limited by the large structures. The volume of sediment in this corner fillet would have historically been distributed along the shore in the region, although the volume of sand is relatively small.

The large structures that are built next to navigation channels are built for the purposes of preventing sand from entering the navigation channel. These structures have the potential to cause serious blocks in the sediment movement along the lakeshore and extend offshore by sometimes 100 m or more. However, the sediment process on Lake Simcoe typically results in these structures being less impactful than in some other locations. Placing these larger structures adjacent to natural headlands can limit the extent of the detrimental impact. The future construction or modification of large shore perpendicular structures would need to be carefully studied to assess the impacts. There are almost certainly impacts that will occur; it is the severity of these impacts that need to be quantified.

Smaller structures that might be built for the purpose of a dock would ideally be porous (e.g., pile supported) structures that do not impact sediment movement. However, these structures have challenges with ice movement and are typically removed in the winter, which can limit the size/extent of the structure that is practical.

A shore-perpendicular semi-porous structure that uses large stone, but no solid fill will allow sand to move through the structure. It will create a small blockage in the sediment, but only to a limited extent. These types of structures might be more resistant to ice forces than piles or are at least more forgiving if there is some ice-related movement. A structure of this sort might be used to provide ice protection to piles, but serves limited purpose otherwise.

A solid shore perpendicular structure will block the movement of sand. Provided that the structures are short and only block a small position of the active nearshore profile, their impact is limited. The amount of sand that can be retained is limited and could be mitigated by pre-filling adjacent to the structure so that additional sand trapping cannot occur. With small impervious structure that are pre-filled, the overall impact on the sediment regime is localized and limited in shallow areas.

In summary, larger shore-perpendicular structures may have significant impact on adjacent shorelines and need to be carefully assessed. These would likely only be constructed adjacent to entrance channels that must maintain a navigable water depth; they are not intended for shoreline protection purposes. Smaller structures may have limited adverse impacts if they disrupt only the inner portion of the active sediment transport profile. However, beach fill should be placed adjacent to these structures to limit adverse impacts on adjacent shorelines.

9.3 Offshore Breakwaters

The concern with offshore breakwaters is that improperly designed structures, or structures that are in region with very high sediment transport, will result in significant changes to the shoreline. In some instances, an offshore breakwater can cause a near-complete blockage of sediment transport and a tombolo will form behind the structure. The formation of tombolos can be mitigated by limiting the breakwater length and/or situating it further from shore. However, if the structure is built such that there is almost no reduction in the shoreline wave conditions, then the value of the structure may be questionable.

There are many examples of offshore breakwaters on Lake Simcoe, with most of these being small structures that may be part of a dock or are just in front of a dock. Most of these structures are in regions that do not have sandy substrates and there has therefore been little if any accumulation of sediment in the lee of these structures. An example of this is in the region adjacent to Snake Island, as shown in Figure 9.4. This region does not have visible sand bar formations in the aerial imagery and appears to be a hard bottom. Consequently, the alignment of the shoreline appears mostly unaltered and even very enclosed basins appear to be clear of sediment accumulation.

Figure 9.4: Offshore Breakwaters Along Shore South of Snake Island

In other regions of Lake Simcoe, there are more obvious sediment features in the nearshore, typically consisting of shore parallel sand bars. While most of these sandy areas do not have offshore breakwaters, there are some regions, such as the region just east of Georgina Beach (Figure 9.5) where some offshore breakwaters are present.

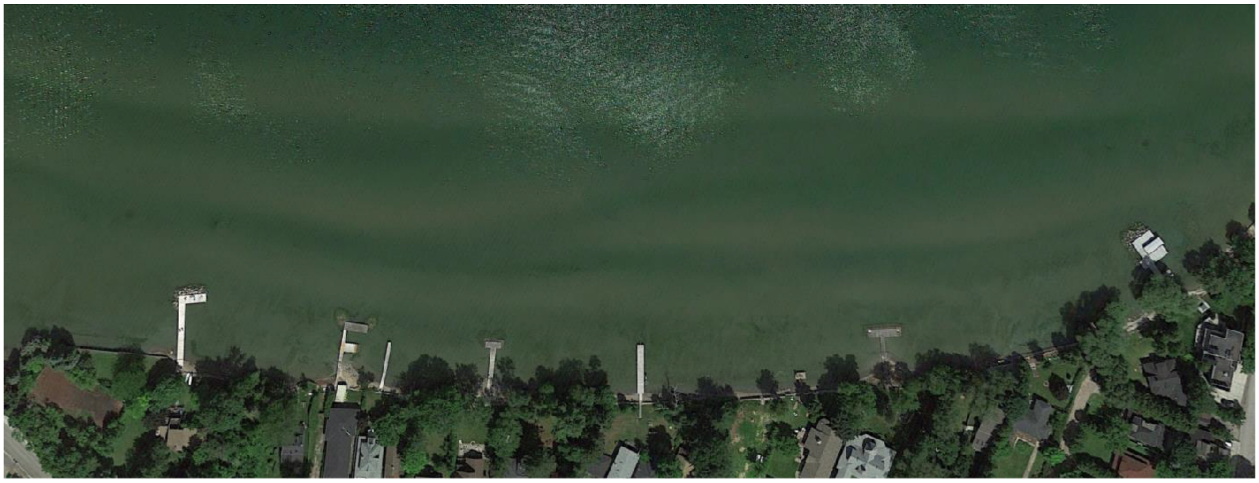


Figure 9.5: Offshore Sand Bars and Offshore Breakwaters East of Georgina Beach

The conditions around most of Lake Simcoe's shore involve gentle, shallow nearshore slopes and offshore breakwaters, where they exist, are typically small and relatively close to shore. These are very different than offshore breakwaters that might protect a port complex on an ocean coast where the structures are hundreds of metres long and in water depths of perhaps 10 m or more. On Lake Simcoe, wave breaking and significant sediment movement takes place over the sand bars that may be located 100 m or more from the shoreline, as shown in Figure 9.6. The offshore breakwaters are typically 20 m or less from the shoreline and do not cause any appreciable interruption of longshore transport (assuming the waves are oblique and longshore transport is occurring).

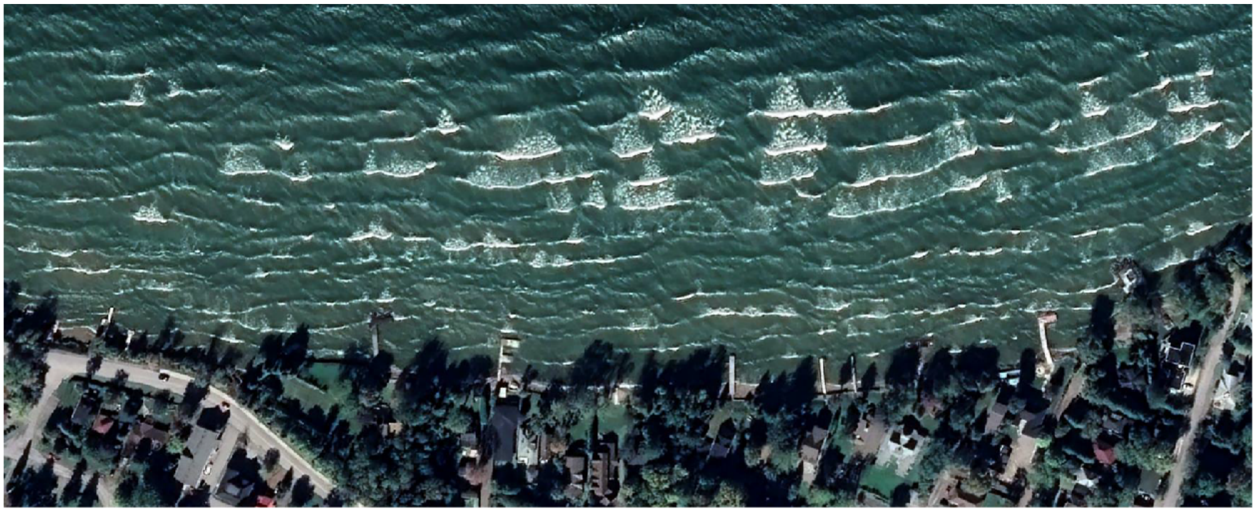


Figure 9.6: Offshore Wave Breaking East of Georgina Beach

A review of the shoreline alignment adjacent to offshore breakwaters suggests that there is limited impact from these structures on Lake Simcoe. In regions where there is little if any sand, the consequence of these structures may be a slight accumulation of the finer fractions that make up the nearshore substrate (i.e., some gravel may accumulate where there is a gravel/cobble shoreline).

In regions where there is a sandy nearshore zone, evidenced by sand bar formations, we would expect offshore breakwaters to cause some minor accumulation behind the structures but to have little if any detrimental impacts to the surrounding area. These impacts could be mitigated by filling a small accretion along the shoreline, to mimic the expected small shoreline change. Minor shoreline adjustments of this sort will be inconsequential to flood levels but should be considered from a habitat perspective.

We would therefore advise that small offshore breakwaters, as might be constructed to protect a typical recreational boat dock on Lake Simcoe, has insignificant adverse impact on the shoreline process in regions where there is a cobble/gravel bed and there are no visible sand bars. In regions where sand is present, the adverse impacts are limited and could be mitigated subject to any environmental concerns.

9.4 Shore Protection Impacts

The shoreline of Lake Simcoe is relatively static compared to many sea/ocean coastlines and the coast of the Great Lakes. The rate of erosion is low and is estimated to be typically in the range of 5 to 10 cm per year (Section 4.1). With generally flat nearshore slopes (50:1 to 200:1 slopes are not uncommon) the corresponding downward adjustment (or downcutting) of the nearshore profile is also very small. For example, 5 cm per year of horizontal erosion on a 100:1 slope equates to a vertical lowering of 0.5 mm per year, or 5 cm per century.

Protection of the shoreline with revetments and seawalls certainly changes the look of the shoreline and the environmental function of the nearshore zone. However, it appears to have limited impact on the overall shoreline position and characteristics of the adjacent areas. For proposed works, site-specific studies should be used to assess impacts and determine appropriate mitigation measures.

The potential for shore protection in one area to adversely impact the shorelines in adjacent areas is limited. There are no obvious supply areas (such as eroding bluffs) that are required to nourish beach areas in a downdrift location. It is likely that erosion of the lakebed is a contributor to the regional sediments, as well as some isolated bluff areas. Protection of the shoreline could slightly reduce the sediment supply, although sediment production through lakebed erosion would probably not be impacted. Some mitigation of localized effects may be required but should not prevent modest and appropriate development from taking place.

Shore protection on Lake Simcoe is limited to the use of natural boulder material that is typically of igneous origin. Importing limestone for building revetments is not permitted. An assessment of water quality issues on Lake Simcoe is outside the scope of this study and we understand that there may be concerns about how limestone could impact water quality in the lake. The potential for large blocks of limestone (with hopefully limited dissolving) to impact the 11.6 billion cubic metres of water in Lake Simcoe has not been assessed as part of this study.

One advantage of using natural boulders is that they are typically of better quality since the stones would have previously broken along weak seams in their historical sorting/rounding process. There are fewer weak seams in the rounded boulders that have been produced by the natural rounding process.

A detrimental impact of limiting the use of quarry-produced limestone is that the natural stone building products are rounded and therefore need to be larger and/or more gently sloped to achieve the same stability under wave action. This means that steeper revetments, or stacked stone walls are not possible. Instead, structures need to be wider with rounded stone which increase the overall footprint of the structure. Rounded stone can also be difficult to source and more expensive; this may be one reason that it appears that gathering of in-situ stones has occurred in many areas of the shore.

10. Conclusions

An update to the Lake Simcoe hazard maps has been produced using more recent information and modeling techniques. Mapping was developed on a reach basis; 38 reaches were identified.

A review of water level data supported the continued use of 219.5 m (CGVD28) for the 100 year water level. This water level was then adjusted in response to storm surge in each reach.

Numerical modeling of storm surge was completed for Lake Simcoe to define the reach-specific conditions at the shoreline. This work was undertaken using historical bathymetric data for Lake Simcoe, as well as more recent multibeam bathymetric data in selected areas, and satellite derived bathymetry in the shallow nearshore regions. A wind-surge level was defined for each reach, with values of 5 to 20 cm in most reaches and a few reaches with surge up to 40 cm. These surge values are added to the 100 year 219.5 water level to define a flood level along the shoreline. Wave uprush was then added to these levels.

Wind speeds were examined for various near-lake wind stations and the 20-year storm conditions were determined and applied to the numerical model of surge and waves. A 20 year wave condition was then used in conjunction with the 20 year storm water level to define the conditions at the shoreline. The wave uprush elevation was then defined for each reach based on the EurOtop model (on steeper shorelines) or CSHORE for flatter regions.

Variabilities within the reach, and a reach-based approach to defining a wave runup elevation, resulted in some challenges in completing the mapping based on elevation contours. Instead, a more reliable method was determined to be applying an inland propagation distance from the flood level. This avoided some unrealistically far inland propagation distances.

The erosion hazard was assessed and was defined based on a default 15 m erosion allowance around the lake. A 3:1 (H:V) stable slope allowance was then applied inland from the erosion allowance.

Topographic data around the shore of the lake limits the accuracy of the mapping and consequently a conservative approach was used in the flood hazard mapping. Future updates to the topography around the lake may provide the opportunity to update the maps using the flood levels and wave conditions described in this report.

With 300 km of shoreline and bathymetric/topographic details that are not available on a property by property basis, there will undoubtedly be instances where the mapped lines may require a site specific assessment (undertaken by the proponent) for submission of site development applications. A site specific assessment of the flood and erosion hazard limits may be undertaken in a simplistic manner where the horizontal and/or vertical offsets are defined based on published values for the selected reach. Alternatively, it may be necessary or appropriate to complete more detailed analyses and used a series of measured profiles at the site to then compute runup elevations. This would then supersede the results from a more general profile, representative of the reach, used to develop the hazard mapping.

Climate change is expected to have minimal impacts on flooding and erosion around Lake Simcoe; these anticipated future differences do not impact the hazard mapping extents.

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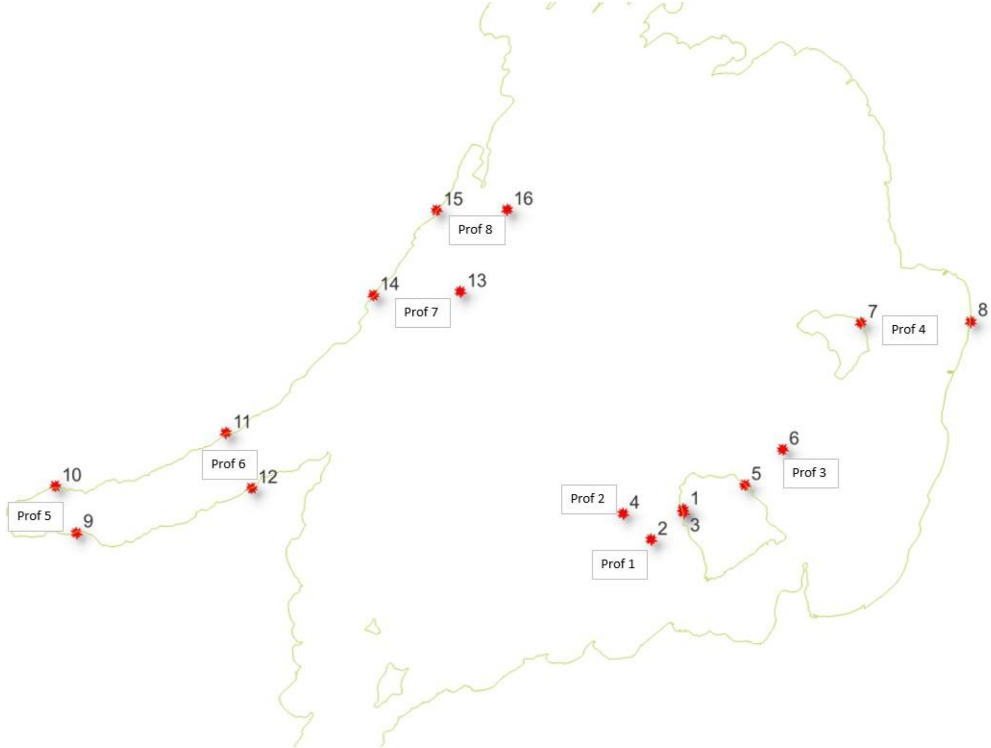
Appendix A

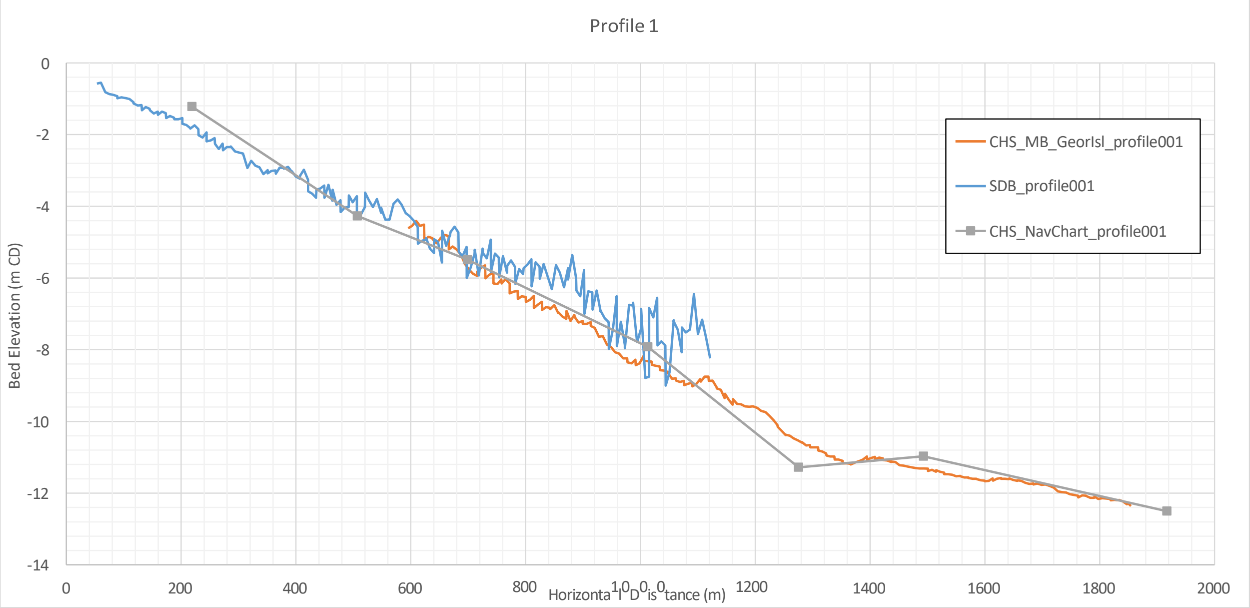
Comparison of Bathymetric Data



Bathymetric Survey Comparison Profile Locations (red dots indicate start/end points of profiles)

Note: In the comparisons on the following pages:

- CHS_MB* lines are Canadian Hydrographic Service Multi-Beam survey data
- CHS_NavChart* lines are from 1957 survey
- SDB* lines are Satellite Derived Bathymetry


Profile 1
Bed Elevation (m CD)
Horizontal Distance (m)
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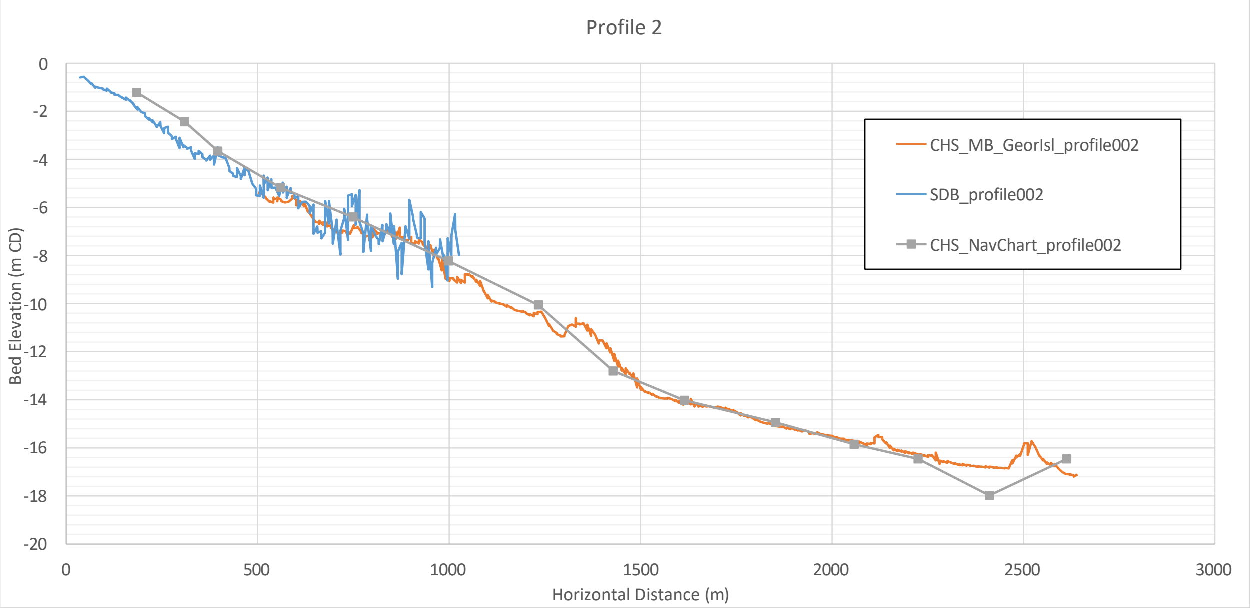
-2
-4
-6
-8
-10
-12
-14
0
200
400
600
800
1000
1200
1400
1600
1800
2000
CHS_MB_GeorIsl_profile001
SDB_profile001
CHS_NavChart_profile001


Profile 2
Bed Elevation (m CD)
Horizontal Distance (m)
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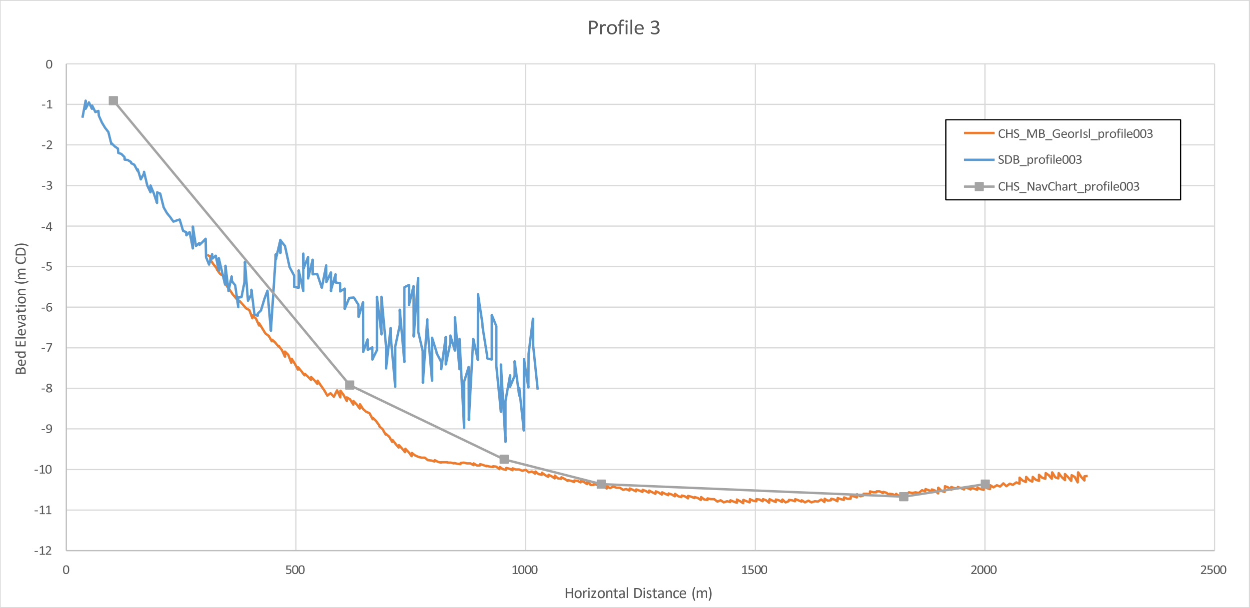
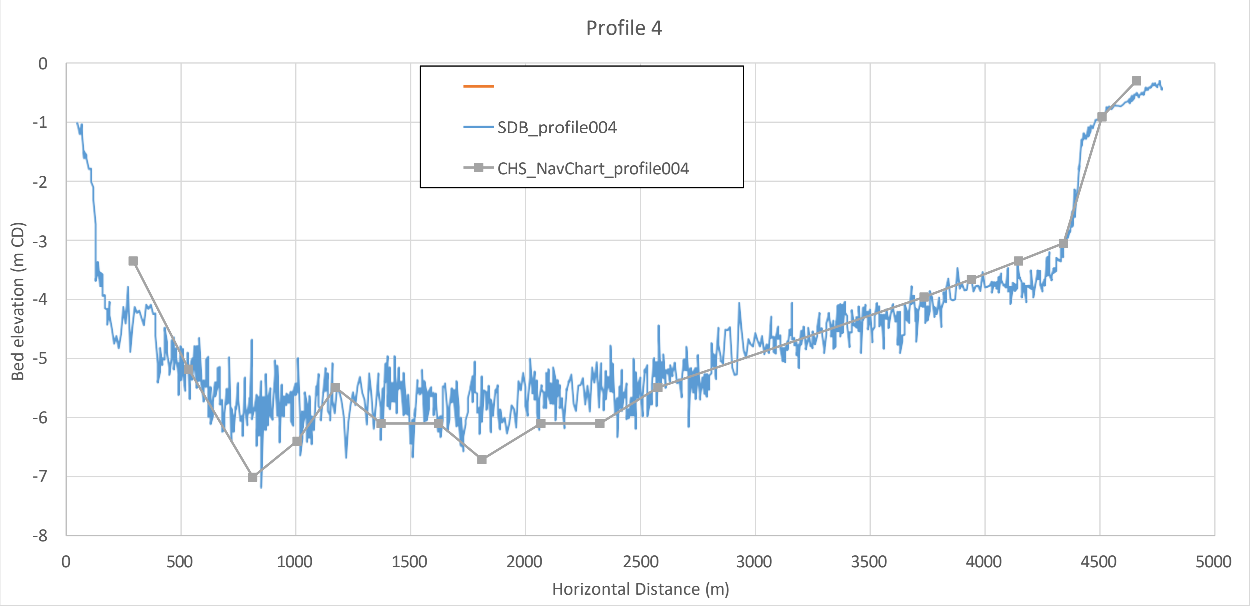
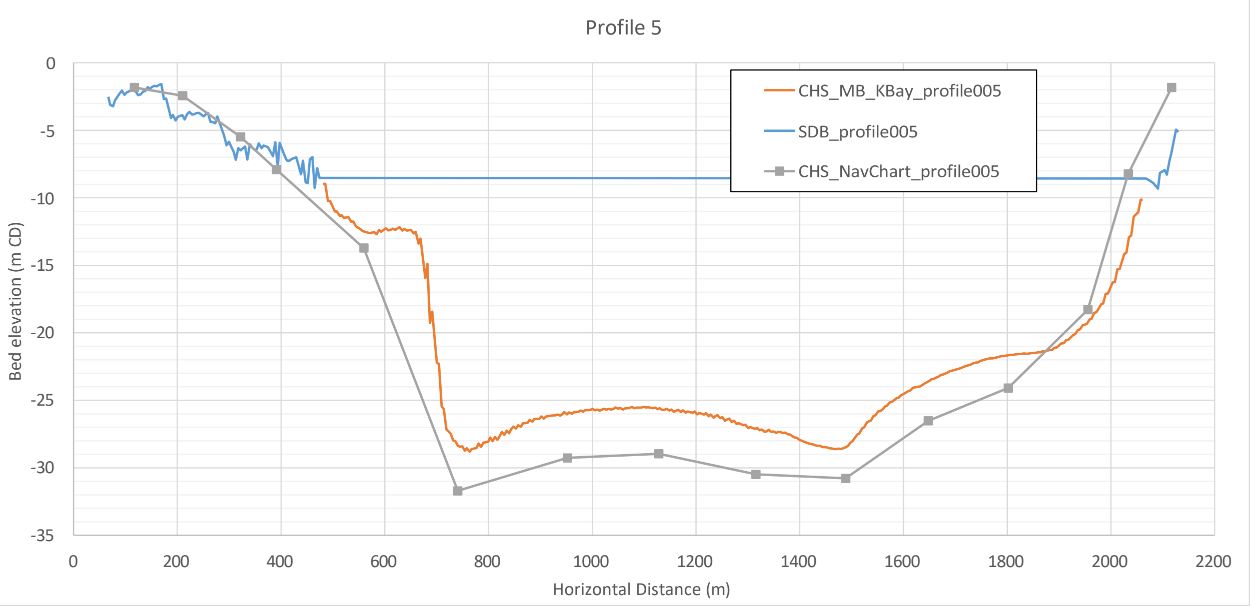
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
0
500
1000
1500
2000
2500
3000
CHS_MB_GeorIsl_profile002
SDB_profile002
CHS_NavChart_profile002





Note: No Multibeam data at this location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CHS_MB_KBay_profile005
SDB_profile005
CHS_NavChart_profile005
Bed elevation (m CD)
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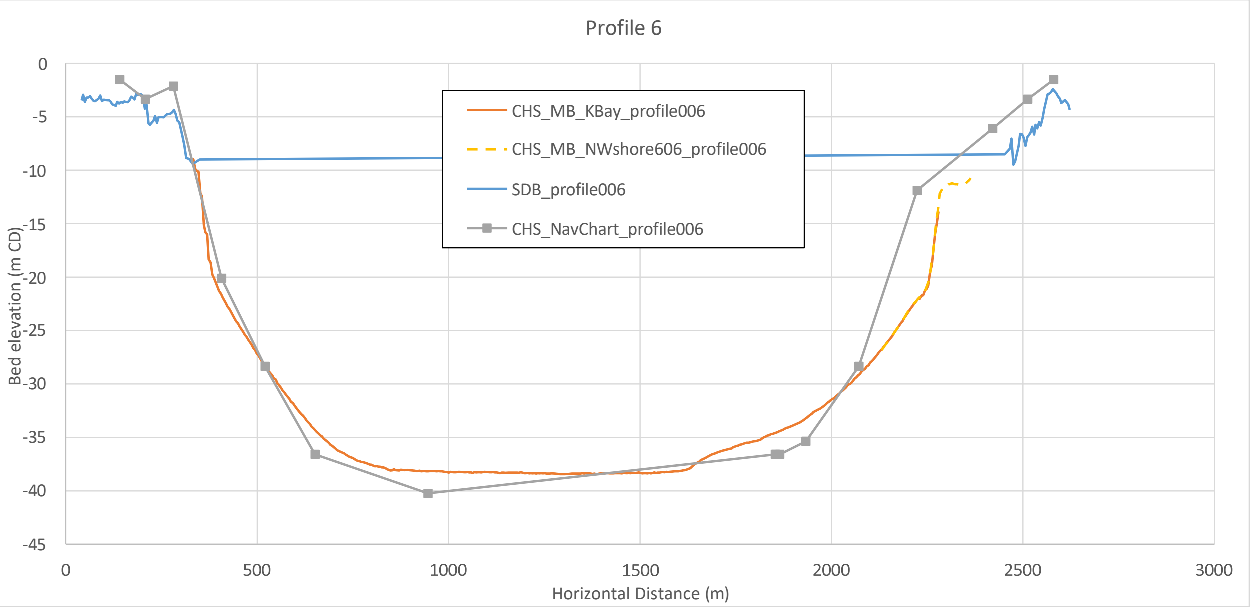
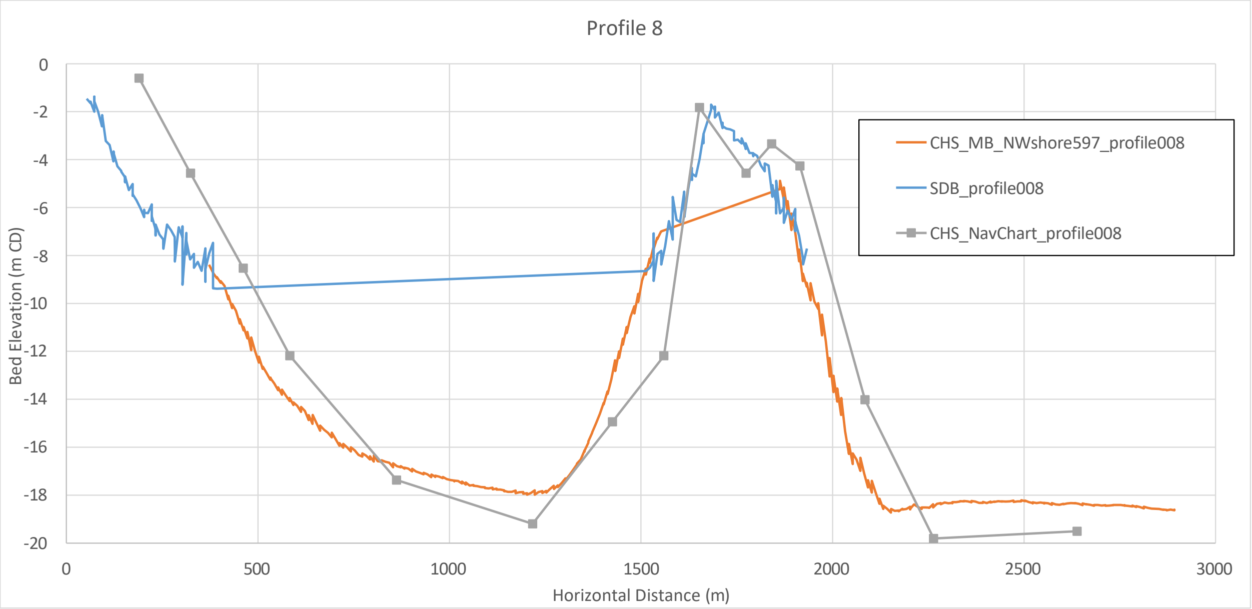
-10
-15
-20
-25
-30
-35
0
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
Horizontal Distance (m)


Profile 6
CHS_MB_KBay_profile006
CHS_MB_NWshore606_profile006
SDB_profile006
CHS_NavChart_profile006
Bed elevation (m CD)
0
-5
-10
-15
-20
-25
-30
-35
-40
-45
0
500
1000
1500
2000
2500
3000
Horizontal Distance (m)

Note: No Multibeam data at this location



Appendix B

Flood Mapping Data by Reach

Reach	Rounded Surge (m)	Surge Level (m CGVD28)	Runup Level (m CGVD28)	Inland Distance (m)
1	0.35	219.85	220.33	5
2	0.30	219.80	219.80	5
3	0.30	219.80	220.43	5
4	0.30	219.80	220.52	5
5	0.30	219.80	219.80	5
6	0.30	219.80	220.67	5
7	0.30	219.80	221.03	5
8	0.30	219.80	220.55	5
9	0.30	219.80	221.26	5
10	0.30	219.80	219.80	5
11	0.25	219.75	220.17	5
12	0.20	219.70	220.20	5
13	0.25	219.75	220.62	5
14	0.20	219.70	221.90	7
15	0.20	219.70	221.16	7
16	0.30	219.80	221.06	5
17	0.40	219.90	221.50	5
18	0.55	220.05	220.46	5
19	0.60	220.10	220.10	5
20	0.45	219.95	220.87	5
21	0.20	219.70	220.80	7
22	0.20	219.70	221.94	7
23	0.25	219.75	220.90	8
24	0.20	219.70	222.35	8
25	0.15	219.65	220.81	6
26	0.15	219.65	220.92	6
27	0.15	219.65	221.31	6
28	0.25	219.75	220.58	5
29	0.30	219.80	220.22	10
30	0.10	219.60	219.60	5
31	0.15	219.65	221.03	5
32	0.25	219.75	219.75	5
33	0.10	219.60	219.60	5
34	0.20	219.70	220.73	5
35	0.20	219.70	220.39	5
36	0.25	219.75	220.32	5
37	0.25	219.75	221.36	6
38	0.20	219.70	222.05	8